Assessment of water leakage through the right abutment of the Seymareh dam

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Abstract

One of the major issues in dam construction is water seepage, post impounding. Assessment and prediction of the amount of water leakage can be useful in preventing such events. The Seymareh dam has been constructed on the Seymareh River in Ilam province, Southwest of Iran. The dam controls the floods and generates hydroelectric power. It is already under impoundment and the seepage problem is being considered. Grout curtains have been employed in two directions at the right abutment of the dam to control the seepage. The normal reservoir level is 720 m and it has been impounded at the 660 m level up to the point. The purpose of this study is to predict the amount of water seepage through the right abutment of the dam by using numerical modeling. For this purpose, a new GW finite element code was used for a two-dimensional simulation of the water seepage. The Levels of the observations wells and the discharges of the downstream springs on the right river bank are used as the main data for this modeling and its verification. Assessments show that if the dam impoundment rises to the normal level, significant seepage may occur through the right abutment.

Keywords: *GW code, Numerical modeling, Seepage, Seymareh dam.*

Introduction

Excessive seepage from dam sites has been reported in a great number of dams in the karstic areas across the world (Milanovic, 1981; Merritt, 1996; Turkmen *et al*., 2002). This type of problem has been encountered in many dams after impounding. It is, therefore, normal to conduct a series of remedial studies and follow through with remedial operations to reduce the amount of seepage. Lack of a precise view under karstic conditions at the dam sites, particularly prior to the construction, is one of the chief reasons for significant water seepage in dams in the karstic areas (Mohammadi *et al.*, 2006). Milanovic (1981) propounds that precise geological and hydrogeological mapping with remote sensing methods, a combination of different geophysical methods, dye tracing, cave investigation and long-term control of groundwater are necessary to study water seepage. There are some indicators for the increase in water seepage, namely the increase in the discharge of the downstream springs, as well as the water levels in the observation wells (Turkmen *et al.*, 2002).

For instance, the seepage problem in the right abutment of the Shahid Abbaspour dam was assessed by hydrogeochemical analysis, dye tracing and XRF testing (Ghobadi *et al.*, 2005).For evaluation of the seepage potential in the Kafrein Dam, the change in the water level in the observation wells was studied in accordance with the change in the reservoir level (Malkawi & Al-sheriadeh, 2000). Numerical analysis is a powerful tool that enables the prediction of water seepage in different environments. Seepage and permeability analyses for the dam foundations and banks are the essential analyzing methods in the different phases of dam construction projects, including the design, construction and operation phases.

Application of analytical methods to analyze the seepage through the rock masses in large development projects has been the standard of practice for a long time. Currently, the use of quantitative methods based on numerical expressions is emerging as the new standard of practice. The common computer codes for such numerical analyses are UDEC, FLAC, PLAXSIS, SEEP/W, FEEFLOW, MODEFLOW and FLUENT. Two- and three-dimensional models of seepage through the foundation of the Gotvand dam were simulated using the SEEP/W finite element code and the outputs of the models were compared with each other (Sadrekarimi *et al.*, 2011). Uromeihy and Barzegari (2007) evaluated the potential of the seepage in the Chapar Abad dam site with the PLAXIS finite element code and it was they who suggested the use of grout curtains to reduce the seepage.

The Seymareh Dam and the powerhouse have been impounded on the Seymareh River with an average flow rate of 100 m^3/s. The dam has double arches and is 130 m above the river bed. The main purpose of its construction was to generate electrical power, facilitate flood control in the river and regulate the upstream branches of the Karkheh River. Monitoring of the levels of the observation wells and the amount of discharges from the springs in the right abutment indicates that seepage occurs after impounding, via the abutment. These results are not numerical and have been obtained according to the empirical data and site investigation. Discharges from the springs and fluctuation in the levels of the observation wells are the main field data for simulation of the limestone aquifer in the right abutment of the Seymareh dam.

In this study, the GW finite element code was applied for the estimation and prediction of the amount of seepage via the right abutment in the upper reservoir levels. This code is one of the newest numerical softwares used to analyze groundwater flow. The reason for utilizing the software is its advantage in karstic and fractured environments. It corresponds to a portable finite element library allowing one, two and three-dimensional simulations of variably saturated flows and transports in the sub-surface.

Geological setting

The study area is located in the Ravandi Anticline, at the Zagros simply folded Zone, southwest of Iran. The Zagros Zone is one of the five major structural zones in Iran, studied by Stocklin, (1968). About 10 km in thickness it mainly includes sedimentary rocks such as limestone, marl, gypsum, salt, shale, siltstone, sandstone and conglomerate. Since the Miocene period, it has been folded into a series of anticlines and synclines of varying sizes. The stratigraphy and structural conditions of the Zagros Zone have been studied in detail by Stocklin and Setudehnia (1977) and Alavi (2004).

The anticline axis and dam site situation is shown in Fig.1.The general trend of the anticlines in the area studied follows the Zagros Mountain ranges in a Northwest–Southeast trend. The trend of the Ravandi anticline, however, has rotated to the East-West at the dam site (Karimi & Tavakkoli, 2007).This can be caused by different tectonic forces or different strengths of the constituents of the formations around the site. The lithostratigraphic sequence of the area studied, as shown in Figure 1, includes the Asmari and Gachsaran formations. The main properties of these formations have been summarized in Table 1.

Figure 1. The geological formations, anticline axis and dam site

Table 1. Description of the formations

Formation	Age	Lithology
Asmari	Oligo-Miocene	Limestone
Gachsaran	Miocene	Salt, anhydrite, marl and gypsum.
Bakhtiari	Plio-Pleistocene	Conglomerate

The Asmari Limestone formation is the main constituent of the aquifer system at the Seymareh dam site which was studied by the Mahab Ghodss Consulting Engineers (2003). The valley of the dam is mainly surrounded by Asmari Limestone (Oligo–Miocene) formation.

From the hydrogeological point of view, the Asmari Formation can be classified into three units in the dam site, viz., the upper, middle and lower Asmari. The lithology of the upper Asmari (U-As) consists of layered limestone with interbedding marl layers; the middle Asmari (M-As) is formed of thick and massive limestone with a few small karstic caves on its surface while the lower Asmari (L-As) includes massive limestone and low fractured marly limestone. The profile of the Ravandi anticline around the anticline axis can be seen in Figure 2. The Gachsaran (Gs) Formation (Miocene age) which overlies the reservoir and some part of the Asmari Formation is composed of salt, anhydrite, marl and gypsum. Also, some coarse grained alluvial deposits, fine grained lake sediments and old river deposits are visible especially along the river line and the reservoir domain.

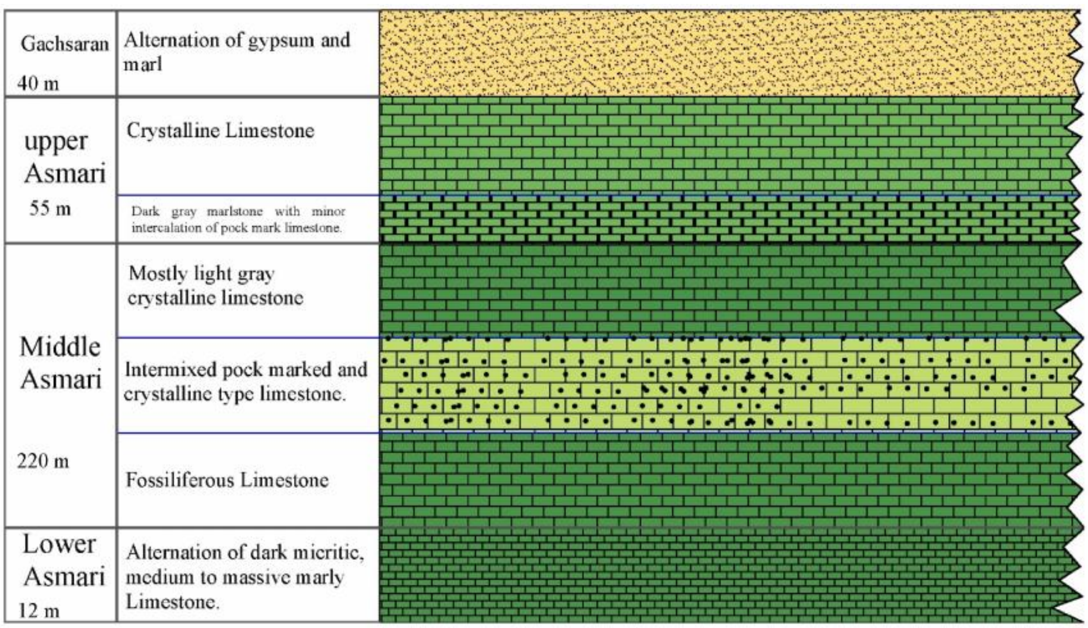

Figure 2. Geological profile around the anticline axis

Hydrogeological setting

The Pabdeh Formation, as an impermeable medium, underlies the Asmari limestone at a deeper level of the riverbed at the dam site. This causes a connection between the northern and southern flanks of the anticline (Ashjari & Raeisi, 2006). Up to 113 springs have been identified downstream and along both the river banks. These springs discharge water from the Asmari limestone aquifer into the river. In fact, 49 of the springs appear along the right bank (as shown in Fig. 3) and 64 along the left bank, all located in the southern flank of the Ravandi anticline. Due to the position of these springs, the evaluation of their hydrogeological characteristics bearsa significant importance in seepage monitoring, especially for numerical modeling. Most of the springs appear at the geological structures in the Asmari formation.

Precipitation is the primary source for the aquifer recharge, which penetrates through the fractures and percolates to the river via the springs. Based on the previous studies (Shiraz university, 2008), water resources from both abutments are different and do not exhibit any hydrogeological connection with each other.

Permanent and seasonal springs in the right river bank have been monitored before and after impounding. Based on the prior measurements, the total discharge of all right bank springs was about 300 Lit/s. The discharge after filling the reservoir up to a level of 660 m increased to about 800Lit/s.

Nine observation wells are used to monitor the

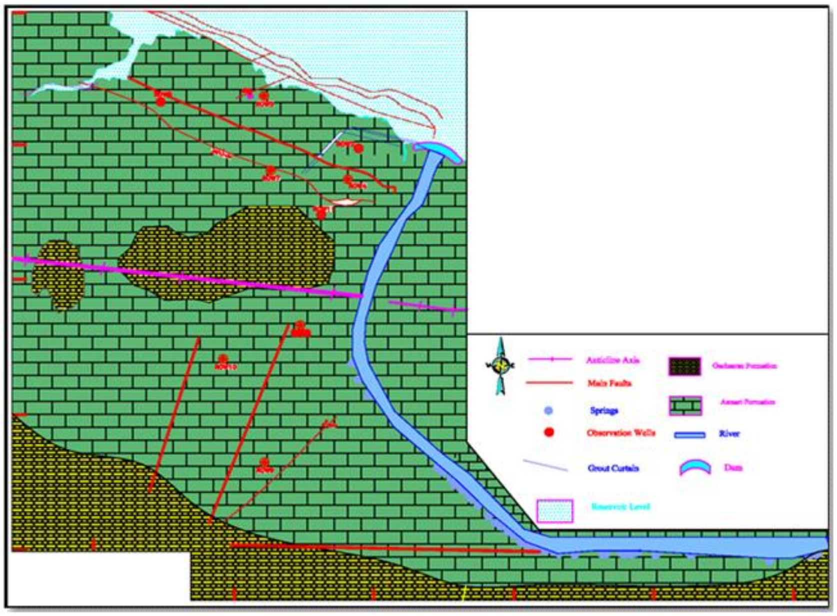

Figure 3. Geological engineering map of the right bank of the Seymareh dam site. Scale: 1/5000

fluctuations in the water table in the Asmari aquifer at the right abutment, namely 2, 4, 5, 6, 7, 8, 9, 10 and 11 (Fig. 3). The position of the observation wells, springs, major joints and grout curtain directions are shown in Figure 3. Based on the lithology and dip of the bedding planes, joints and fracture densities, the existence of major joints and also the grout curtain situation, several zones or regions with different permeabilities can be determined in the right abutment. Faults play an important role in the hydraulic conductivity of the rock masses by creating high permeable zones. Generally, fractures, major joints and fault structures are the main features in the seepage and underground water flow in the right abutment.

Before impounding, the aquifer was recharging by precipitation and the level of the Seymareh River reached to 602 m at the maximum. No source can be considered on the southwestern side of the aquifer, because it is overlaid by thick marls of the Gachsaran formation, while recharging the aquifer is enhanced during the wet and flooded months from the West side. The aquifer could not be recharged from the reservoir side before impounding because it is covered by fine grained alluvial deposits. However, after the impounding the main resource of the recharge is the dam reservoir. The amount of recharge from the reservoir is more than the amount supplied by the other resources. A large number of springs discharge a great proportion of the aquifer water into the river downstream.

Engineering geology

Rock mass permeability

As mentioned earlier, the Seymareh dam site is composed of limestone. The primary permeability of the limestone is low. The secondary permeability, however, is more because of the karstification and tectonic processes (White, 1977).Secondary permeability varies in different zones and depths. This makes the determination of the high permeability zones challenging. The water take results were used to gain more information regarding the hydraulic conditions in some parts of the aquifer.

The grout galleries are similar in direction. Some boreholes were considered as sample indicators of the luge on changes along the galleries alignment. The locations of the boreholes are shown in Figure 4. It should be noticed that the grout curtain and galleries have two different directions which are seen in Figure 3. As illustrated in Figure 4, galleries Nos. 1 (GR1) and 3 (GR3) are aligned in two different directions, whereas galleries Nos. 2 and 4 are aligned in a straight direction from East to West at the right abutment of the Seymareh dam.

The lugeon and RQD value changes versus depths for different boreholes have been plotted in Figure 5.

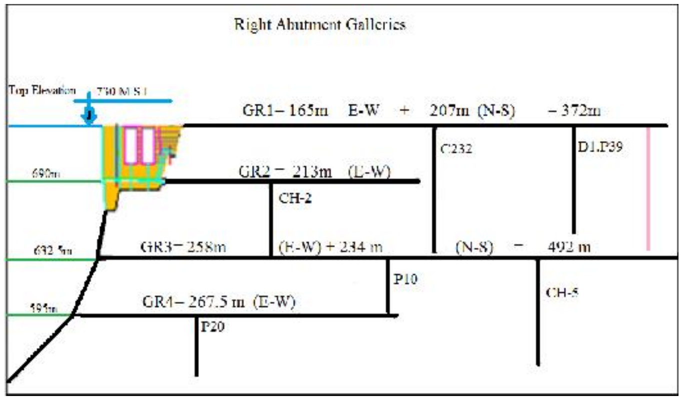

Figure 4. Profile of the boreholes in the grout galleries at the right abutment

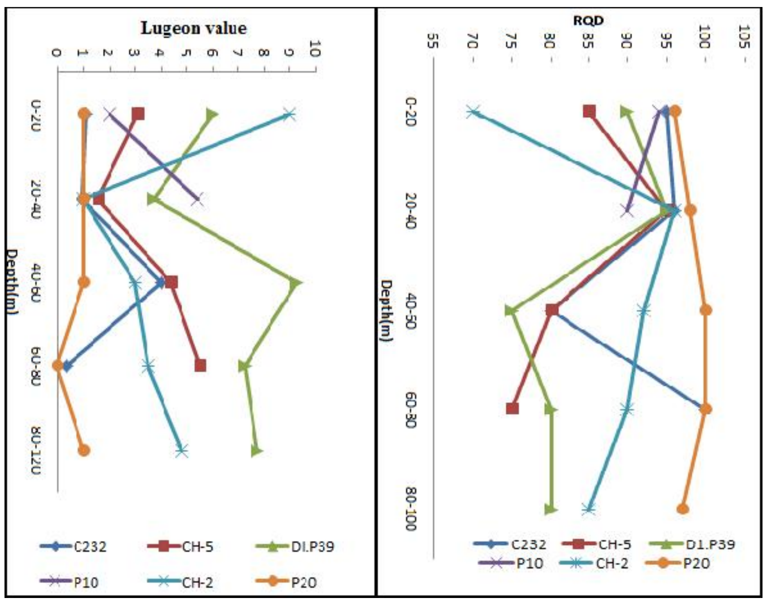

Figure 5. Lugeon and RQD value changes graphs of boreholes in the galleries

Evaluation of the graphs shows that the borehole D1.P39 from the first gallery in the highest elevation has the most water takes compared with the others. On the other hand, the borehole P20, drilled in gallery No.4, shows the lowest absolute value and variation range of the lugeon. By comparing the values of the core quality and water take in each borehole, it was concluded that any increase in the joint density results in an increase in the water take. In some cases, large apertures of the faults have caused rod fall and an abrupt increase in water take. For example, the fault plane which crosses the end of gallery No. 1 has resulted in a20cm aperture which can be easily seen at the beginning of the gallery, as shown in Fig.6. Therefore, it can be concluded that the water take increase at the borehole D. P39 is a result of these fault fractures and related joints.

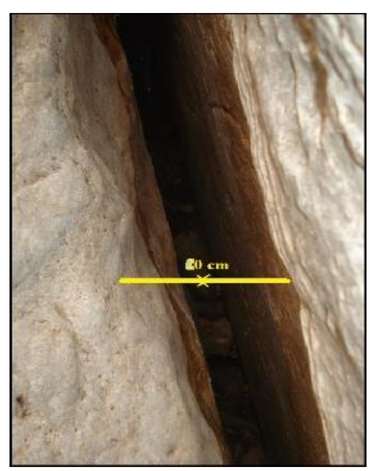

Figure 6. A major opening created by fault at the beginning of gallery No. 1

Accordingly, the fracture density and consequently the water take decrease in the deeper sections. Low permeability along the borehole P20 in gallery No. 4 demonstrates such phenomenon. Recovered cores from this borehole also show limited fractures. This comes naturally as the borehole is located in the gallery with the lowest elevation and limited water take.

General evaluation of the variations in the Lugeon plots does not show the same changes with depth in the boreholes drilled in the galleries. The general trend, however, shows an inverse relationship between lugeon and depth. Evaluation of the permeability and Lugeon tests in the right abutment boreholes indicates that the rock mass consists of an alternation of permeable (low to high permeability) and impermeable zones. This situation is affected by the fracture conditions around the borehole which has been drilled. The opening and spacing values of the joints were evaluated in the right abutment the results of which are shown in Figures 7 and 8, respectively. Also, specifications of the major discontinuity sets are shown in Table 2.

The evaluation of the opening graphs of the joint shows that the major opening (>10mm) in the northern flank is more than in the southern flank. This implies that the rock masses of the northern flank (Fig.7A) were more affected by the fault structures rather than the southern ones. Therefore, it is expected that the hydraulic conductivity must be higher than that of the southern flank. Most of the opening values are less than 1 mm and the second grade is related to the values between 1-3mm. Evaluation of the whole data related to the joint spacing in the right abutment shows that most of the joint spacings are between 6-20 cm and the second grade is related to a size between 20-60 cm (Fig. 8). Often, the spacing between 60 and 200 cm is related to bedding in both the flanks. Thus, the spacing of less than 60 cm is related to the joints related to the fault features and therefore, statistically the joints play the most important role in water seepage in the right abutment; however, because the dip direction of the beddings is toward the reservoir, the water will not be allowed to pass the beddings. On the other hand, based on the field study, there are lots of joints having the N-S direction, especially near to the main valley of the dam site, which greatly increase the possibility of the water flow along them to finally reach the southern flank.

Karst features

According to the subsurface studies done at the site, no cave or large cavity was observed in the right abutment of the dam site. By investigating the whole coreboxes of boreholes drilled at different points of the right abutment, the maximum observed rod fall was about 1.5 m and most of the rod falls were along the apertures of the faults. Some rod falls were observed in the grout or explored in the galleries during the field studies.

Table 2. Major discontinuity sets and their specifications

Discontinuity set	Dip direction	Dip	Spacing	Discon.surface	Opening	Filling
Set1	170-175	65-75	0.55m	Rough-wavy	2-20mm	Clay, calcite
Set2	270-275	80-90	0.65m	Rough-wavy	2-20mm	Clay, calcite

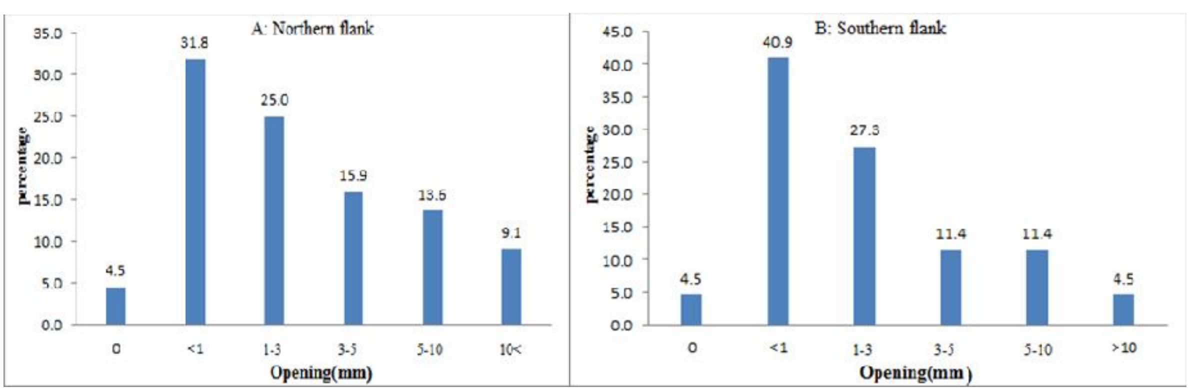

Figure 7. Graphs of joint opening conditions in the northern flank (A) and southern flank (B)

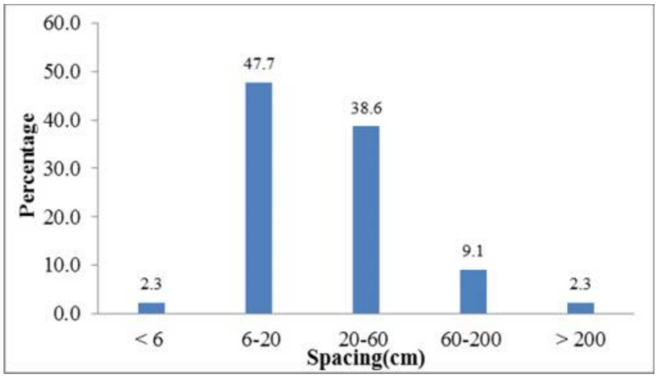

Figure 8. Joint spacing conditions in the right abutment

Observations indicate that there is no developed karst system which can connect the cavities or fractures hydraulically.

Small karstic cavities, however, are observable at the different elevations of the bedrock in the outcrops. These cavities rarely connect with the adjacent ones and the connection is seen only at those points where the discontinuities have resulted in enormous fracturing in the rock mass. Therefore, it can be concluded that the solution cavities observed in the boreholes or surface outcrops are not connected with each other. Besides, some of the cavities or solution joints are filled with recrystallized calcite. During the exploration of some boreholes, the density of the fractures had increased at high elevations (around 690 m from sea level). Hence, the small cavities can be connected hydraulically in the high reservoir levels. Besides the information obtained from the inspection of the core boxes, observations of the limestone outcrops and grout galleries showed no solution conduits and/or large cavities in the right abutment.

Dye tracing conducted by the Shiraz University (2008) did not indicate any conduit flow in the right abutment. Therefore, it was concluded that no remarkable solution cavity or large aperture existed in area mentioned or that they were simply rare and would not affect the main flow pattern of the aquifer. The appearance of a large number of springs in the right bank of the river downstream is another evidence for the lack of dominant conduit flow in the right abutment of the dam. These springs have low discharge; in a few springs, however, the discharge is not negligible. They are fault springs formed due to local high permeable fault structures. Therefore, the dominant flow system in this area is diffuse.

Preparing conceptual model and determining seepage course

Based on the spring discharges, from the water level fluctuations of the observation wells, major joints directions and their spacing and opening values, RQD and Leugan values and grout curtain direction, the water seems to be seeping from the northern to the southern flank. Therefore, it was concluded the course of the water flow is along the yellow arrows shown in Fig. 9. Several reasons support the statement given above, as follows:

1. The downward fractures in observation well No. 7 toward the anticline axis were not affected by the grout curtain. This phenomenon has caused water seepage downwards of the course.
2. Observation wells Nos. 11 and 4 are close to the grout curtain in the north flank. It is observed that the increase in the water level in the reservoir induces a greater increase in the water level in wellsNo.11 than in well No.4 behind the grout curtain. This implies either a weakness in the wall or water course between the ending of the grout curtain and anticline axis. Therefore, the seepage is more likely to occur from this part to the south flank.
3. Based on the field studies and site investigations, no cross or traverse joint to the anticline axis was seen or suspected of seeping along the red line (Fig.9).
4. Unloading in the main valley side decreases the confining stresses which results in the formation of the release joints with N-S direction. These joints are covered by the Gachsaran formation. An observed N-S fault in the southern flank is evidence for this phenomenon. The fault begins near the observation well No. 9 and continues up to the western part of ROW8 and disappears under the Gachsaran formation around the fold axis. The

disappearance of this fault under the covering sediments does not imply its discontinuity toward the northern flank.

Therefore, the reservoir water can seep through these joints or major joints in the same direction as the fault. These structures can cause water seepage from the northern flank to the southern flank and downward.

5. After impounding, the water level in observation wellNo.8 is often higher than that in observation well No.10. This is an indicator of the concentration of flow close to the main valley along the river. As a result, the flow first recharges ROW8 and then it affectsROW10. As the seepage would normally occur from the western part of the aquifer, the water level in ROW10 should be higher than ROW8.

The seepage, however, occurs in the right abutment. Discontinuities are the major reason for this phenomenon. At the higher levels of the reservoir more seepage potential is expected at the right abutment. Some reasons for such a potential are the joint apertures and their density, decrease in the joint filling, possibility of connecting to a thin karstic layer and an increase in the contact surface of the water to the abutment.

Numerical modeling

Hydraulic models can be used to evaluate seepage potential and groutability. An accurate evaluation, however, depends on realistic input parameters. The GW finite element code was used to predict the seepage at the higher levels of impounding. The code has specific abilities in the analysis of the flow and subsurface mass transport. It has been applied in different environments including the alluvial, fractured and faulted, karstified, caved and combined environments. The code can do the simulation in one-, two- and three-dimensional conditions (Cornaton, 2006). Due to the advantages afore mentioned, GW was used in this study. On the other side, using GW poses its own difficulties; for example it is more complicated to simulate the flow with GW than the codes with visual environments. In this study 2D models were used for the seepage simulations.

The following steps were taken to simulate the flow: 1. Defining the geometry and boundary conditions, 2. Calibration, 3. Verifications and 4. Sensitivity analysis.

Geometry and boundary conditions

The geometry of the model was defined based on the results of the surface and subsurface studies, topographical mapping, as well as aerial photos. The geometry comprises most of the aquifer on the right abutment. Based on the subsurface geological and geotechnical investigations, the bed rock level is assumed to be 550 m above the sea level. No special fracture or water course was found in the investigations and the top elevation was defined at

Figure 9. Seepage potential course (yellow arrows) and course without cross fractured to axis strike (red line)

1000 m by code defaults. As stated earlier, the main sources that recharge the aquifer are primarily precipitation and secondarily adjacent aquifers. The springs discharge the aquifer downstream of the dam axis. The east side of the model is limited to the Seymareh River with about a 0.3% gradient elevating from 594 to 600 m above sea level. The north side of the model connects to the reservoir, which changes at different levels. Therefore, the eastern and northern sides are considered an open boundary, whereas the other sides, which have no specific connection, are defined as closed boundary conditions (Fig. 10).

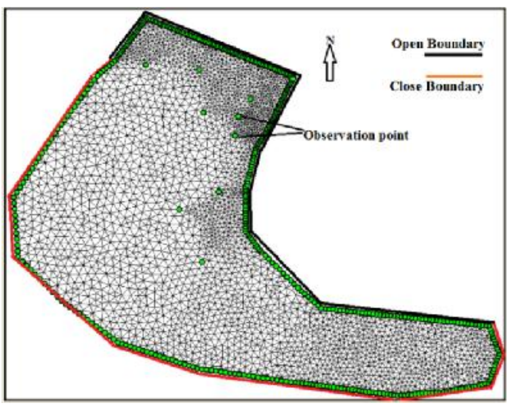

Figure 10. Geometry and boundary conditions of the model

After determining the geometry and the boundary conditions, the geometry finally proposed was classified into 12 zones with different hydraulic conditions. The basis for such classification was to enable site characterization studies to be performed. The hydrogeological properties of the elevation of 630 m MSL (Mean Sea Level) were considered the properties of the simulated layer. As the model used was 2D it required only one hydrological layer for modeling. As the characteristics of the elevation had been arrived at from different surface and subsurface studies and as the effect of the water level in 630 m of the reservoir was clear as well, on the rock masses, this elevation was selected for the 2D modeling. The classification is done based on the variations in the hydraulic conductivity in different parts of the abutment. The field study and geological data such as joints and faults strike, spring location, geological formations and fluctuations in the observation well level are also considered in the classification. The grout curtain is considered a low permeability zone in the model. In the high fractured zones the possibility of high permeability and conduit flow is present. To model the higher rate of water flow in the high fractured zones, a set of one-dimensional pipelines extending downstream are defined. The radius of a pipe varies in the different hydrogeological zones. The permeability is low around the anticline axis so that the water cannot cross the axis easily. This also results in an increase in the hydraulic gradient at the sides of the axis. This zone is illustrated as No. 8, and is shown together with all the other zones in Figure 11.

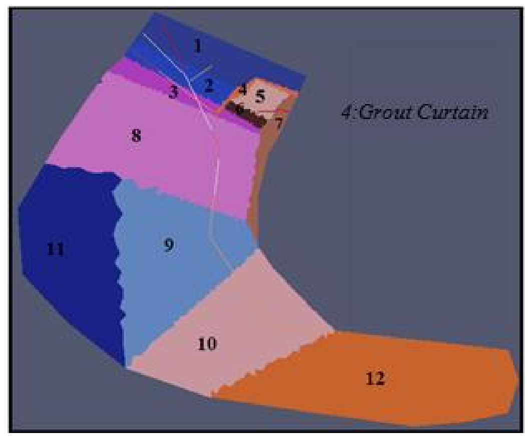

Figure 11. Classification of the model into 12 zones and one pipe line

Considering different hydraulic parameters for each zone makes the process of modeling time consuming. The classification of the study area into different zones according to geotechnical and engineering geological data and field study helped in calibrating the model more easily.

Calibration

The aim of this simulation is to estimate the seepage value from right abutment of the Seymareh dam in the top level of the reservoir. The current water level in the reservoir is about 660 m and the data of the effect of this high hydraulic head on the rock masses of the right abutment is present. Therefore, the model was calibrated for the current reservoir level (660m) and then the water seepage value was predicted for the top elevation of the reservoir (730m).

In order to do so, the levels of the observation wells and spring discharges were used to calibrate the model. Therefore, the model outputs are calibrated using real data and similar parameters of the aquifer were inserted into the model before it was prepared for simulating the top level of the reservoir. For calibrating the model at level of 660m, it first needs to be calibrated for the initial conditions, i.e. prior to impounding. The data from the observation wells were inserted as software inputs of the hydraulic head. The water level in the wells was automatically interpolated by the software to all the nodes of the network to define the initial conditions prior to impounding. The model was calibrated for the initial conditions with the well elevations and spring discharges one year prior to impounding. The parameters Kij, Ss and Ne which, respectively, represent hydraulic conductivity (m/day), storage coefficient and porosity, were adjusted based on the calibration the initial conditions. The parameter values of each zone are shown in Table 3.

Table 3. Hydraulic parameters value of the zones

Zones	Ne	Kxx	Kyy	Kzz	Ss
1	0.20	2.00E-04	2.00E-04	2.00E-04	1.00E-05
2	0.10	4.00E-04	4.00E-04	4.00E-04	1.00E-06
3	0.15	6.00E-04	6.00E-04	6.00E-04	1.00E-04
4	0.10	2.50E-06	2.50E-06	2.50E-06	1.00E-06
5	0.20	3.00E-04	3.00E-04	3.00E-04	1.00E-04
6	0.10	1.00E-04	1.00E-04	1.00E-04	1.00E-05
7	0.15	1.00E-05	1.00E-05	1.00E-05	1.00E-05
8	0.20	6.00E-05	6.00E-05	6.00E-05	1.00E-05
9	0.20	2.00E-04	2.00E-04	2.00E-04	2.00E-04
10	0.20	6.00E-04	6.00E-04	6.00E-04	2.00E-04
11	0.20	5.00E-04	5.00E-04	5.00E-04	1.00E-05
12	0.20	5.00E-04	5.00E-04	5.00E-04	1.00E-05

The impounding of the reservoir to the 660 m MSL was considered in the model for a period of 16 months with 41 time steps. Data from the unsteady state flow during the simulation of impounding was used to recalibrate the model. To accomplish this, in an iterative process, the hydraulic parameters including *K*, *S* and the radius of the pipes were changed and the model was run. The best accordance between the real data graphs and model graphs was selected as the best condition for the successive simulations. The results of the numerical analysis with real data are shown in Figure 12.

The blue lines indicate the analysis of the outputs and the red lines represent the real data of the observation wells. By comparing the simulated and real graphs, it can be concluded the calibration has been done well. According to Figure 12 the graphs of two sets of data show an acceptable accordance.

The discharge values of the right bank springs obtained from numerical analysis are higher than those of the field values. The value of 1 m^3/s was reported for the discharges from the springs while the seepage value of 1.5m^3/s was estimated by the numerical modeling for levels below 660MSL. Based on the field studies and real measurements, some springs underlie the river flow level, which explains the difference between the two values. Therefore, the simulated discharge value by numerical analysis is compatible with the aquifer conditions and is acceptable.

Validation of the model

This part is dedicated to control the inputs and the results of the numerical analysis. We attempted to assess the validity and reliability of the results by comparing them with the real-world measurements. The variables investigated included hydraulic conductivity, storage coefficient, drainage porosity, discharges from the springs and water table fluctuations data at the right abutment.

As the aquifer is mostly composed of limestone, the drainage porosity is quite logical. Also, based on the field studies, *in situ* tests (Lugeon values) and the nature of the fractured limestone, the hydraulic conductivity and storage coefficient value of each zone appear to be logical. To validate the analysis results, we compared the calculated water level and discharge to the water table data obtained from the discharges from the wells and springs.

As mentioned prior, the nine observation wells in the right abutment and outputs of the model were considerably similar to the real observation points. Moreover, the simulated seepage value showed good accordance with spring discharges

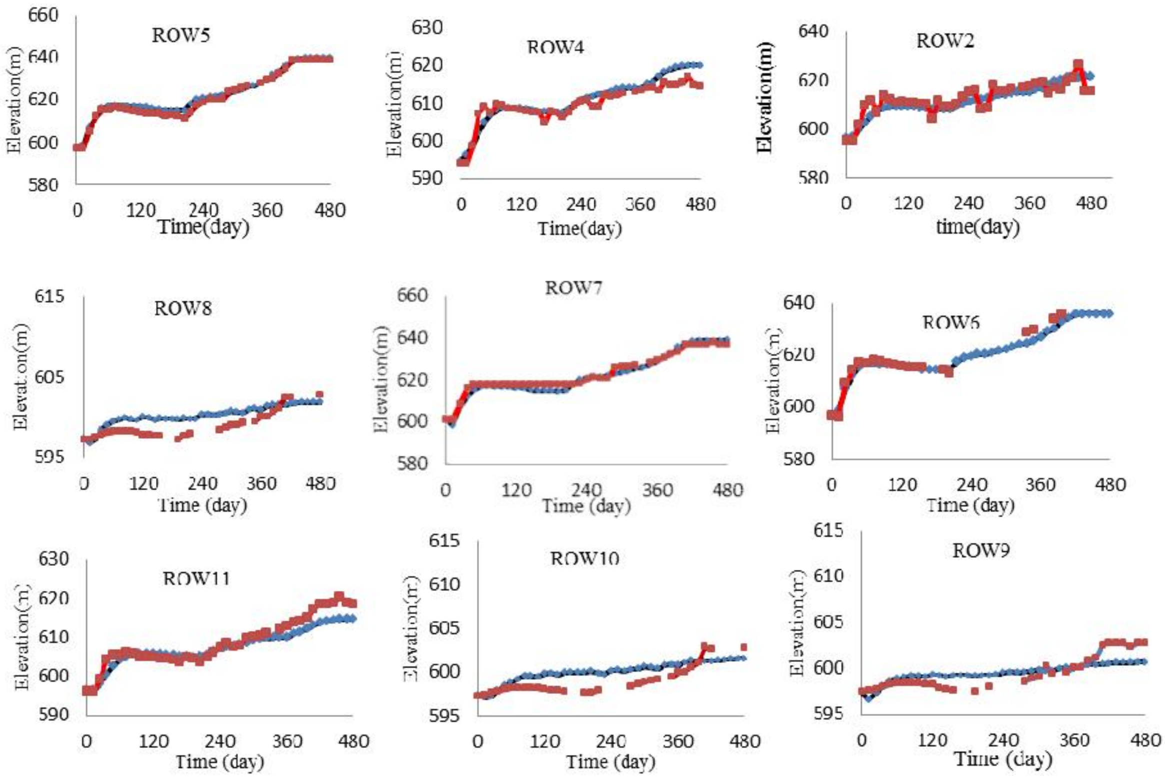

Figure 12. Calibration graphs of the model outputs (blue line) and observation wells (red line)

downstream. The estimated seepage value for a level above 660m MSL is 1.5 m^3/s, which is similar to the real value of the spring discharges. After validation of the model and its calibration with real-world data, the next step was to perform the simulation at the higher level of the dam reservoir.*Sensitivity analysis*

To determine the model's sensitivity to hydraulic parameters, we defined the 1/2 of the assumed values of the hydraulic parameters as baseline values. Then, we incrementally changed the baselines in stages of a 10% cumulative increase and decrease. In each simulation, one parameter was variable while the others were constant. The analysis results were then plotted on a diagram and compared. Discharge (Q) and Head were considered the dependent variables, while hydraulic conductivity (K), Storage coefficient (S), and Recharge of the aquifer by precipitation were independent. The results indicated that the discharge was mostly sensitive to the storage coefficient than the other parameters, and the Head at the observation point was mostly dependent upon the hydraulic conductivity. Variations in the recharge did not exert any considerable influence on the results, which are ascribable to the vast difference between the recharge from reservoir and the precipitation. As the amount of precipitation which recharges the aquifer is considerably less than the recharge from the reservoir, its effect on the results is negligible (Fig. 13).

Estimation and prediction of the seepage value

The model has been calibrated for two different conditions; the initial condition and the impounding up to 660m MSL. The aim of the calibration in different conditions and reservoir levels is to obtain the best input hydraulic parameters. For prediction of the seepage value between the levels of 660 to 720m, we simulated the problem in a two-year time span.

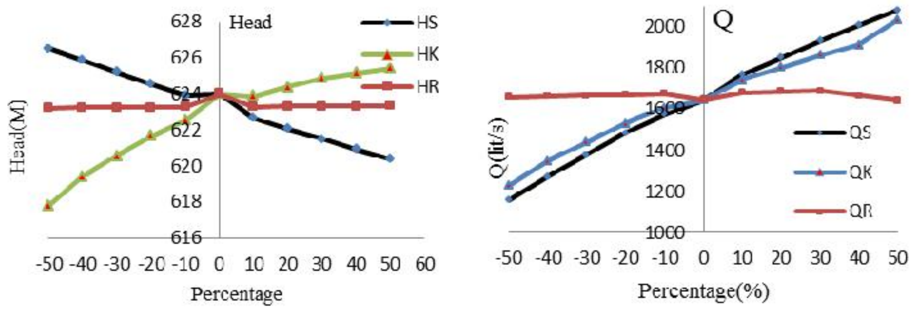

Figure 13. Graphs of sensitivity analysis

As the increase in the water elevation in the reservoir would be slower than before, we selected a two-year time period. This also resulted in the increase in the area of the reservoir. In the new reservoir conditions, a level of 660m MSL was considered as the initial condition. Then, the simulation was performed by imposing the hydraulic head in a time span of 24 days. The hydraulic parameters of the elevation of 660 m MSL were considered for the higher elevations as well. The model outputs showed that with the rise in the water to the normal level of the reservoir in a two-year period, the amount of seepage through the right abutment reached 4.1m^3/s. In this situation, it is expected that the water level in the observation wells will be much higher than before.

Conclusions

The Seymarehdam and its powerhouse have been constructed and are under impoundment. A grout curtain has been designed and performed to reduce the seepage. Water table fluctuations in the observation wells are the critical data for the numerical and analytical studies of the seepage at the Seymareh dam. The studies show the hydraulic connection between the two flanks of the anticline at the 660m level of the reservoir. The overall assessment of the springs' discharges confirms this connection. The new GW finite element code was used to predict the seepage value on elevationsabove660 m. To verify the simulation results we checked the results with the fluctuations of the water tables of the observation wells and changes in the springs' discharges. Numerical modeling indicates that a considerable amount of water can seep through the right abutment of the dam to the level of 720m of the reservoir. To avoid the consequences of this phenomenon it is necessary to take some remedial measures. Such measures should be taken regarding the base flow rate of the river and economic limits of the project. One possible remedial operation is executing a grout curtain about 200 m from the end point in the NE-SW direction of the right abutment. In such scenario, the drain boreholes which are located backward of the grout curtain should be checked and measured regularly and the unnatural changes need to be interpreted and clarified for the next step of impoundment.

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