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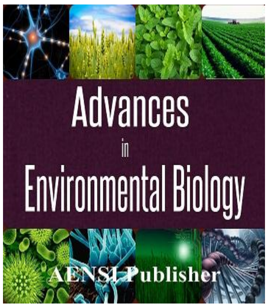

The Seepage Analysis of Water Stopping Supplementary Layouts of Karkheh Earth Dam by Finite Element Method and Comparison with Instrumentation Data

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ABSTRACT

Nowadays, design of rock fill and earth dams as the most constructed dams, because of technical and economical factors are vastly used by design engineers. Karkheh earth dam with clay core is located in southwest of Iran. There were some reasons which caused excessive water discharge was seen in the dam after dewatering in 1999: first, heterogeneous of the dam foundation; second, diverse conductivity in different direction; third, incorrectly constructing of the dam; last but not least, wrong design of the cut off wall. Hence in order to seepage control and reduction of the hydraulic gradient, three water stopping supplementary layouts were designed and performed. In this research, in order to comparison and validation of high-precision instruments results and estimation of seepage after the supplementary layouts, finite element numerical analysis has been used. Seep/w and seep/3d software are utilized for 2D and 3D seepage analysis, respectively. As can be seen, the results obtained by the finite element approach are in good agreement with real values of water discharge which were recorded by high-precision instruments, while 3D results are more accurate than 2D results.

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INTRODUCTION

Nowadays, construction of different type of dams have attracted the attention of government for some reasons: first, optimum use of flowing waters for agricultural, industrial and household consumption; second, production of electricity by hydro power plants; third, prevention of floods; fourth, store of water; fifth, navigation and haulage; sixth, protecting of environment. Depend on the site topography, the river slope, availability of materials, transit distance of materials, economical and political situation, constructions of dams are divided to: Concrete dams (gravity dams, mono arch dams, two arch dams, multiple arch dams, hollow dams, RCC dam and etc.) Earth dams (earth dams with clay core, homogeneous dams, rock fill dams, arch dams and etc.) Other (rubber dams, masonry dams, wooden dams, steel dams and etc.)

Today, because of some reasons like availability of materials, rapid construction and economical factors are preferred to other kinds of dams. Thus, technical points in design, constructing and exploitation time should be considered in order to optimum use of dams and more stability of dams. One of these technical points is the seepage problem and how to control it. Seepage is defined gradual flow of liquid through soil layers. Seepage in earth dams causes the instability of the dams, water loses and finally the threat of human life. Thus most effective step in the earth dams design is the seepage analysis and selections of most appropriate kind of the control seepage system. It is noticeable; the seepage phenomenon is unavoidable in earth dams and their foundations. It should be tried to control this phenomenon.

SEEP/W is a numerical model that can mathematically simulate the real physical process of water flowing through a particulate medium (1).H. Hasani and *et al*.(2) investigated the amount of water leakage in Ilam Dam by using the Seep/w software.L.Quanshu and L.Jianjun(3) used this software to analysis of the seepage field in core-dam.Dunbar and Sheahan (4) represented a case study on embankment dam seepage control remediation problems at the Hodges Village Embankment Dam.M.S Pakbaz and *et al*. (5) used Seep 3D to predication of

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seepage after construction of a completely penetrated wall in the left and right abutment and impervious blankets showed decline in seepage by 20% and 60% in right and left abutment, respectively.

In this study, Seep/w which is based on finite element method is used. Because models are 3D dimensional in reality, Seep/3D is used to reach more accurate results. The results are compared with data which were recorded from high-precision instruments.

MATERIALS AND METHODS

Introduction of Karkheh dam:

Karkheh Dam is located southwest of Iran, in Khuzestan province,20 km north-west of the city of Andimeshk, in 48 degree and 7.8 minutes of eastern longitude and 32 degree and 29.6 minute of northern longitude. The volume dam reservoir is7.4 billion cubic meters in flood conditions and 5.6 billion cubic meters a normal level of 220 meter.In point of view of water storage, Karkheh dam is the largest dam in Iran's history dam with dam crest length of 3030m, aheight from foundation of 127m, a crest width of 12m and a maximum foundation width of 1,100m.

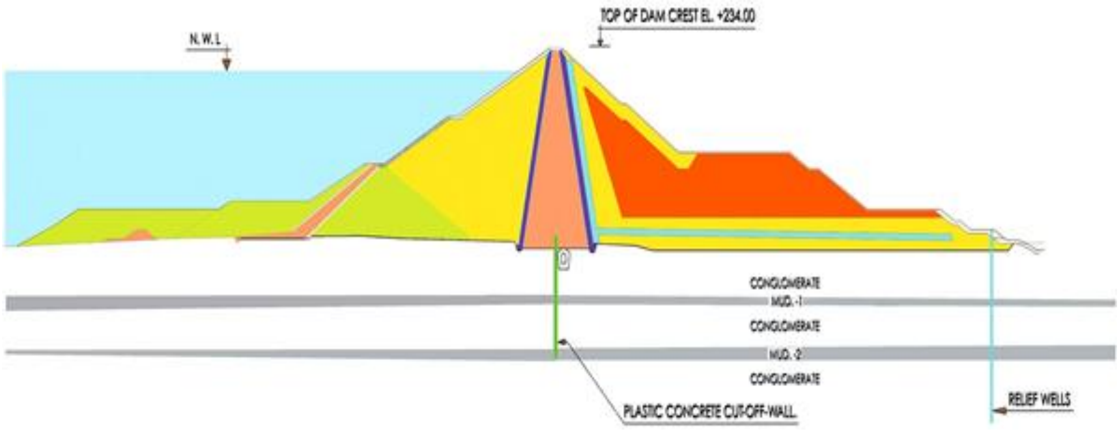

Fig. 1: Cross-sections of Karkheh Dam.

Karkhe dam is located in south western of Zagros Chain Mountains. The foundation of the dam is located on Bakhtiari conglomerate which is a combination of sand stone layers and lichen. Mudstone layers are nearly horizontal. Permeability in the horizontal direction is very low and is assumed impenetrable. But dam foundation conglomerate matrix has a variety of grain size in different directions. Both depending on the type of material (clay or silt or sand) and the rate of cementation has caused complex and diverse conglomerate rock geotechnical characteristics. The conglomerate has high permeability especially in the horizontal direction. Calculated Permeability for the dam foundation based on different methods, ranging from a minimum range of 1 to maximum range of 2 centimeters per second and calculated results have differed by about 300 times (6). As a result, it should be noticed which Karkheh dam foundation has special and complex situation.

Modeling methods:

This paper considers the real results of leakages which obtained from the instrumentation in the various stages of the supplementation program of Karkheh dam and compare with values of software simulation by Seep/w and Seep/3D. For better comparison, the actual values of the materials conductivity have been used which are mentioned in Table 1.

Table 1: Properties of materials used in the Karkheh.

Y (kPa/m^2)	E (kPa/m^2)10^4	φ %	C (kpa)	Ky (m/s)	Kx (m/s)	γ_d(kPa/m^3)	Type of matter	
0.4	3.5	6	70	1 E-7	1 E-6	20.2	Clay core	1
0.27	10.2	39	0	1E-4	1E-3	20.5	Crust	2
0.23	12	22	70	5E-7	5E-6	19.5	*Mudstone* (-2)	3
0.3	100	39.4	5	5E-4	5E-3	22	*Conglomerate* between *Mudstone* (-2) and (-1)	4
0.23	12	22	70	5E-7	5E-6	19.5	*Mudstone* (-1)	5
0.3	80	39.4	85	5E-4	5E-3	22	*Conglomerate* between *Mudstone* (-1) and (+2)	6
0.4	4	28	65	1E-6	1E-6	22	Watertight Cut-Off Walls	7
0.28	60	42	0	1E-2	1E-2	17	filter	8
0.28	60	42	0	1E-1	1E-1	17.5	drain	9

Assumptions:
To achieve more accurate results, some assumptions have been made in the modeling, including:
1. Nonlinear analysis of the seepage has been done.
2. Thick of cut off wall based on the thickness effective is assumed 1 m.
3. Analysis of the flow is steady state.
In figure 2 the assumptions and models used in the two-dimensional geometry is shown schematically.

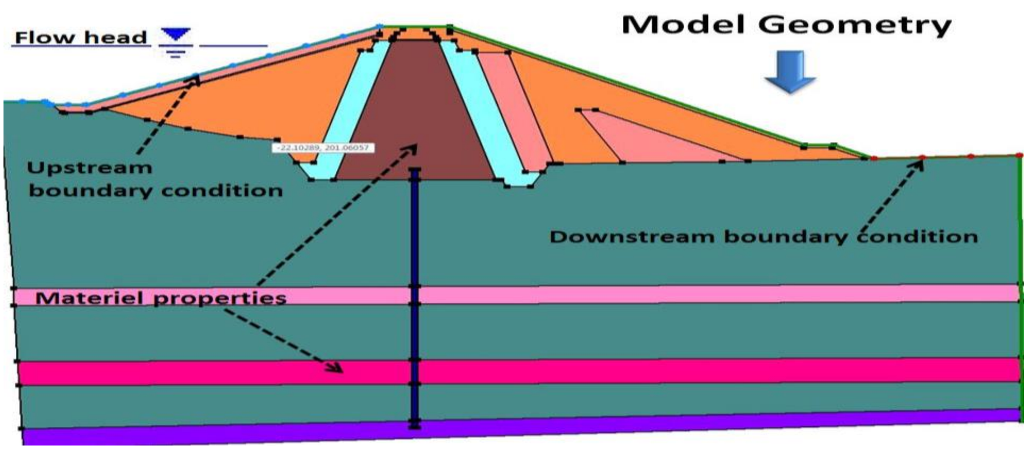

Fig. 2: The two-dimensional model assumptions.

The basic equations used in the analysis:
The movement of water in the saturated porous medium is described by Darcy as follows:
Q =k.i.A (1)
WhereQ is the water discharge, K is the hydraulic conductivity of the soil (soil permeability), A isthe cross sectional flow area and i is the hydraulic gradient which is given by the following equation:

$$i = \frac{\partial h}{\partial l} \quad (2)$$

Where l is the length of the movement of water in porous media. Accordingly, the general equation for the nonhomogeneous, anisotropic soils when there is no input and output would be as follows. This equation is known as the Richards equation (Ibn glory and ShafaiBajestan, 2005).

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(k_z \frac{\partial h}{\partial z}\right) = \frac{d\theta}{dt} \quad (3)$$

Where, h represents the pressure head and Kz, Ky, Kx are the hydraulic conductivity of the soil in the vertical direction (z), longitudinal (x) and transverse (y), respectively. Also, θ is volumetric moisture content of the soil mass.
In steady-state flow conditions for the saturated soil when the changes of moisture content with respect to time is zero; Equations will be summarized as follows:
Three dimensional:

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(k_z \frac{\partial h}{\partial z}\right) = 0$$

Two dimensional:

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial h}{\partial y}\right) = 0$$

For homogeneous soil where Kz=Ky=Kx
Three dimensional:

$$\frac{\partial}{\partial x}\left(\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(\frac{\partial h}{\partial z}\right) = 0$$

Two dimensional:

$$\frac{\partial}{\partial x}\left(\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{\partial h}{\partial y}\right)=0$$

There are several ways to solve the Laplace equation:

Laboratories methods, graphical methods, experimental methods, mathematical methods and numerical methods. Solving of the problems related to the seepage control cannot be achieved to exact answers. So answer will be approximate. In each of these methods depends on the type of simplification, the accuracy of these methods is reduced. Each of these methods has limitations, but these limitations are much less in numerical methods. So, these methods have been widely used today. In fact, due to the complexity of analytical methods to solve the problems of seepage and the lack of such a method for three-dimensional problems, numerical methods are the only practical solution. Numerical solutions of Laplace's equation are done in various ways, Such as finite difference, finite volume, finite element, boundary element and natural element methods. Among these methods, finite element method because of its compatibility with the problem conditions is a more appropriate approach for solving this problem.

The Solving Laplace equation with finite element method:

FEM is one of the most powerful methods of numerical solution of differential equations, such as the seepage equation which today are vastly applied in engineering problems. The method involves dividing the domain of the solution into a finite number of sub domains, the finite elements, and using variation concepts to construct an approximation of the solution over the collection of finite elements. The matrix form of the seepage equation is as follows

$$[K]\{H\}+[M]\{H\}_t=\{Q\}$$

In steady state analysis,

$$\{H\}_t=0$$

As

$$[K]\{H\}=\{Q\}$$

Above matric are computed with numerical integration. With apply the boundary conditions and solving the system of equations, pressure head values are obtained at the desired points. After the calculation of H, flow lines and potential lines are plotted and water discharge value is calculated.

RESULTS AND DISCUSSIONS

After dewatering Karkheh dam in 1999, according to these subjects which the Karkheh dam have been constructed on weak rock layers with different conductivity, also, due to inappropriate connection of cut off wall to foundation impermeable layers in supports, observed seepage was over permitted limit. Water stopping supplementary layouts are performed in three phases:

1- Embankment of upstream banks and downstream valley
2- Relief in downstream coffer dam
3- cut off wall supplementary layouts

Figure 3 shows Karkheh dam supplementary layouts

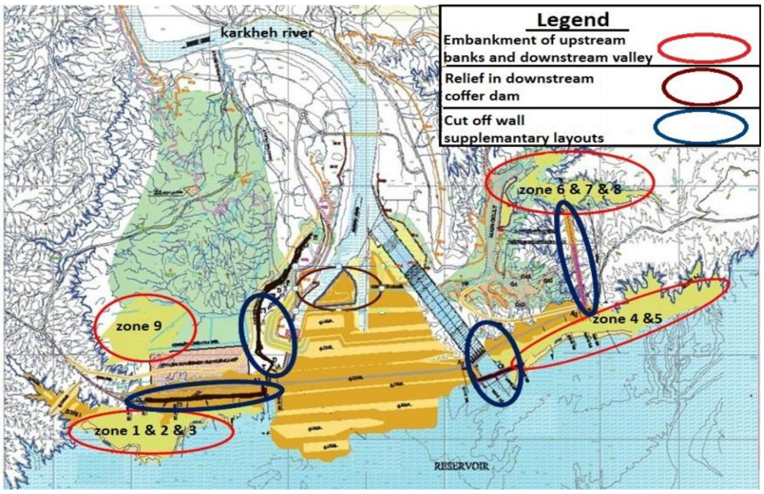

Fig. 3: Karkheh dam supplementary layouts.

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Embankment of upstream banks and downstream valley:

Upstream and downstream embankment is completed in two parts. First, zones 1-5 embankments were constructed to prevent water erosion of upstream bank. Second, zones 6-9 were implemented to reduction and guide leak waters. Changes of water discharge in left wing are shown in figure 4. As shown in the figure, after the implementation of the upstream embankment in the left wing, water discharge have been decreased about 200 liters per second (11 percent) in comparison with recent years (from 2700 to 2500 liters per second).

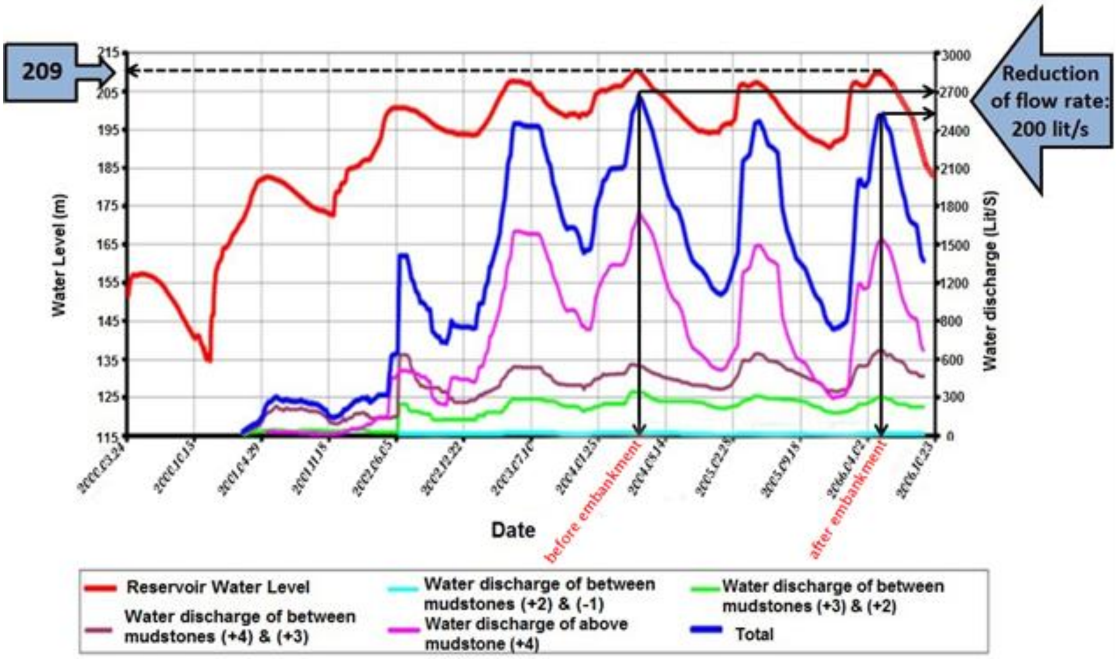

Fig. 4: Changes in reservoir water level and total seepage discharge in the left.

Real values have been compared with results which are obtained from Seep/w and Seep/3D. these results are shown in table 2.

Table 2: Comparison of real values and software results.

Simulation Discharge Seep/3d Lit/S	Simulation Discharge Seep/w Lit/S	Actual Discharge Lit/S	Date
2691	2685	2700	May 27, 2004
2488	2450	2500	May 18, 2006

Drilling of relief wells in downstream cofferdam:

After dewatering the damand increasing the reservoir water level, it was found which Performed relief wells within the downstream cofferdam are not efficient, because of complexity and non homogeneity of the site. The uplift safety factor was low in the downstream cofferdam and this value was decreased to the value of 1 in the reservoir level of 220 meters (normal water level).Therefore, to increase the value of safety factor, 10 and 60 small(2 inches) and large(6 inches) diameters wells, respectively, were drilled with an average depth of 45 m. Also an embankment with height of 5m was constructed in downstream cofferdam area. Figure 5 shows changes in water level of relief wells in downstream cofferdam area. As can be seen in the figure, with implementation of the wells, Despite increasing of the reservoir water level, the water pressure on conglomerate layer of below mudstone (-2) were decreased. It shows positive roles of the relief wells. These layouts caused approximately water level loss of 17 m in elevation of 207 m in comparison of the past years. According to instruments data and numerical analysis, it is anticipated which if the reservoir water level reaches to of elevation 220 m (normal level); the uplift safety factor will be raised from value of 1(before the wells) to values of 1.4-1.5(after the wells).

Cut off walls of the supplementary layouts:

Four cut off walls were drilled in different parts of the dam. Cut off walls numbers 1 and 2 were placed in left wing and numbers of 3 and 4 are in right wing. (Blue line in figure 3)

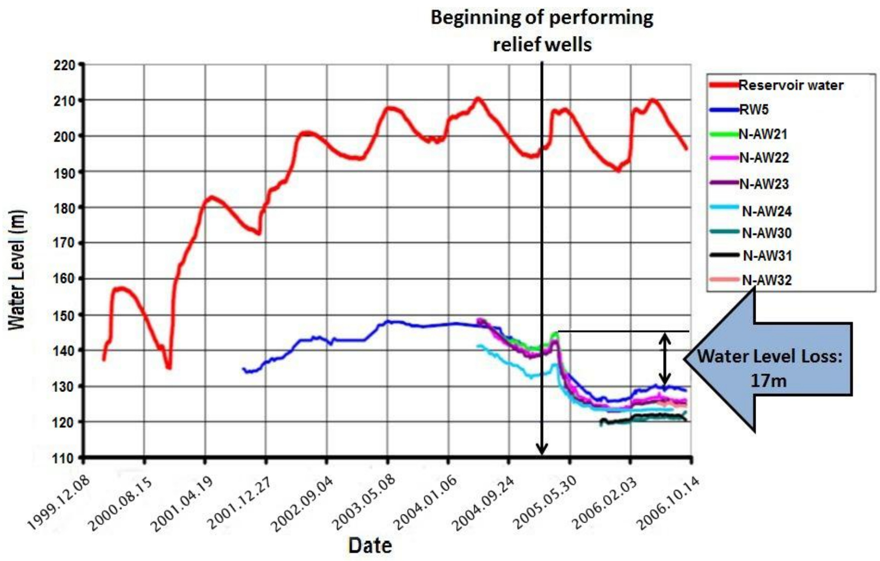

Fig. 5: Changes in water levels in wells in conglomerate layer between mudstone layers, (-2) and (-3).

Left side:

According to Figure 6, implementation of cut off wall no.1 and no.2 in upstream and downstream in the left side caused hydraulic gradient decreased from 0.15 to 0.07 in conglomerate layer between mudstone layers (+2)-(+4). Allowable hydraulic gradient for Karkheh dam is 0.07.Real values in downstream of left side in different layers of foundation have been compared with results which are obtained from Seep/w and Seep/3D. These results are shown in table 3.

Fig. 6: Cut off walls No.1 and No.2 in left side.

Table 3: Comparison of real values and software results in level of 220 m .

Simulation Discharge Seep/3D Lit/S	Simulation Discharge Seep/w Lit/S	Actual Discharge Lit/S	Location
2633	2630	2640	Up of mudstone (+4)
433	427	435	Middle of mudstone (+4) & (+3)
382	380	385	Middle of mudstone (+3) & (+2)
3448	3437	3460	sum

Right side:

According to Figure 7, implementation of cut off wall no.3 and no.4 were implemented. Cut off wall No.3 is in the end of right wing. This wall with length of 432m was utilized to decline of seepage in the conglomerate layer above the mudstone layer (+3).Construction of the wall caused hydraulic gradient decreased from 0.2 to 0.07. The wall No.4 connected to mudstone (+2). This wall was connected to the main wall in station (2+115) and continued to station (2+500). Design of the cut off wall had a few purposes; first reduction water discharge below the spillway in order to long-term stability of chute under uplift, second, reduction of hydraulic gradient in the conglomerate layer. Real values in downstream of right side in different layers of foundation have been compared with results which are obtained from Seep/w and Seep/3D. These results are shown in table 4.

Fig. 7: Cut off walls No.3 and No.4 in right side.

Table 4: Comparison of real values and software results in level of 220 m .

Simulation Discharge Seep/3d)Lit/S(	Simulation Discharge Seep/w)Lit/S(	Actual Discharge)Lit/S(	Location
3083	3081	3090	Up of mudstone (+3)
939	945	940	Middle of mudstone (+3) & (+2)
4027	4022	4030	sum

Finally, the rate of water discharge after the supplementary layouts and compare the simulated values are as follows:

Table 5: Comparison of real values and software results.

Error %	Simulatrion Discharge(Seep/3D)	Error %	Simulatrion Discharge(Seep/w)	Actual Discharge(Lit/S)	Water level
1.73	1136	2.3	1129	1156	180
1.62	1522	1.9	1517	1547	190
0.97	2352	1.9	2329	2375	200
0.31	3193	1.3	3161	3203	210
0.55	3990	0.67	3985	4012	220
Still not reached to this level					More than 220

Conclusions and recommendations:

The uncertainty in the calculated conductivity of Karkheh dam foundation and lack of properly connect of the primary cut off walls and impermeable layers of foundation, especially in the left and right side, caused seepage is more than allowable value. So, three water stopping supplementary layouts were recommended. These layouts were so expensive. Inadequate designs, caused huge amount of financial recourses have been wasted. Although there are many powerful commercial softwares, efficient and accurate design needs the problems understanding carefully. Seep/w and Seep 3D are the one of the most powerful softwares in saturated and unsaturated seepage analyses. The softwares have ability to measure water discharge in each section and find regions which have unreasonable seepage. The results show that both softwares, if model geometry and boundary conditions applied correctly, they could calculate seepage in body and foundation of dam with the lowest error. 3D models are more accurate than 2D models. Because, 3D models have greater consistency with reality. Closeness both software simulation results with the real data, shows drainage system and instruments are accurate and seepage values are reasonable. According to the results, with increasing the water level, the water discharge is increased and results software is more accurate. Although there is a good agreement between modeling results and instruments data, there are low errors which are because of some reasons. Long time of the project construction caused pour water pressure decreased which it leaded to the conductivity increase. Other reason is poor construction and lack of proper implementation of soil compaction. Also, the flow equation is solved approximately. Problems are modeled in software with high simplification. Although FEM is a powerful method, it has short comings which cause some errors in water discharge calculation. It was a controversy between experts to calculate of real values some parameters such as conductivity. Lack of improper supervision caused the clay core was filled with poor quality clay.

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