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Analysis of Seepage through Embankment Dams as Case Study (Al-Shahabi Dam) in Iraq

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Abstract

One of the causes of the embankment dam failure is seepage. Seepage analysis is very import issues that should be considered. For this purpose a finite element method through a computer program, Geo Studio through its sub-program named SEEP/W, was used to determine the surface seepage line, amount of seepage through the dam and its foundation, the seepage velocity measurements, the pore water pressure distribution, the total head, the pressure head, and the exit gradient of homogenous earth dam. A case study was considered to be Al-Shahabi dam which is homogenous earth dam located in Wasit, Iraq. The dam at its actual design was analyzed by using the program SEEP/W 2012. Then several analyses are carried out to study the seepage through Al-Shahabi dam during different conditions; when empty reservoir (no water level), normal water level, and maximum water level. It was concluded that the amount of seepage, velocity of seepage and exit gradient during maximum water level greater than in case of normal water level which indicate that the amount of seepage, velocity of seepage and exit gradient increase with increasing height of water level in the upstream of the dam.

Keywords: embankment dam; seepage analysis; finite element method; Geo Studio; SEEP/W.

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1. Introduction

Embankment dams are mainly constructed of earth and rock-fill materials. They are generally simple structures which are depends on their self weight to prevent the sliding and overturning. Earth dam failure is attributed to the following: structural failure, hydraulic failure, seepage failure, and piping through dam body. The design and construction of an earth dam is one of the key challenges in the field of geotechnical engineering, because of the unavoidable variation in foundation condition and the properties of the available construction materials. The practical seepage problems are not easily convertible into an equivalent numerical counterpart because of the heterogeneity of the natural soils and the varying boundary conditions [1]. Seepage can cause erosion within an embankment in places where a high hydraulic gradient is present. In the case erosion occur within a dam voids can be created. These voids take the form of channels, also pipes, which impairs the dam stability [2]. Accurate calculation of seepage amount from the body and foundation in dams is very important for economic and technical considerations. Water escape from the body and foundation of earth dams can lead to unacceptable water losses in arid climates and can have destabilizing effects on the earth dam. 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 [3]. The seepage control of any dam may be analyzed by of various available methods. Seepage is the main aspect and its control enjoys main position in designing, construction and maintenance of any dam. Thus a dam engineer must be well versed in understanding seepage problems, their solution and preventive measures monitoring. The flow conditions of any porous environment can be investigated by using numerical techniques framed in the form of a software solution [4]. Irzooki [5] has used finite element method for analysis and investigation of seepage problems on the left side of Al- Qadisiya dam. Also, the finite element method has developed to solve the governing equations of flow through earth dams. Al-Damluji and his colleagues [6] compared the results obtained from finite elements method with the boundary elements methods for solving the flow issue in steady state conditions. Noori and Ismaeel [7] used a finite element method through a computer program, named SEEP2D to determine the free surface seepage line, the quantity of seepage through the dam, the pore water pressure distribution, the total head measurements and the effect of anisotropy of the core materials of Duhok zoned earth dam. The effect of the ratio of the permeability in horizontal direction to that in vertical direction (Kx/Ky) on seepage was tested and results indicated an increase in seepage quantity as this ratio increased. The stability of Duhok zoned earth dam was analyzed using a slope stability computer program, named STABIL2.3. The slope stability analysis results showed that the factor of safety decreases with the increase of Kx/Ky ratio. The analysis of the results of this study showed that Duhok zoned earth dam is safe against the danger of piping and slope sloughing under the present operation levels. The finite element method was utilized by Fattah and his colleagues [8] to solve the governing equations of flow through earth dams. The computer program Geo-Slope was used in the analysis through its sub-program named SEEP/W. Eight-node isoparametric elements were used to model the dam and its foundation, while mapped infinite elements were used to model the problem boundaries. A case study adopted was Al-Adhaim dam which is a zoned earth fill dam of 3.1 km length. The dam in its original design was analyzed by adopting the SEEP/W program. After that, several scenarios were conducted to investigate the control of flow in the dam through investigating the effect of different parameters which included the hydraulic conductivity of the shell material and the construction of impervious core at different locations and thicknesses. It was found that the construction of clay core in the dam provides an important influence on decreasing the exit gradient, that could increase in the order of 300% when there is no core in the dam, and the safety factor may be critical when the level of water in the reservoir is at 143.5 m. The sloping core is the best design for core for Al-Adhaim dam than other choices because it produces the lowest values of rate of flow and lowest exit gradients. Ali [9] used a finite element software SEEP/W in simulating the seepage flow at Putrajaya Dam, measured seepage values obtained from the Putrajaya Dam Authority were compared with the simulated result of seepage obtained using the SEEP/W software. Based on the findings of this study, the Putrajaya dam can be considered safe. In this research, seepage through body and foundation of Al- Shahabi dam was analyzed. Finite element approach was employed to solve the governing differential equations pertaining the seepage through body of Al- Shahabi dam and its foundation. SEEP/W is a useful tool that uses numerical modeling to solve complex groundwater seepage problems [10]. The SEEP/W software (program) is a sub-program of the Geo Slope (software) computer, which is used for seepage problems through porous soil media.

2. Descriptions of Case Study (Al- Shahabi Dam)

Al-Shahabi Dam is homogenous earth dam located in Wassit Governorate in the south east of Baghdad. The city of Kut, center of Wassit, is located about 170 km south east of Baghdad. Google earth program is used to show in Figure (2) a scale picture for the Al-Shahabi Dam location with respect to the kut city.

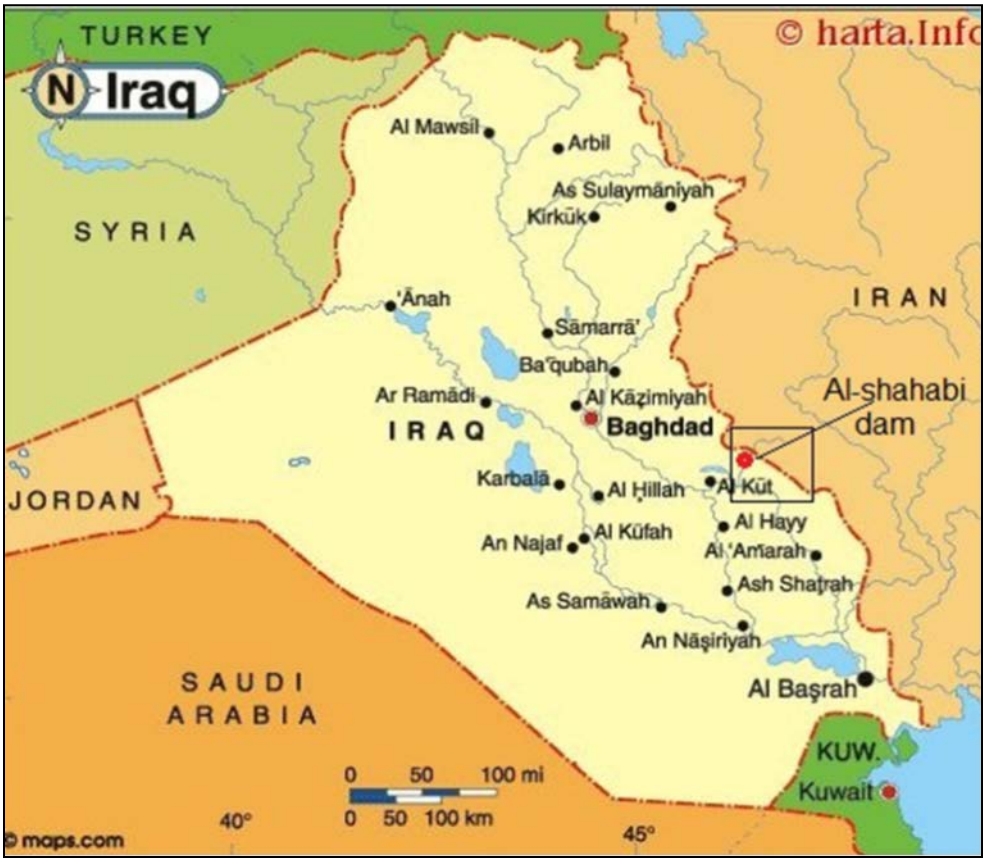


Figure 1: Al-Shahabi Dam in Iraq Map [11].

Figure 2: Dam location with respect to the Kut City [11].

2.1 General Features for Al – Shahabi dam

- Type of dam; homogenous dam
- Length of dam: 271 m
- Length of reservoir : 3 km
- Crest level : 50 m.a.s.l
- Maximum storage level: 48 m.a.s.l
- Maximum discharge: 769 m^3/sec.

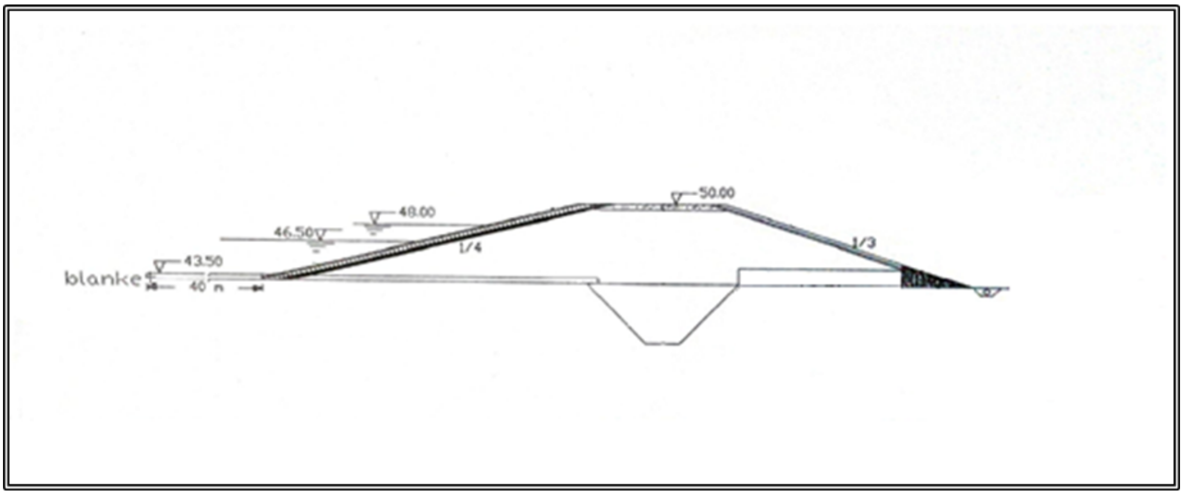


Figure 3: Cross section of Al-Shahabi Dam [12].

2.2 Materials properties for Al-Shahabi dam

The permeability of materials for Al-Shahabi dam as shown in Table (1).

Table 1: Materials properties for Al-Shahabi dam [11].

Material	Permeability (m/s)
Shell	$1*10^{-6}$
Cutoff	$1*10^{-8}$
Horizontal drain	0.0001
Toe drain	0.1
Blanket	$1*10^{-8}$
Foundation	$9.5*10^{-6}$

3. Seepage analysis of Al-Shahabi dam for different conditions

In the following sections, the dam section will be analyzed for different conditions; during empty reservoir (no water level), normal water level, and maximum water level.

3.1 Analysis of seepage when empty reservoir (no water level)

The steady state seepage through and under the earth dam was analyzed by using the program SEEP/W. The finite element mesh was used for the analysis when the reservoir is empty as shown in Figure (4). The mesh includes elements for entire body of dam. The numbers of elements for all boundaries are 1387 and the numbers of nodes are 1490.

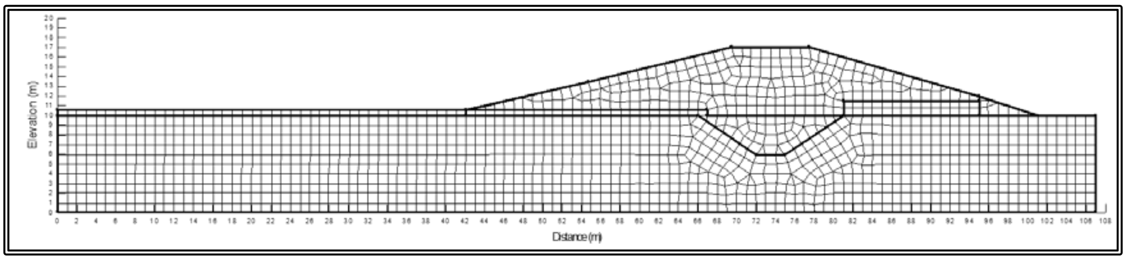
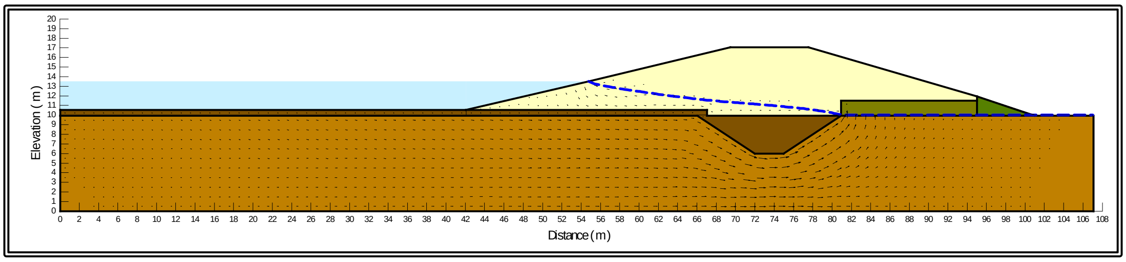


Figure 4: Typical finite element mesh for Al-Shahabi dam. (empty reservoir)

3.2 Analysis of seepage when normal water level

The analysis of seepage during the normal water level (N.w.l.) will be drawn as shown in Figure (5) which illustrates the path of the phreatic line through the dam.



Figures 5: Phreatic line and velocity vectors (the black arrows) for Al-Shahabi dam.

A dot blue line represents the phreatic surface in dam during normal conditions. The phreatic surface is low throughout the dam and exits at the dam toe, which is desirable for stability.

Figure (6) shows the distribution of the pore water pressure and the value of water flux through the flux section.

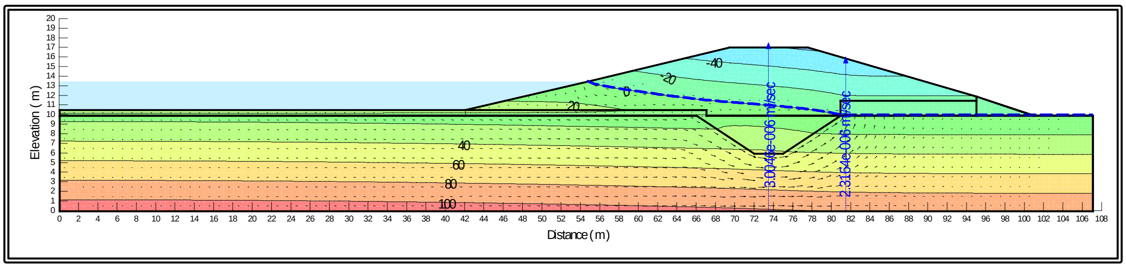


Figure 6: The distribution of the pore water pressure (Kpa) and the value of water flux through the flux section for Al-Shahabi dam.

The phreatic surface is shown as the dot blue line, which is the iso-line where the pore water pressure is zero. The pore water pressure is negative above the phreatic surface and positive below the phreatic surface. The water flow was measured across the blue vertical lines, also called flow lines.

Figure (7), (8) and (9) represent the total head, pressure head and XY- velocity respectively.

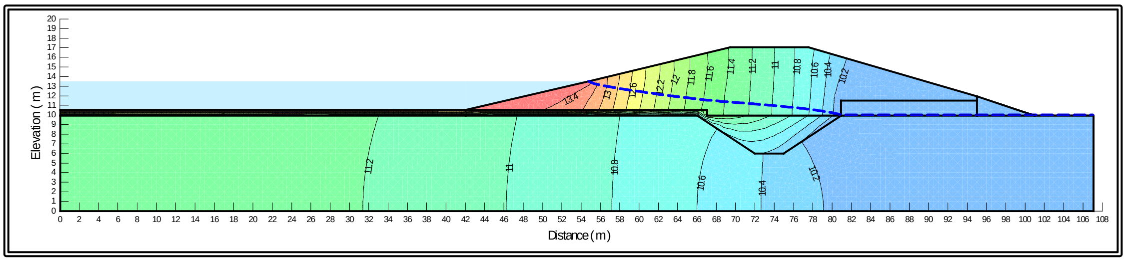


Figure 7: Contour lines of total head (m) for Al-Shahabi dam.

Figure (7) shows that the total head on the left is larger than the total head on the right. The total head difference creates a water flow from the left to the right.

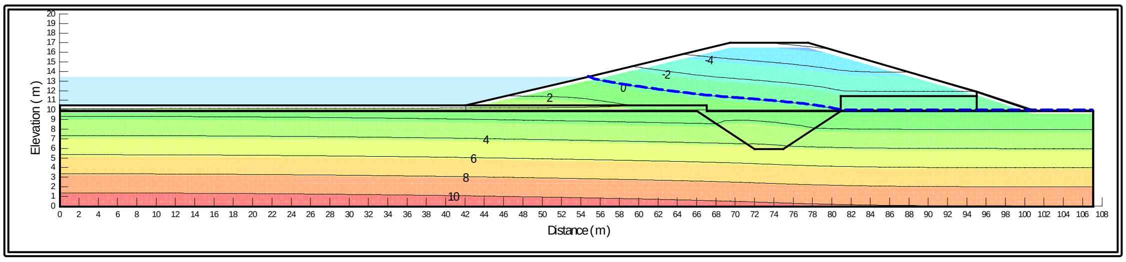


Figure 8: Contour lines of pressure head (m) for Al-Shahabi dam.

Figure (8) shows how flowing water within the dam builds up a negative pressure head above the phreatic surface and a positive pressure head below the phreatic surface.

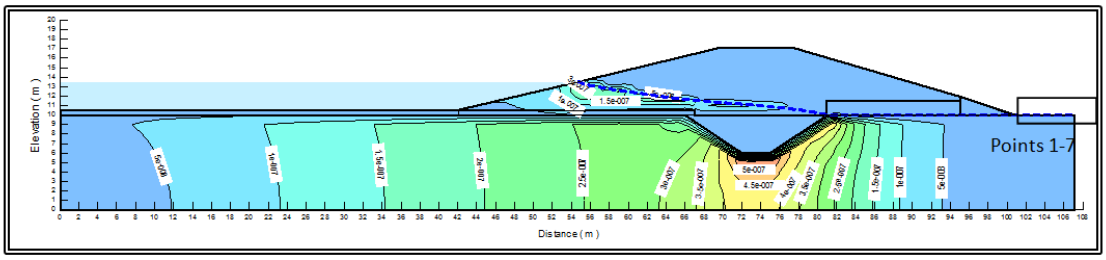


Figure 9: Contour line of XY- velocity (m/sec) for Al-Shahabi dam**.**

It can be noticed from Figure (9) that the maximum velocity is ($5x10^{-7}$) m/sec and minimum velocity is ($5x10^{-8}$) m/sec.

Figure (10) shows the XY- exit gradient for critical points at last part of downstream for Al-Shahabi dam (points 1-7).

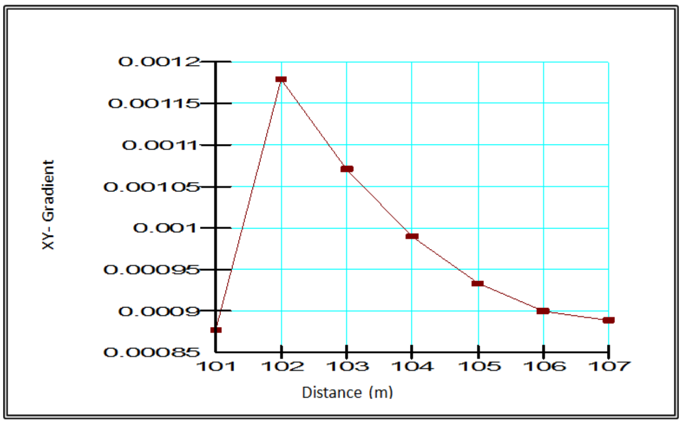
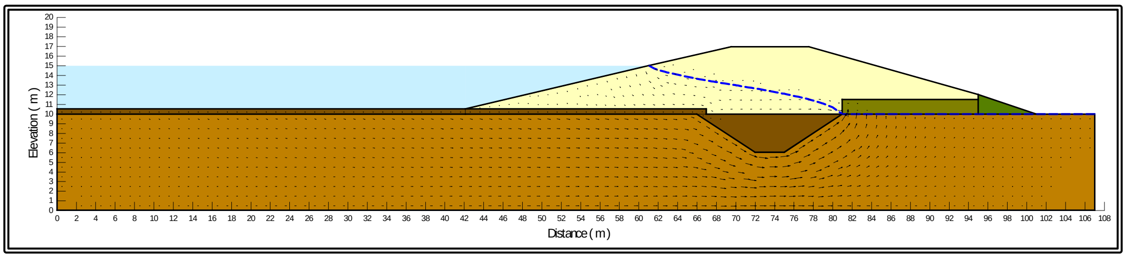


Figure 10: Values of XY- exit gradient at selected points (1-7) for Al-Shahabi dam.

3.3 Analysis of seepage when maximum water level

The analysis of seepage during the maximum water level (M.w.l.) will be drawn as shown in Figure (11) which illustrates the path of the phreatic line through the dam. In addition, Figure (12) shows the distribution of the pore water pressure and the value of water flux through the flux section.



Figures 11: Phreatic line and velocity vectors for Al-Shahabi dam.

A dot blue line in figure (11) represents the phreatic surface in the dam during maximum water level. The phreatic surface is now beginning at a higher water level where it decreases throughout the dam and exits at the dam toe, which is desirable for stability.

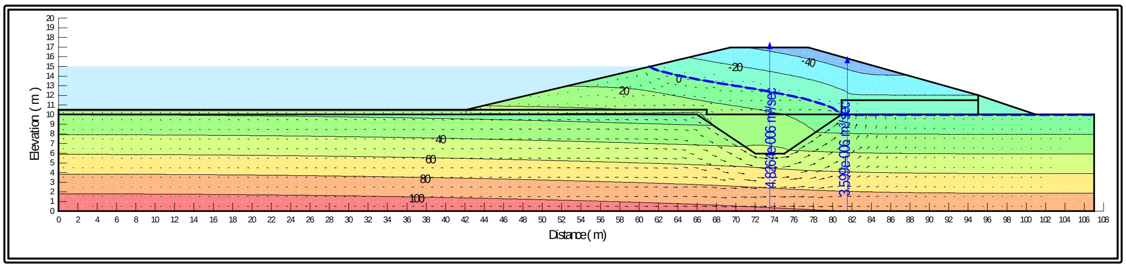


Figure 12: The distribution of the pore water pressure (Kpa) and the value of water flux through the flux section for Al-Shahabi dam.

A phreatic surface is shown as the dot blue line, which is also the iso-line where the pore water pressure is zero. The pore water pressure is negative above the phreatic surface and positive below the phreatic surface. The water flow was measured across the blue vertical lines, also called flow lines.

Figure (13), (14) and (15) represent the total head, pressure head and XY- velocity respectively.

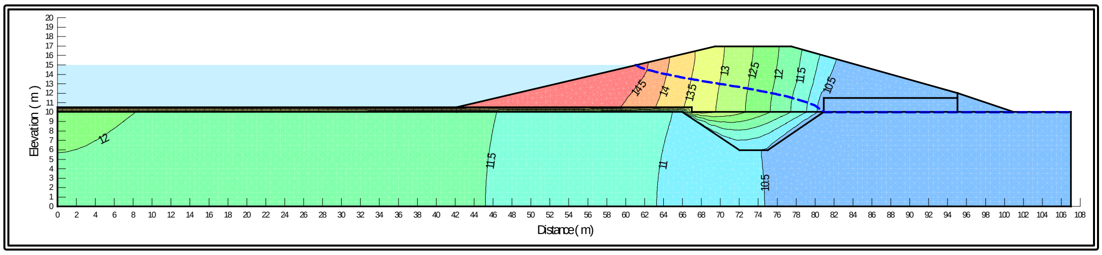


Figure 13: Contour lines of total head (m) for Al-Shahabi dam.

Figure (13) shows the total head on the left is larger than the total head on the right. The total head difference creates a water flow from the left to the right.

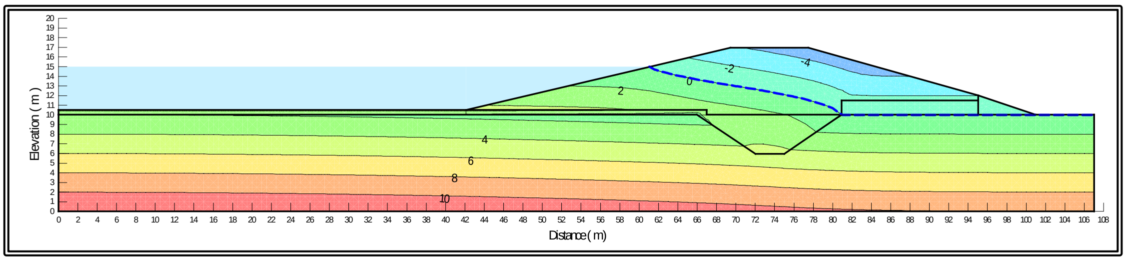


Figure 14: Contour lines of pressure head (m) for Al-Shahabi dam.

Figure (14) shows how flowing water within the dam builds up a negative pressure head above the phreatic surface and a positive pressure head below the phreatic surface.

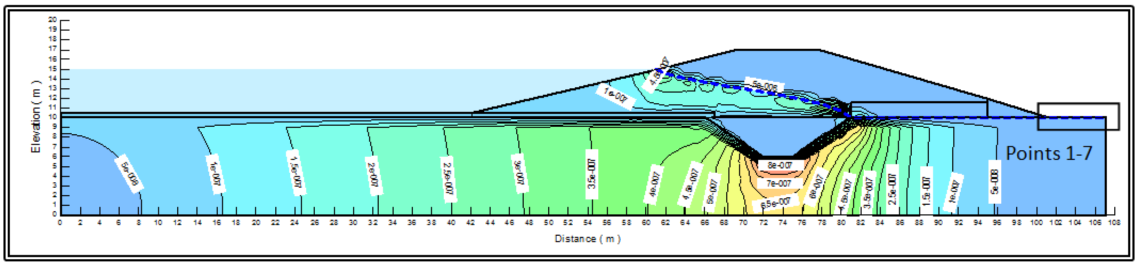


Figure 15: Contour line of XY-velocity (m/sec) for Al-Shahabi dam.

It can be noticed from Figure (15) that the maximum velocity is ($8x10^{-7}$) m/sec and minimum velocity is ($5x10^{-8}$) m/sec. Figure (16) shows the XY- exit gradient for critical points at last part of downstream for Al-Shahabi dam (points 1-7)

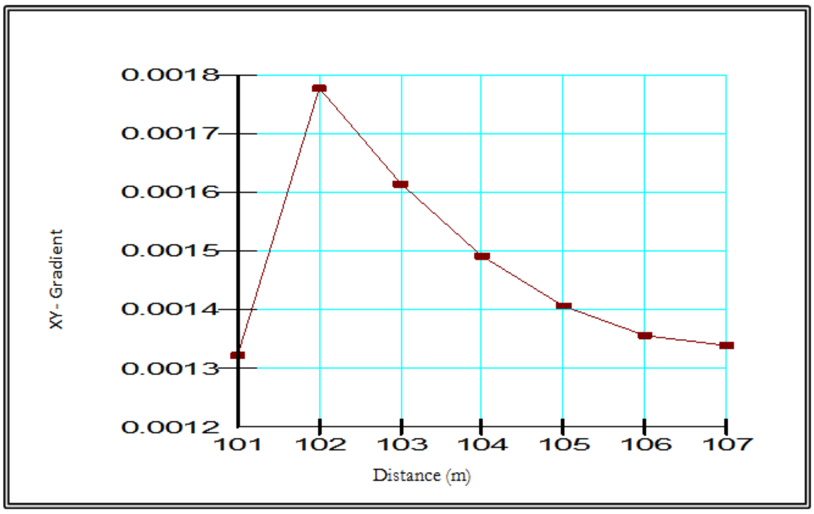


Figure 16: Values of XY- exit gradient at points (1-7) for Al-Shahabi dam.

It can be noticed from Figure (16) that the exit gradient during maximum water level greater than in case of normal water level which indicate that the exit gradient increase with increasing height of water level in the upstream of the dam.

4. Results

The results of steady state seepage analysis for different water levels are summarized in Table 2.

Table 2: Results of steady state seepage analysis for Al- Shahabi dam.

		During normal water level	During maximum water level
Seepage (m^3/sec/m)	At flux section in dam	3.0046×10^{-6}	4.8264×10^{-6}
	At flux section in drain	2.3164×10^{-6}	3.599×10^{-6}
Maximum velocity (m/sec)		5×10^{-7}	8×10^{-7}

Table (2) shows the two scenarios at different operating conditions where maximum water level and normal water level. It can be noticed that the quantity and velocity of seepage during maximum water level greater than in case of normal water level which indicate that the quantity and velocity of seepage increase with increasing height of water level in the upstream of the dam.

5. Conclusions and Recommendations

5.1 Conclusions

From the seepage analysis that was carried out on Al – Shahabi earth dam, the following conclusions can be drawn based on the results obtained from numerical analysis, the results obtained from the model analyzed with SEEP/W show that there are some effects, this depends on characteristics of dam and water level in reservoir. Now the important conclusions can be given as follows:-

1. It can be noticed that the quantity and velocity of seepage during maximum water level are greater than in case of normal water level, which indicate that the quantity and velocity of seepage increase with increasing height of water level in the upstream of the dam.
2. Seepage through the dam at flux section at normal water level is (3.0046×10^{-6} m3/sec) and it is increased up to (4.8264×10^{-6} m^3/sec) during maximum water level.
3. The maximum velocity of seepage through the dam at normal water level is (5×10^{-7} m/sec) and it is increased up to (8×10^{-7} m/sec) during maximum water level.
4. The exit gradient values in downstream of the dam at normal water level are lower than the values of exit gradient at maximum water level.

5.2 Recommendations

We recommend the researchers as possible to re-analysis the seepage of Al-Shahabi dam if there is change in water level.

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