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MANAGEMENT OF RISK THROUGH SEEPAGE REDUCTION FOR TWO EARTH DAMS IN KURDISTAN REGION, IRAQ

Sangar Hasan Abdulkareem, Thamer Mohamed Ahmed and Abdul halim Ghazali
Department of Civil Engineering, Universiti Putra Malaysia, UPM Serdang, Selangor, Malaysia
E-Mail: eng.sangar@yahoo.com

ABSTRACT

Risk management through seepage reduction for earth fill dams with evaluation of risk and reliability has been a major concern for the hydrosystem and geotechnical engineers. Several techniques have been established to measure risk and reliability of a system. One of the main approach of risk reduction for seepage at earthen dams is modeling technique. In case of existence of seepage problem through or underneath the earth dams, reliability of the analysis should be based on review of as-built drawing and construction/operation photography of the dam site in order to tackle the defects which cause the problem. This study aimed at managing the seepage risk reduction of two existing zoned earthen dams that newly constructed in Kurdistan Region, Iraq, namely Hamamuk dam and Bawashaswar dam. Both dams have been suffering from downstream flat slope seepage since initial filling. For this purpose, construction/operation photography were reviewed and SEEP/W models wasplied. Construction defects that caused seepage problems at both dams were detected based on the construction/operation photography. Also, the effects of these defects on seepage rate and seepage path were simulated using SEEP/W model. Appropriate solutions were proposed based on different guidelines and references.

Keywords: earth fill dams, risk reduction, SEEP/W models, seepage.

INTRODUCTION

Throughout the world, the risk reduction of existing earth dams has become the major focus of dam engineering. Dams require certain structures and design to increases reliability, efficiency and safety. The potential function of a dam is realized in the course of good design, planning, and investigation. Structural defects that correlated with poor design and construction can cause problems that lead to dam breaches or collapse which results in catastrophic consequences (Stephens, 2010).

However, seepage is a major concern associated with dams during design, construction and operation of earth dams. Zhang *et al*. (2007) examined 593 causes of earth dam failures and discovered that 58.3% of the failures occur by piping beneath or through the earth dams. All earth dams are subject to seepage through embankment, foundation, and abutments.

To mitigate seepage at existing dams, different design features or actions have been used. These actions can be categorized into two generic types: seepage control and seepage reduction. Generally, seepage control in embankments focuses on drainage of seepage flows and proper filtering. Seepage control is necessary to reduce and control the development of harmful behavior such as piping phenomenon through and beneath the embankment, instability of the downstream slope and uplift pressures. Seepage reduction can be achieved through extending the seepage path by using horizontal or vertical barriers. As a result, hydraulic gradient that causes piping will be decreased (Engemoen, 2012; USACE, 1993; USBR 2011). For safety evaluation of existing dams, a construction photograph provides an excellent visual interpretation of the project. By reviewing construction photographs, structural features can be visually evaluated and the problematic area can be detected (USBR, 1995). Numerical simulation of seepage can provide valuable insights about understanding potential seepage issues and evaluating the relative effectiveness of various seepage reduction measures (Engemoen-USBR, 2012). The numerical computer program (SEEP/W) was used widely by researchers by virtue of the accuracy of its results. It also simulates approximately actual seepage paths and rates through and beneath earthen dams (USBR, 2011; Giglou *et al*., 2013).

This study aims to reduce seepage risk at Bawashaswar and Hamamuk earthfill dams in Kurdistan Region, Iraq. Construction/operation photos of both dams were reviewed to determine the problematic area. SEEP/W model was applied to predict the seepage performance and determine the seepage path in order to identify shortcomings during the construction and causes of the main defects which resulted in high seepage rate at these two dams.

Study area

Bawashaswar dam

Bawashaswar earthfill dam was constructed in 2011and located in the Southeast of Sulaymaniya province in Kurdistan Region, Iraq. The dam has embankment length of 240 m and a height of 22 m. The reservoir that is formed by the dam has a capacity of 6.5 x 10^6 m^3 and is used for irrigation and flood control. The uncontrolled concert spillway is located 350 m away from dam's left abutment and it has a maximum capacity of 440 m^3/s. The embankment section is shown in Figure-1. Monitoring of seepage at Bawashaswar dam was limited to recording its rate only due to lack of piezometer standpipes in the dam body and abutments.

From geological point of view, the dam axis is situated over Injana (Upper Fars) formation. This formation consists dominantly of sandstone, siltstone and

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claystone, and is covered by 4 m quaternary sediments which are composed of a mixture of gravel and sand at the mid valley. For further safety of dam, a single line of 15 m deep grout curtain was constructed beneath the dam centerline as shown in Figure-2.

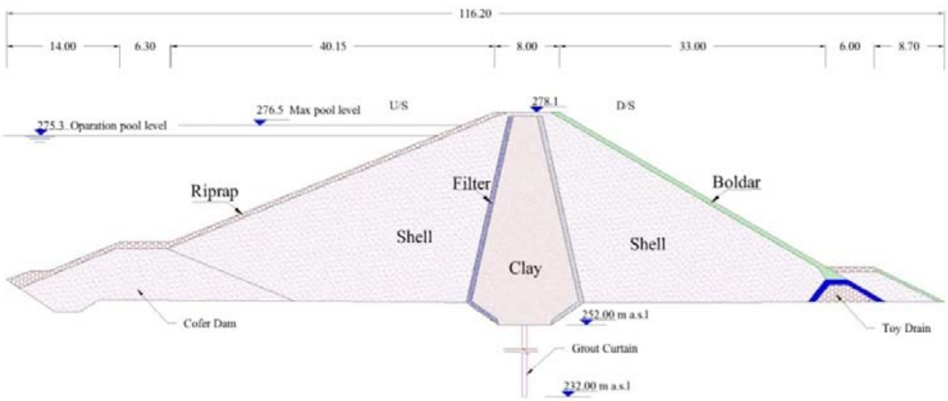

Figure-1. Cross section of Bawashaswar zoned earthfill dam.

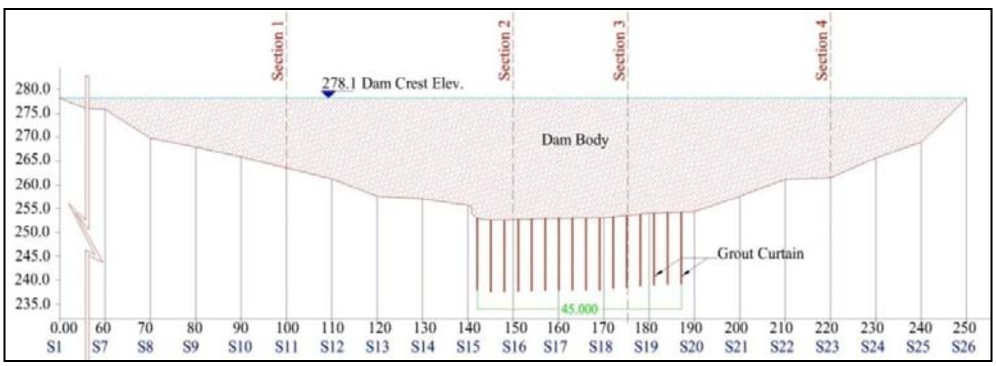

Figure-2. Location of Grout Curtain on longitudinal section of Bawashaswar Dam.

Evidence of seepage problems at Bawashaswar dam appeared during the first filling of the reservoir in January 2011 when a high seepage rate was recorded at the expansion and construction joints of the outlet gallery (Figure-3) particularly at the expansion joints of gallery walls which are located under upstream shell zone. Also seepage was observed at the downstream flat slope beside the stilling basin (Figure-4).

Figure-3. Seepage at the expansion and construction joints of the outlet gallery of Bawashaswar dam.

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Figure-4. Seepage at the downstream flat slope of Bawashaswar dam.

Later, after filling the reservoir, seepage was visually observed at the right abutment of Bawashaswar dam. To overcome the seepage problem at the right abutment, an extensive grouting was performed in the bedrock. As a consequence, the seepage problem at this area has been contained. To mitigate the seepage problems at the joints of the bottom outlet gallery, another extensive cement-bentonite grouting was performed through the wall of the gallery and Sika was used for joints treatment. As a result, the seepage rate was reduced by than 80% and became about 0.5 l/s. However, the seepage problem at the downstream flat slope remains without solution. And the maximum recorded seepage rate at downstream flat slope is 1.8 l/s at the maximum reservoir elevation. Moreover, the drainage arrangement at Bawashaswar dam is not functioning because the drainage pipe has been constructed at a high elevation as shown in Figure-5.

Figure-5. Location of the drainage pipes at Bawashaswar dam.

Hamamuk dam

Hamamuk zoned embankment dam was completed in 2011 and it is located at Hamamuk village which is 85 km from Erbil city. The dam has a maximum height of 28 m and a crest length of about 130 m. An uncontrolled concrete spillway with a crest elevation of 804 m is located on the right abutment. A reservoir storage of 0.5 x 10^6 m^3 is formed by the dam and used primarily for recharging groundwater with secondary uses for irrigation and recreation. A typical cross section of the dam is presented in Figure-6.

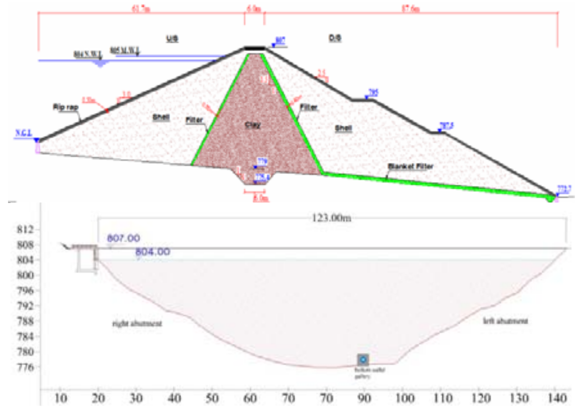

Figure-6. Typical cross section of Hamamuk dam.

The main components of the embankment are central core, shell and blanket filter. The core zone is specified as a mixture of clay, silt and sand. The shell of the dam consists of a mixture of gravel and sand with a small ratio of silt and clay. The embankment design includes a 60 cm filter as a transition zone separating clay core from the shells. A 60 cm thick gravel and sand blanket drain was constructed beneath the entire downstream shell as shown in Figure-7. The bottom outlet pipe divides the blanket filter into two separate parts. Thus, the v-notch measurement chamber is divided in two parts.

Figure-7. Blanket filter and v-notch chamber at Hamamuk dam.

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Geologically, the dam area is mainly composed of intercalation between mudstone, sandstone and claystone. The outcrop of rock beds forms the most area of the reservoir with thick layers of siltstone and mudstone. Tests on materials on 3 boreholes show that the permeability of claystone-sandstone and claystone-siltstone are 1.6 x 10^{-7} m/s and 1.05 x 10^{-7} m/s, respectively. Also, many fractures were observed at upper layer of claystone-sandstone which led to increasing in permeability value of this stratum.

There are two piezometer standpipes at the dam site, one at the right abutment beside the spillway which has malfunctioned since the first filling of the reservoir, and the second one is at downstream (at the right side of v-notch chamber). Currently, the head of water in the piezometer at downstream is +3 m.

Similar to Bawashaswar dam, evidence of seepage problems was observed during the first filling of the reservoir when a 9 l/s of total seepage rate was recorded at the v-notch weirs and downstream flat slope at Hamamuk dam. The seepage rate declined with time to be 4.4 l/s of a steady rate of total seepage at Hamamuk dam when the reservoir was at an elevation of 804.0 m which is the maximum reservoir elevation. In March 2014, about 1.6 l/s of the seepage was continuously discharging from the downstream piezometer and approximately 1.8 l/s and 1.0 l/s were discharging from left and right v-notch weirs respectively. In addition, many spots of wet areas were observed at the flat slope at downstream as shown in Figure-8.

Figure-8. Seepage at Hamamuk dam site.

METHODOLOGY

SEEP/W modeling and evaluation of construction/ operation photographs were used for seepage risk reduction of the studied dams. By reviewing construction photographs the problematic area and the construction defects were detected. SEEP/W modelling was conducted for simulating the seepage pattern and rates with and without the detected defect in order to find its effects on seepage rate and path.

SEEPAGE ANALYSIS

Seepage analysis at bawashaswar dam

Reviewing construction photographs identified that part of the dam at downstream (from S15 to S17 as shown in Figure-2) was built on boulder and sandy gravel filter (recent deposits) as shown in Figure-9. This stratum is located 2.5 m below the drainage pipe at the dam toe. And the recent deposits stratum that is located beneath bottom outlet gallery with 2 m to 3 m thickness has been replaced by rock concrete.

SEEP/W model was carried out to find the effects of this stratum on seepage path through and beneath the dam and another condition was simulated where the recent deposits are not considered in the dam body. The result indicated that during filling of the reservoir, the recent deposits was worked as a blanket filter at the dam downstream as shown in Figures 10 and 11. As a consequence, the drainage arrangement is not functioning because the drainage pipe is located at an elevation higher than the phreatic line.

Figure-9. Recent deposits at downstream shell foundation of Bawashaswar dam.

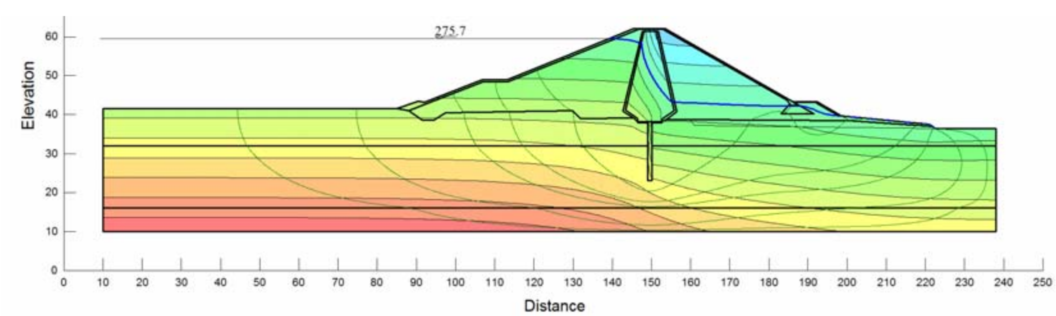

Figure-10. Modeling of Bawashaswar dam as proposed.

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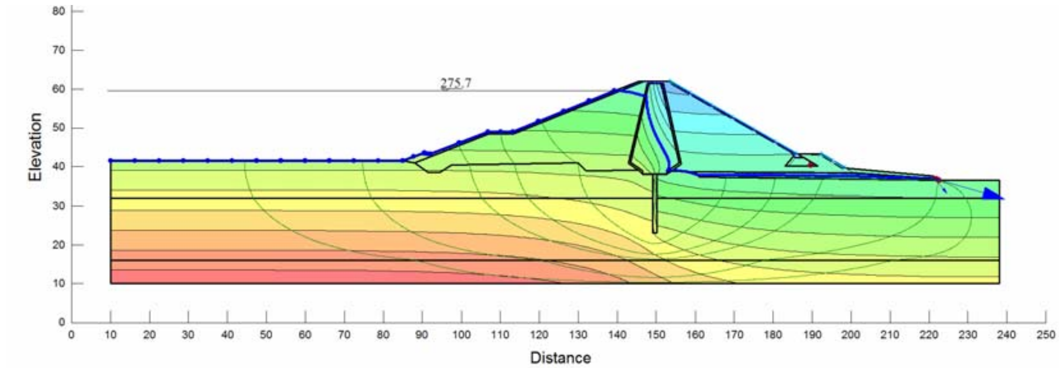

Figure-11. Modeling of Bawashaswar dam within recent deposit stratum beneath bottom outlet gallery.

Also, the models show that seepage rate increased by about 21% due to the effect of recent deposits on decreasing length of seepage path through and beneath the dam. Generally, measures to control seepage include cutoff walls for reducing the seepage rate and decreasing the exit gradients, and drainage or relief structures increase flow rate but reduce seepage pressure (USACE, 1993).

Based on photographs during modifications of the dam, the main causes of the seepage at the bottom outlet gallery are construction defects and floods. Two major floods had occurred at the site of Bawashaswar dam during the construction of the bottom outlet gallery which was used as a diversion channel during construction of the dam. As a result of these floods, the dam site was covered with silt deposition and the rubber used in the expansion and construction joints to control seepage was damaged as shown in Figure-12.

Figure-12. Effect of flood on bottom outlet gallery of Bawashaswar dam.

Also, it was found that the same type of rubber used in the expansion joints was used in the construction joints too (Figure-13). As a result, any rupture or punch in the rubber will develop a path for water leakage from these joints.

Figure-13. Rubber of expansion joints used for construction joints in the Bawashaswar bottom outlet gallery.

In addition, poor construction of these joints increases the probability of leakage. Furthermore, fractures were observed along the gallery which was wet at upstream side, while residues of seepage were found at the dam downstream side as shown in Figure-14.

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Figure-14. Residues of seepage at fractures along the bottom outlet gallery.

When concrete conduits are placed on non-uniform foundation, differential settlement will occur and this will result in cracking of concrete, opening the exit joints, and rupture the waterstop (FEMA, 2005). At downstream part of Bawashaswar dam, excavations of recent deposits were made at the gallery foundation and it was replaced with rock concrete within different thickness (from 1 m to 3 m thick) as shown in Figure-9 and Figure-15. This was increased the potential for differential settlement and cracking the concrete.

Figure-15. Foundation treatment of bottom outlet gallery at Bawashaswar dam.

Seepage analysis at hamamuk dam

As mentioned previously, the main function of the dam is for recharging the groundwater and based on this, the dam was constructed on an area with high permeability. However, grouting was not included in the dam design. Nevertheless, reviewing construction photographs identified that during initial filling and within dead storage reservoir elevation, water was discharged through a drainage pipe at the tail of the dam. Moreover, flooding was observed at the dam tail behind the retaining wall as shown in Figure-16, which confirms the high seepage recorded rate at Hamamuk dam.

Figure-16. Seepage at Hamamuk dam during initial filling.

The drainage system is designed to separate the seepage of the dam's left side from the seepage of the dam's right side along the diversion channel as shown in Figure-7. But it is found that the design was not working and the seepage from both sides is mixed due to construction defects as shown in Figure-17.

SEEP/W model was employed to find the seepage path and rate through and beneath the dam. The maximum elevation of the reservoir used in the simulation of seepage is 804.0 m as shown in Figure-18. As a result, the seepage simulation shows that about 30% of the total seepage is occurring underneath the dam embankment.

In order to control the underneath seepage, grouting of foundation was recommended (USBR, 2011; USACE, 1993; Rice, 2007). Also, SEEP/W model was employed to simulate the effectiveness of the grouting to reduce seepage rate as shown in Figure-19. Results show that the seepage rate can be decreased by about 30%.

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Figure-17. Defect at drainage system of Hamamuk dam.

RESULTS AND DISCUSSIONS

At Bawashaswar dam, SEEP/W model indicated that the recent deposit at downstream foundation worked as a blanket filter. And this stratum increased the seepage rate by about 21%, and the pore water pressure drop below the drainage elevation. Generally, seepage rate increases within blanket drain and it is used to drawdown the phreatic surface (Fell *et al*, 2005). To seal geologic defects, grouting of the foundation was recommended which also reduces underneath seepage rate (USBR, 2011, Fell *et al*., 2005). But even if dam downstream is grouted or a barrier is constructed at the dam toe in order to raise phreatic line, the drainage system will be partially working because drainage pipe was constructed at high elevation (Figure-5).

The grouting has not been done at the joints of the bottom outlet gallery wall that were located under downstream shell embankment. This is because small seepage rate was observed at these joints which are occurs during rainy days. Thereby, with treatment of recent deposits the phreatic line elevation will rise and water will seep through all these joints and lead to a catastrophic dam failure event. Earth fill materials that surround the conduit (bottom outlet gallery) will be eroded with developing preferential flow paths through conduit joints, and in most probably it leads to piping phenomenon (NZSOLD, 2000; FEMA, 2005; USBR, 1987). Thus, before taking any action for solving the downstream flat slope seepage, the problems associated with joints of bottom outlet gallery must be solved.

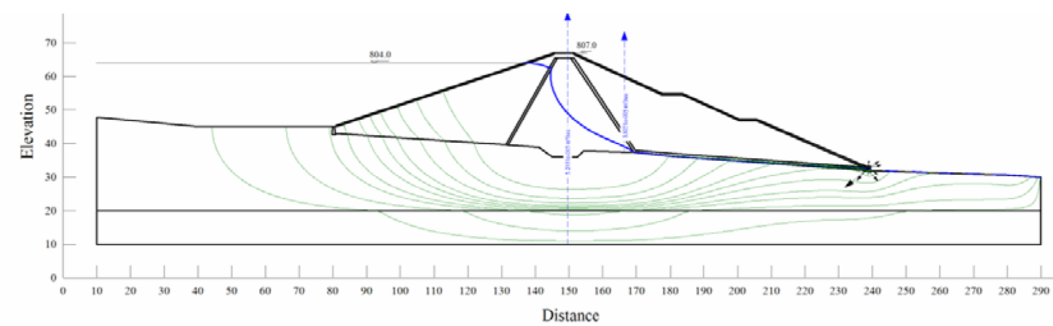

Figure-18. Modeling of pore-water pressure and seepage rate of Hamamuk dam.

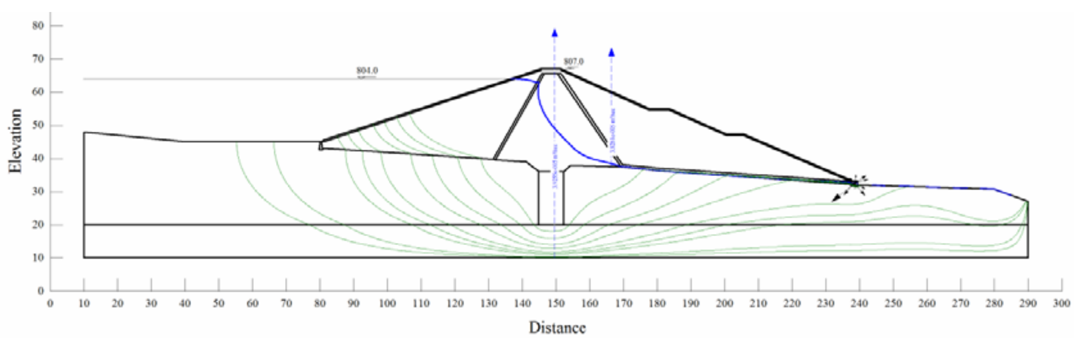

Figure-19. Modeling of pore-water pressure and seepage rate of Hamamuk dam within grouted foundation.

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As mentioned previously, the main causes of seepage problems at the outlet gallery wall are construction defects and floods. The rubber used in the horizontal construction joints to control water seepage was designed to be used at expansion joints. Punching of rubber joint will develop water path along the joints. Flood event and differential settlement of gallery led to the rupture of the water-stop and seepage developed along the gallery. In addition, many cracks were developed at the structure of the gallery due to the differential settlement. However, for cracks that have leakage within low hydrostatic pressure, grouting the crack by injecting either a rigid epoxy mortar or an elastomeric filler (if crack movement is anticipated) are recommended, while for cracks that have leakage within high hydrostatic pressure, installation of a drainage system may be necessary. Generally, the hairline cracks in concrete are not considered as a hazardous problem unless the cracks open up (DNR, 2007; MDE, 2003; NCDENR, 2007). Then, for tackling the downstream flat slope seepage problem, grouting the recent deposits stratum by injecting cement bentonite is recommended for reducing the seepage rate (USACE 1993).

At Hamamuk dam, seepage rates have declined gradually since the first filling and become about 50% in 2014. However, in the case of most seepage from underneath dam embankment, siltation of reservoir with time will tend to reduce this type of seepage (USACE, 1993; Moayedi *et al*., 2011).

The underneath seepage at Hamamuk dam became evident since the first days of initial filling as shown in Figure-8. SEEP/W model indicated that 30 % of the total seepage occurred underneath the dam embankment. This ratio is in agreement with rate of seepage at downstream flat slope area. Generally, grouting was recommended for controlling underneath embankment seepage, but in case of steep abutment slopes (like Hamamuk abutments slopes as shown in Figure-6), grouting has the potential for causing difficulties and possibly can do more harm than good. Therefore, care must be taken when grouting in the abutment to avoid displacements within the rock mass (USACE, 1993).

Regarding the defects at drainage system, the problematic area can be excavated and plugging the open area in order to separate seepage at left side of the bottom outlet from right side and it can help to locate the seepage problematic area.

CONCLUSIONS

In this study, the seepage reduction at Bawashaswar and Hamamuk dams was proposed by reviewing the construction/operation photographs and seepage modeling. SEEP/W models were employed for each dam in order to analyse seepage performance and reduce seepage risk.

At Bawashaswar dam, the results show that the construction defects at bottom outlet gallery and non-consolidation of foundation at the downstream of the dam led to serious seepage problems that have adverse impact on dam safety. For containing these problems, as the first step, the authority should repair the joints at bottoms outlet gallery wall, and next step to grout the recent deposits at downstream foundation of the dam. This is because grouting the recent deposits stratum will lead to the rise the level of phreatic line and will increase the seepage problems at the bottom outlet gallery.

In case of Hamamuk dam, the results show that non-execution of grouting at the dam foundation increases seepage rate and develop seepage problems at downstream flat slope. The study indicates that with careful grouting of the dam foundation, the downstream flat slope seepage can be contained and the seepage rate will be decreased. The grouting at Hamamuk dam foundation requires a careful design and control execution, since there is a probability that the steep slopes of the abutments will be affected during the grouting and this will lead to displacements within the rock mass. Also, the study indicates there is a defect in the drainage system which mixes the seepage from the left and right v-notch pools. This is attributed to the existence of a tunnel under bottom outlet structure. To solve this problem, the study suggests the excavation of the problem area and closing the tunnel with the concrete. In future, this will help more to detect the specific location of the seepage.

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