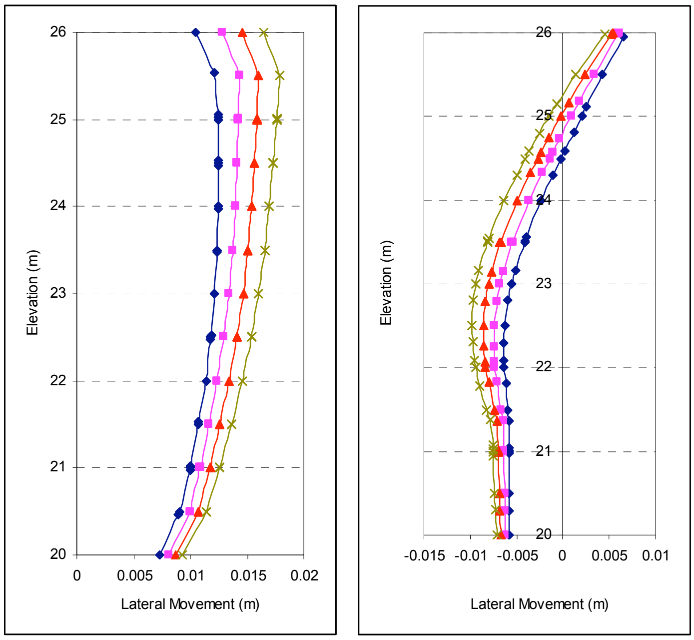
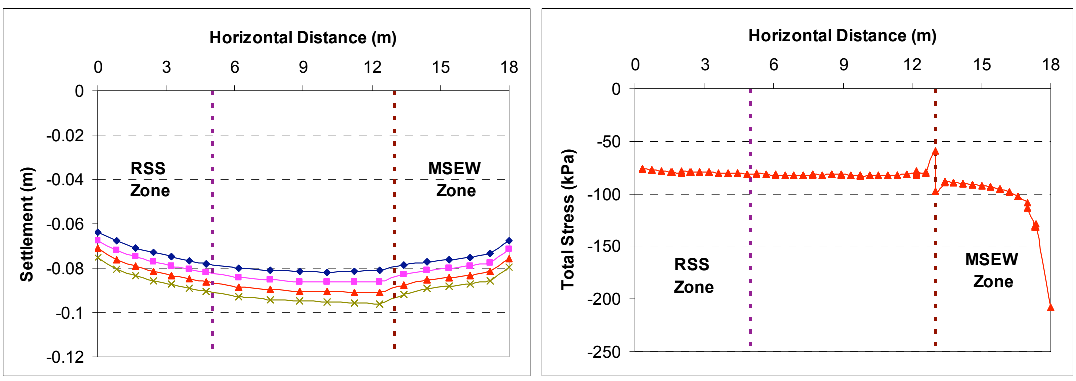


a) MSEW b) RSS

Figure 6. Lateral movement of slope face subjected to different loading conditions

Embankment Settlement

The settlement of the embankment is shown in Fig. 7(a). The results suggested that the settlement was indifferent for both MSEW and RSS. Within the reinforcement zone, the maximum settlement was approximately 0.09 m after 100% loading condition on both types of reinforcement.



(a) (b)

Figure 7. Embankment settlement along the cross-section (a), and total stress distribution on foundation (b)

Pressure exerting on foundations

According to the monitoring plan, total pressure cells are installed underneath the embankment along the cross-section. The maximum total stress was found under the leveling pad of the MSEW, where the stresses were induced by the concrete panels. The total stress distribution under the embankment was plotted in Fig. 7(b). There existed some discontinuities at the boundary of MSEW and unreinforced zone. This could be explained by the difference in stiffness between the higher and lower stiffness zones.

CONCLUSIONS AND RECOMMENDATIONS

A trial reinforced earth embankment was modeled using finite-element analysis to predict the performance behavior of RSS and MSEW. The input parameters were obtained from comprehensive laboratory testing including tensile strength and elongation of extensible materials (PE, PET, and PP geogrids), yield and rupture strengths of inextensible materials (steel wire grid and metallic strip) as well as the pullout resistance properties. According to the FE analysis, it can be concluded that both types of reinforcement yielded small lateral movement and acceptable settlement.

Unfortunately, the trial embankment is under construction. Hence, the FE analysis results could not yet compared with the field measurement results. Further study on field performance behavior of trial embankment is underway. Intensive monitoring program of the trial embankment has been proposed to monitor the deformation and changes in stress condition due to construction and loading. The comparison between the field monitoring and the FE analysis will provide invaluable information on the reinforced earth embankments for road construction and maintenance for the DOH, Thailand.

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Seepage Analysis for Shurijeh Reservoir Dam Using Finite Element Method

S. Soleymani[1], A. Akhtarpur[2]

[1] Group of Dam Construction, Toossab Company, P.O. Box 917751569, Mashhad City, Iran, PH (+98) 511-7684091; FAX (+98) 511-7688868; email: ssoleymani@hotmail.com
[2] Group of Dam Construction, Toossab Company, P.O. Box 917751569, Mashhad City, Iran, PH (+98) 511-7684091; FAX (+98) 511-7688868; email: dam@toossab.com

ABSTRACT

One of the important points in the study stages and during construction of earth dams is seepage through the foundation and dam body. So the calculation of seepage amount from the foundation and dam body and evaluation of control or decrease methods for this problem is essential. Seepage analysis is based on a residual flow scheme involving saturated and unsaturated zones in which the hydraulic properties remain invariant during transient flow. With available software, the solution of any seepage problem is reduced to a simple routine requiring negligible engineering time. Seepage control is necessary to prevent excessive uplift pressures, sloughing of the downstream slope, piping through the embankment and foundation, and erosion of material by loss into open joints in the foundation and abutments. The under-construction Shurijeh dam project is located about 125 km southeast of Mashhad, Iran on the Kashafrud River. A two dimensional seepage analysis was conducted using computer software, Seep/W to determine seepage quantities. Results are shown for two conditions: with and without a cutoff within the dam foundation.

INTRODUCTION

Accurate calculation of seepage amount from the body and foundation in dams is very important for economical and technical considerations. Water escape from the body and foundation of earth dams can lead to unacceptable water losses in arid climates, cause problems during construction and can have destabilizing effects on the earth dam. Seepage analysis in earth dam designs is very important for dam safety, because the water flow in the body and foundation in dam cause creation of pore pressure and seepage forces, that if not within tolerable limits, the dam stability may be in jeopardy, which may lead to dam failure. The statistics show that more than 30 percent of earth dam failures result from a wrong estimation of seepage. Also seepage during earthquake occurrence can create additional problems for dam stability. So seepage control is a management before crisis. Seepage control from dams that are located on foundations with higher permeability is one of the important problems for dam stability and it's necessary for sure and acceptable servicing in water maintenance. The aim of this research is analysis of the necessity of a cutoff beneath a proposed dam in Iran, determination of water discharge content that will leak from foundation and body of the dam and estimation of maximum of gradients due to seepage water in body and foundation of the dam.

Dam technical properties

The Shurijeh reservoir dam site is located on the Kashafrud River approximately 125 km southeast of Mashhad, Iran as shown in Figure 1. The Shurijeh dam is an earth dam with an asphalt-concrete core. Elevation from river bed is 43 meters and reservoir volume is 240 mcm.

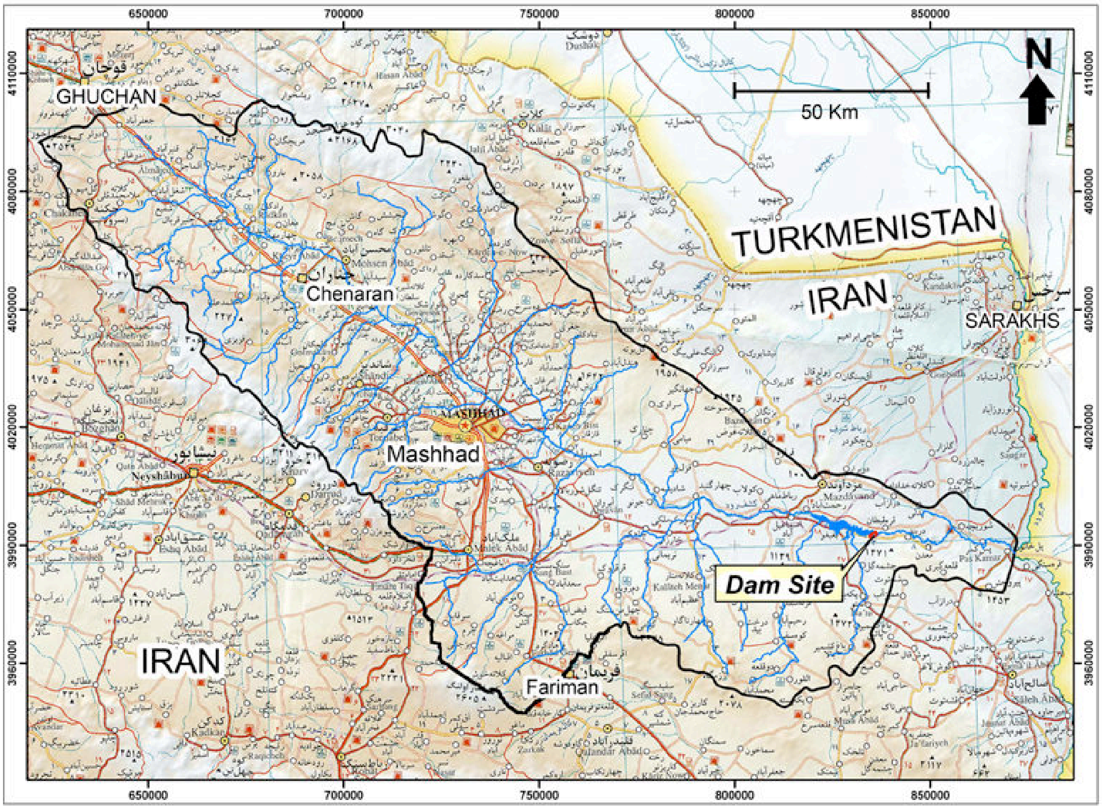

Figure 1. Location of Shurijeh dam site in northern Iran (Toossab Co., 2006).

The dam site is located within the Koppet- Dagh geologic zone. The site geology is from the Triassic time period, Aghdarband Formation, which has alternation of shale and sandstone and some conglomerate and tuff as shown in Figure 2. Bedding of this formation is frequently arranged with a 67/002 dip and dip direction. The dam site is located on the northern hillside of the Mozduran anticline, with an east-west axis. Bedding, joints and fault systems due to complex tectonic of region was exerted on rock mass that these faults named F1 and F2 which are shown in Figure 2. These faults almost have an east-west direction. Trend of these faults almost are parallel to strike of Mozduran anticline axis.

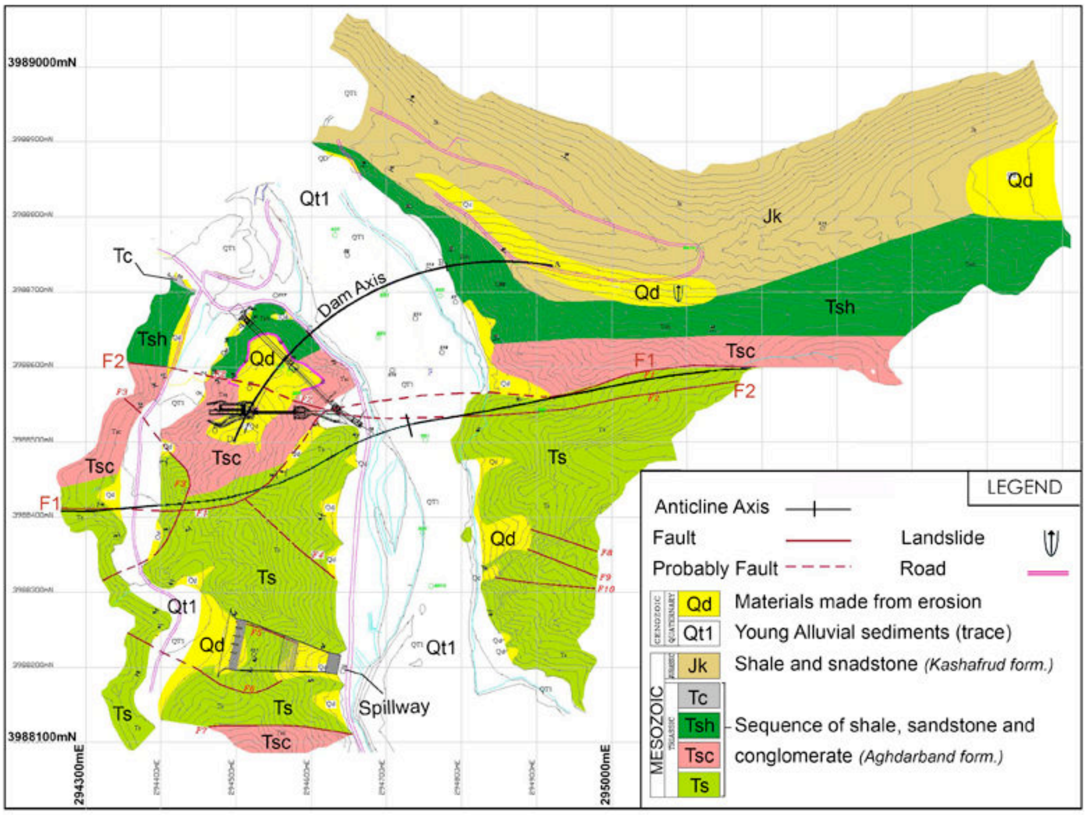

Figure 2. Dam site geological map (Toossab Co., 2006).

Analysis method

Analysis of seepage through the dam was performed by finite element method using SEEP/W software (Geoslope, 2004). Water discharge volumes, pore pressure amount, velocity and water flow through the body and foundation can be determined by this program. Permeability values of the materials in different parts of the body and foundation of the Shurijeh dam are presented in Table 1. The permeability values shown in Table 1 were determined based on laboratory results on dam materials.

Table 1. Permeability properties of the Shurijeh Dam.

Materials	Horizontal Permeability (cm/s)	Vertical Permeability (cm/s)
Core	$5*10^{-6}$	$1*10^{-6}$
Alluvial foundation (Coarse Grain)	$1*10^{-3}$~$1*10^{-4}$	$1*10^{-3}$~$1*10^{-4}$
Cutoff	$1*10^{-6}$	$1*10^{-6}$

The dam foundation consists of a maximum 19 meter thickness of alluvial sediments overlying shale and sandstone bedrock. Alluvial sediments consist of two different units, a coarse grain and fine grain. The coarse grain unit contains gravel and sand with a variable percent of clay and silt (SM). This unit is dominant within the alluvial foundation and has a rather high permeability. The fine grain unit results from weathering of bedrock (CL-ML), and maximum thickness is one meter. This material will be removed from bottom of dam body, so it was not considered in analysis. The permeability of the alluvial foundation was based on in situ permeability experiments results. Based on these results, permeability of the SM unit is variable between maximum $1*10^{-3}$ cm/s to $2.7*10^{-6}$ cm/s, with an average permeability of $1.7*10^{-4}$ cm/s. In the CL-ML unit, two permeability experiments performed by the Lophran method showed that the permeability of this unit ranges from $6.8*10^{-7}$ cm/s to $7.9*10^{-6}$ cm/s. The dominant texture of alluvial foundation is coarse grain (SM), so it has considerable permeability and in attention to soil texture, it has the capability of erosion, and therefore needs special attention due to foundation sealing.

Seepage analysis calculations

Due to the rather high permeability of the alluvial foundation, it was anticipated that it would be necessary that a cutoff be extended to the rock foundation for seepage and gradient control. Comparison of the dam's hydraulic performance with and without a cutoff was performed. The seepage analysis consisted of two stages:

1- Dam section analysis without using a cutoff, to quantify flow and gradient estimation.

2- Dam section analysis using a full cutoff from bottom of core to bedrock to quantify flow and gradient estimation.

Performance of dam without cutoff

Figure 3 shows mesh generation method of the numerical model. In Figure 4 flow lines and potential lines that resulted from the seepage analysis are shown. Also in Figure 5 maximum gradient can be shown. In this manner seepage content from alluvial foundation across the 300 meter dam width is 3,913 m^3/day. It is noticeable that average width equal to 300 meter that is more than dam width located on alluvial area, so seepages from dam body on rock abutments in this analysis considered. The external gradient from alluvium along the downstream side of the dam was estimated to be 0.38, with the critical gradient (I_{cr}) equal to 1. The safety factor against boiling phenomenon is 2.6 that was considered unacceptable. Also piping probability of materials of alluvial foundation in this manner will exist. Therefore in attention to these points, it was obvious that a cutoff would be required. In Figure 6 flow vectors are shown.

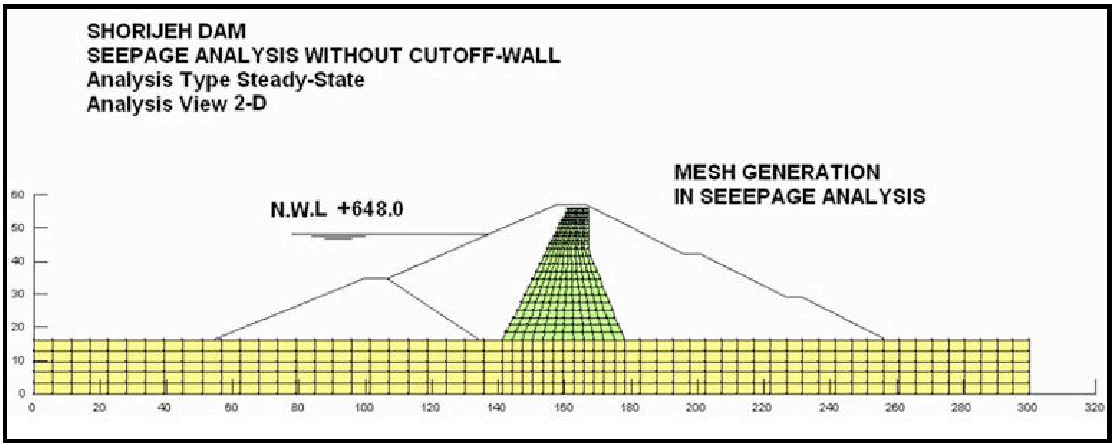

Figure 3. Mesh generation method of numerical model in seepage analysis of dam without cutoff.

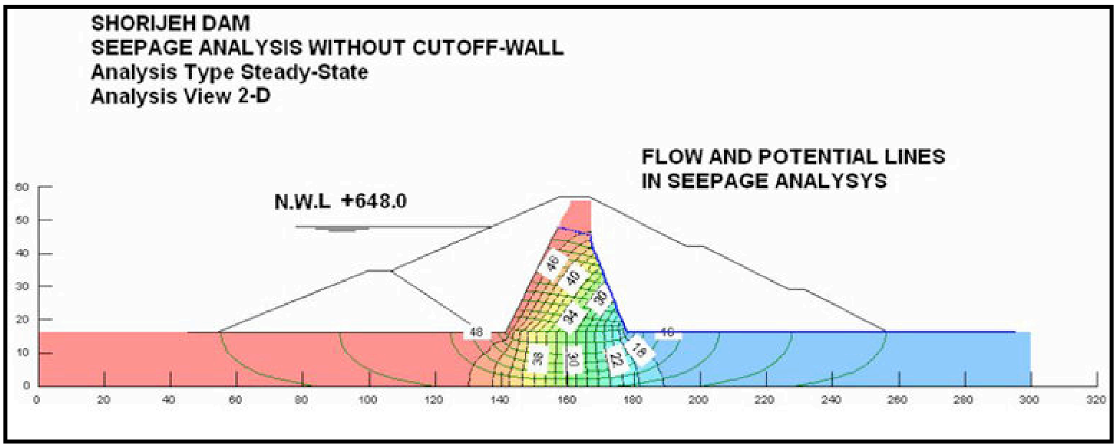

Figure 4. Flow and potential lines in seepage analysis of dam without cutoff.

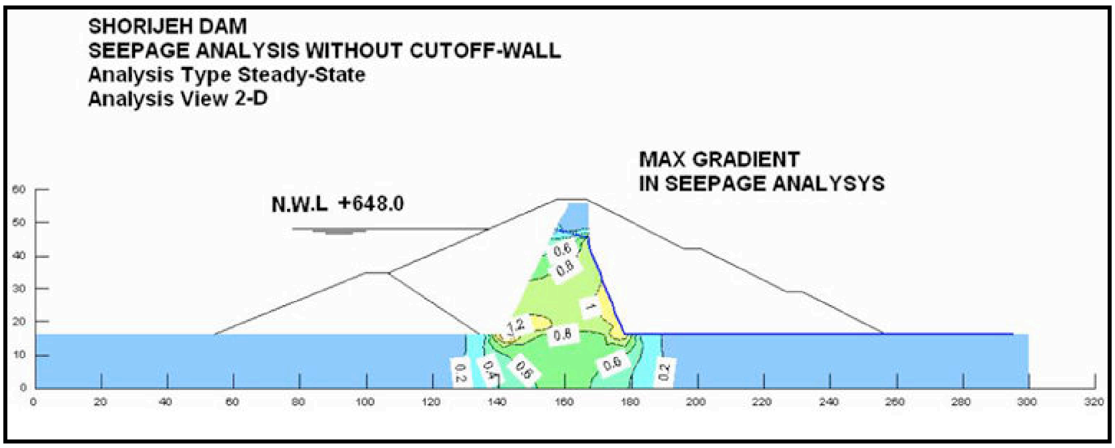

Figure 5. Maximum isogradient curves in seepage analysis of dam without cutoff

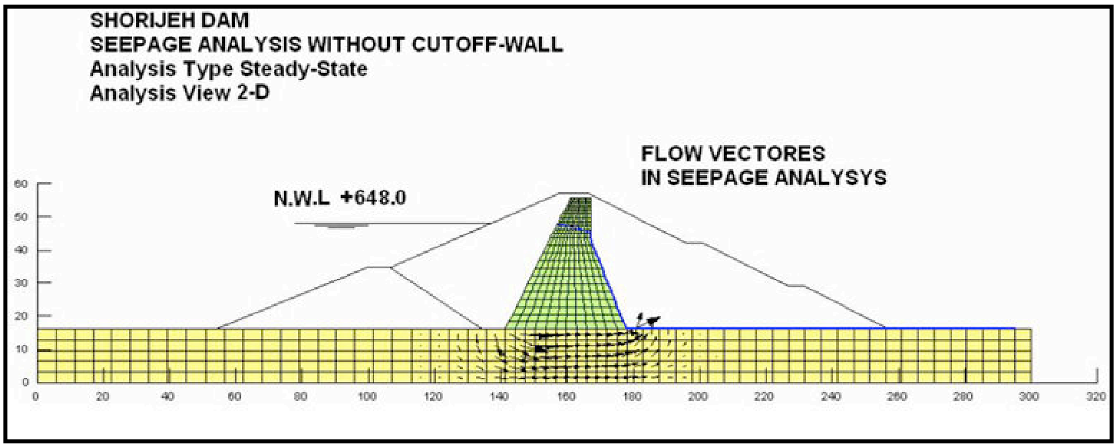

Figure 6. Flow vectors in seepage analysis of dam without cutoff.

Performance of dam with cutoff

The model mesh for the case with a cutoff extending to bedrock is shown in Figure 7. Figure 8 indicates flow and potential lines and Figure 9 shows the maximum gradient lines for this alternative.

In this alternative, seepage from body and foundation will be 138 m^3/day. The maximum external gradient from the alluvium is 0.3, so failure probability in downstream toe won't be a concern. In Figure 10 flow vectors for this alternative are shown.

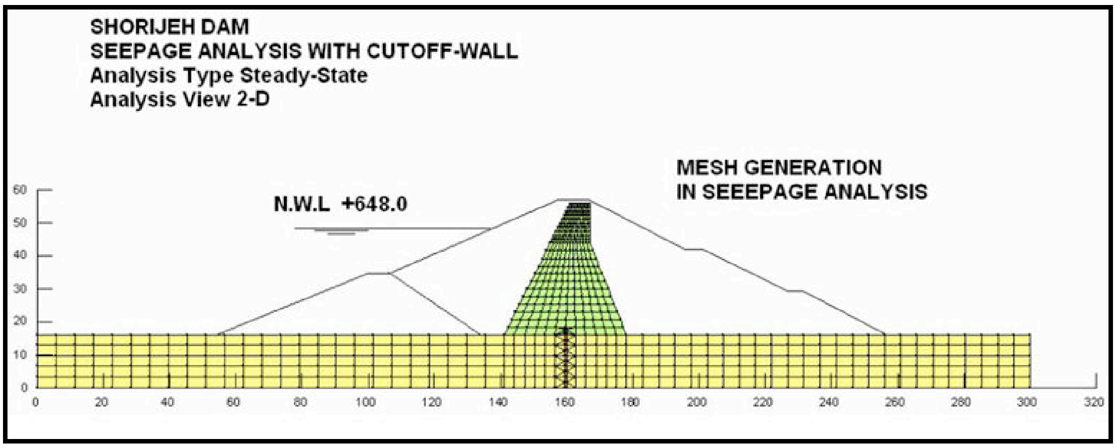

Figure 7. Numerical model mesh generation method in seepage analysis of dam with cutoff.

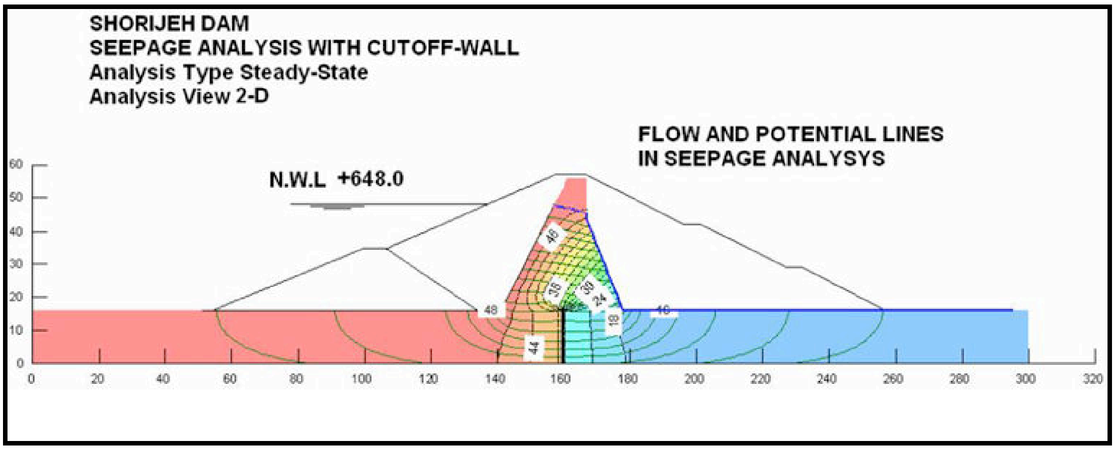

Figure 8. Flow and potential lines in seepage analysis of dam with cutoff.

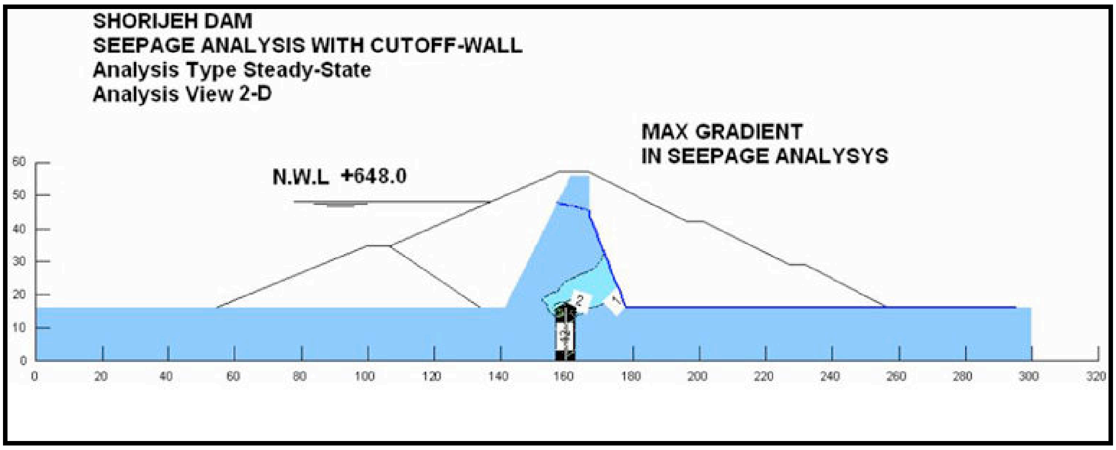

Figure 9. Maximum isogradient curves in seepage analysis of dam with cutoff.

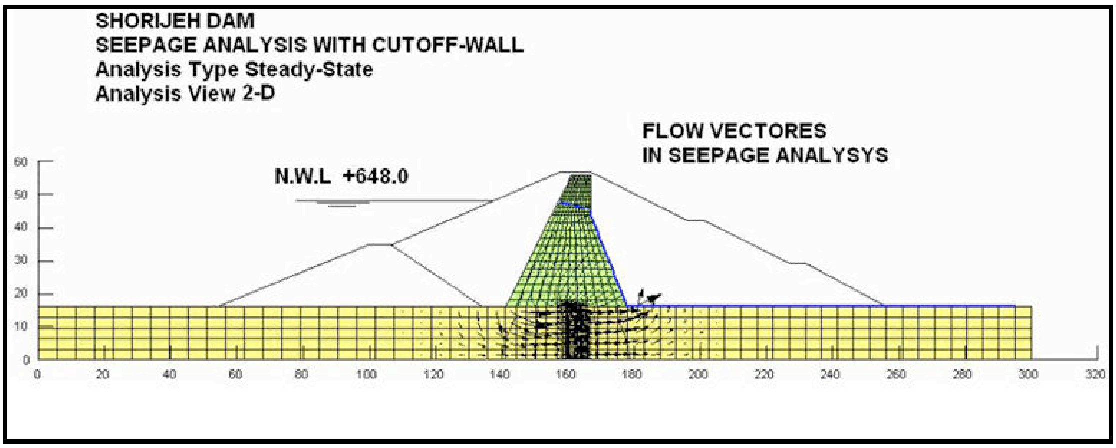

Figure 10. Flow vectors in seepage analysis of dam with cutoff.

CONCLUSION

With comparison of results from analysis of the dam with and without a cutoff it can be concluded that a cutoff to bedrock is necessary, the total water quantity of flow from dam body and foundation in the alluvial area with a cutoff was found to be 138 m^3/day. Acceptable performance for the boiling and piping were determined for the dam with a cutoff.

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