Finite Element Analysis of Seepage for Hemrin Earth Dam Using Geo-Studio Software

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ARTICLE INFO	ABSTRACT
	Finite Element Approach is employed in this research work to solve the governing differential equations related to seepage via its foundation's dam structure. The primary focus for this reason is the discretization of domain into finite elements through the placement of imaginary nodal points and the discretization of governing equations into an equation system; An equation for each nodal point or part, and unknown variables are solved. The SEEP / W software (program) is a sub-program of the Geo-Studio software, which is used by porous soil media to compensate for the problems of seepage. To achieve the research goals, a study was carried out on Hemrin dam, which located in the Diyala River 100 km northeast of Baghdad, Iraq. Thus, one cross-section is selected for different elevations (minimum, normal and maximum or flood design elevations) to compute the seepage of water, pore water pressure and phreatic line. By theoretical analysis appeared that when the water reservoir was connected to the flood level, a problem may occur in the downstream face of the dam lead to seepage failure. A set of solutions checked by using the Geo-Studio software has been suggested in this research to solve this problem. In addition, and by analytical approach SLOPE/W (a sub-program of the Geo-Studio software) are used to assess the stability of the downstream slope and calculation factor of safety.

1. Introduction

Earth dams always connected with seepage as they reserved water in it. The water search for paths of lower resistance through the dam and its foundation. One of the main problems which cause damage in earth dams is the seepage through and under them, that occur due to the variation in water level between the upstream and downstream sides of the dam. The objectives of study the seepage and stability analysis to show the phreatic line behavior inside the body of the dam, estimate the seepage amount inside the foundation or an embankment, exit gradients and pore pressure

and find out the minimum factor of safety and locate the critical slip surface location.

In addition, studying the hydraulic gradient gives a general idea about the potential piping. Seepage becomes a problem only if it loads materials of dams also along with it. Seepage must be controlled to prevent the erosion of embankment or its foundation. The present paper is meant to disseminate information related with seepage analysis of Himren Dam is a major earth-fill dam constructed across Diyala River at its crossing point through Himren Mountains. It is located about 120 Km from Baghdad to the northeast and 68 Km from Baquba city in the same direction. It is a zoned

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dam with a clay core that was originally built for the flood protection and regulation purposes. It currently serves multiple purposes including flood control, flow regulation, electric power production, and recreation ,Official internet site of Ministry of Water Resources. In this study we used Finite Element Method (FEM) based software "GEOSTUDIO". The program of GEOSTUDIO ie. SEEP/W used for seepage analysis through earthen dam portion of dam. And SLOPE/W is the software utilized for computing the factor of safety against slope failure using different methods and under different soil conditions and different elevations. Any failure or accident of dam can cause potential risk to property and lives of millions of people who live downstream of the dam and also other life styles. So that safety of the dams is very important side for protect the national explotation. therefore it is important to assure dams safety of for all times. There are many literature review that discuss seepage and stability for different cases study:-

Darcy (1856) Shaw the fundamental law of flow through porous media through his series of experiments on vertical pipe filled with sand. Darcy's Law was originally derived for saturated soil, but subsequent researches appeared also ability applied it to the flow of water through unsaturated soil (Richards, 1931 and Childs & Collins-George,1950) ;The only difference is that under the flow conditions is no longer the hydraulic conductivity fixed, but they vary with changes in the water content varies indirectly with the changes in the pore water pressure. There are different ways are available for seepage analysis that can be classified as analytical, experimental and numerical methods. The use of many computer programs used nowadays which fascinates researcher to simulate actual field conditions for the performance seepage. Kamanbedast et al. (2011) Focus on the need to use different ways to check the safety of the dam to decrease any errors in the calculation due to maintenance of water storage, especially the structure of the dam.

Hasani et al(2013) showed the safety of earthen dam can performed using GEOSTUDIO software sub product Slope/W. Arshad and Baber et al.(2014) showed that seepage analysis of earth dam can be efficiently performed utilizing finite element based SEEP/W software. This program is able to estimate various flow net parameters such as seepage discharge, exit gradient, seepage velocity, pore pressure, and lifting pressure at any desired point in the flow net. Shivdakumar et al.(2015) show that using PLAXIS 3D software, the finite element modeling results are presented for stability analysis and earth dam seepage analysis.

2. Governing equations

The method of finite element was utilized in this research to find solution the differential equations of stability and seepage in the body and foundation of the dam. The software (program) of the SEEP / W is a sub-program of the Geo-Slope (software), which is utilized by permeable soil media to support the problems of seepage. SEEP / W is a CAD-type program based on FEM that is utilized for study seepage and groundwater problems. The controlling equation utilized for modeling the SEEP/W system is partial differential equation (PDE), show is Following:

$$\partial/\partial x\ (k\_x\ \partial H/\partial x\ )+\partial/\partial y\ (k\_x\ \partial H/\partial y)+ Q =\partial\theta/\partial t \qquad (1)$$

where, Kx = hydraulic conductivity in x direction, Ky = hydraulic conductivity in y direction, H = head of Hydraulic; Q = applied boundary flux; t = time domain; θ = volumetric water content.

Equation (1) is a period variable and gives that "the distinction between the stream that enters the volume and leaving an essential volume at a point equivalent to the adjustment in the water substance of volumetric in a specific time. On the off chance that the deluge volume is equivalent to the out-transition volume, at that point, the condition meeting the consistent state conditions, and in this manner the correct hand of the condition changes to zero.

$$\partial/\partial x\ (k\_x\ \partial H/\partial x\ )+ \partial/\partial y\ (k\_x\ \partial H/\partial y\ )+ Q = 0 \qquad (2)$$

Furthermore, to discover safety factor and find the basic slip surface area for various rises use SLOPE/W which tackles, two safety factor equations (force and momentum). All the used techniques for cuts can be envisioned as privet instances of the General Limit Equilibrium solution. A safety factor is portrayed as that variable by which the shear quality of the soile must be limited so the mass of soil will bring into a state of obliging equalization along a picked slip surface.

The stability analysis includes passing a slip surface through the mass of earth and dividing it into vertical slices. The slip surface may be circular, linear or comprises of any shape characterized by a progression of straight lines.

The factor of safety with respect to moment equilibrium is:

$$F_m = \Sigma(c' \beta R + (N - u\beta) R\tan\phi')\Sigma Wx - \Sigma Nf + \Sigma kWe \pm \Sigma Dd \pm \Sigma Aa \tag{3}$$

where: W is the slice weight; N is the normal force on the base of the slice ; D is an external load; kW is the horizontal seismic load; R is the radius for a circular slip surface ; x and e are the horizontal and vertical distances from the centerline of each slice to the center of rotation respectively; d is the vertical distance from a point load to the center of rotation ; a is the vertical distance from the resultant external water force to the center of rotation; A is the resultant external water forces.

3. Materials and methods

3.1 Study location

The present study is undertaken for seepage modeling of the Hemrin earth dam, which located on the Diyala River 120 km northeast of Baghdad, Iraq. Hemrin dam is an earth fill masonry dam, which is built on the Diyala river from year 1976-1981. In the present study an attempt has been made to perform seepage analysis through an earthen portion of Hemrin dam. The dam consists of three reaches –two embankments on upstream and downstream sides and centrally masonry portion. The length of the dam Alrkama total of 3500 m. (Figure.1) show Typical Cross Section of Hemrin Earth Dam.
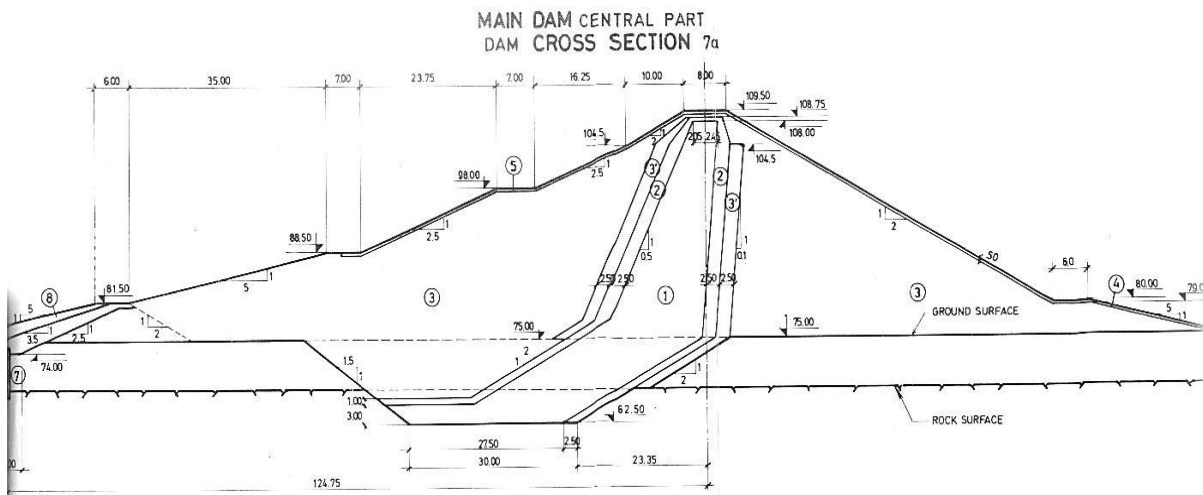

Fig. 1. Typical cross section of hemrin earth dam

3.2. SEEP/W and SLOPE/W

According to Geo-Slope International (Geo-Slope), "SEEP / W software product is limited CAD software product for analyzing of groundwater seepage and leakage problems

dissipate excess pore pressure within porous materials such as soil and rock. Its comprehensive formulation allows for one to consider analyses ranging from simple, saturated steady state problems to sophisticated, saturated/unsaturated timed depended program. And SLOPE/W is the

software utilized in computing the factor of safety against slope failure using different methods and under different soil conditions and different elevations.

It can be applied SEEP / W on the analysis, design, hydrogeological and Geotechnical civil engineering products and mining." Seepage analysis steps by applying SEEP/W are as follows:

1- Formed mesh and installed by using SEEP/ W program

The Hemrin Dam separation process is developed by utilizing the SEEP / W program. The material properties of this section with the correct measurements can be an introduction to the program, and the cross-section testing has been performed accordingly. The mesh of FEM at this section is composed of four forms of elements, i.e. triangular, square, rectangular and trapezoidal type of elements of different sizes (Figure.2). The field is largely separated by some elements by placing nodal points.
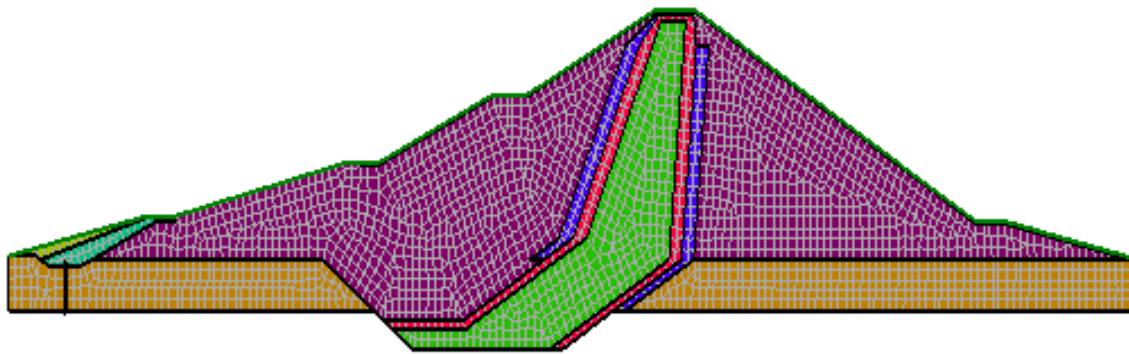

Fig. 2. Mesh formation for Hemrin earth dam cross section

After all the required inputs, the computerized system Seep / W has been checked with most of the information given and the comprehensive reports that horizontal linear messages are powerful enough and there are no errors in its development. This model is thus easy to re-calculate and evaluate the effects.

1- Setting of Boundary Conditions:

Calculations are performed for three different cases: -

(i) Maximum elevation of water level (107.5 m).
(ii) Normal elevation of water level (104.5 m).
(iii) Minimum elevation of water level (92 m).

Boundary conditions are set as:

(I) For all the above-mentioned cases, top level off and downstream boundary conditions are considered to be Dirichlet boundary terms.
(II) Close to zero-transition conditions, for example Neuman limit conditions for all the

above-mentioned conditions, are considered in setting up-, down- and base point
2. Output of computer Simulation:
The output to be obtained by analysis in software are as follows:

(i) Development of stream net by following streamlines and equipotential liners for separated upstream water level states.
(ii) 2d vector vision and thus seepage behavior for variations situations.
(iii) The description of the phreatic line for variations situations.
(iv) The calculation of the motion of seepage by means of the establishment and the profile of the dam for differentiated heights
(v) Calculation of exit gradient, most extreme stream volume, pores water pressure along the dam's body and under differentiated heights

4. Result discussion

4.1 Material properties

The properties of material for earthen section of Hemrin dam which it component eight zoned shown in Figure 1, watched hydraulic heads with the recreated ones. Using the programming of SEEP/W, the material properties (hydraulic conductivity) optimized for the region chosen for the distinct types of materials used in Table.1.

Table 1 Material properties of Hemrin earth dam

R. No	Material Type	Hydraulic Conductivity (m/Sec)	Bulk density (Y) (Kpa)	Angle of internal friction (ω)	Cohesion (C) (Kpa)
01	Foundation	1E-05	22	15	40
02	Shell	1.69e-05	19	37	-
03	Core	2.31e-09	18	23	30
04	Fine filter	1.2e-05	16	35	-
05	Coarse filter	0.0001	16	35	-
06	Cofferdam	2.31e-09	18	30	15
07	Random fill	1e-05	17	36	7
08	Slope protection	0.0001	19	35	-

4.2 Flow net with current- and equipotential lines, phreatic line activity and velocity vectors

The SEEP / W program is utilized for seepage analysis in Hemrin embankment and its establishment for various lake-level situations to obtain invasive information.For this reason, utilizing the product flow net has been drawn to the chosen area and for various rises as appeared in Fig.(3) to –Figure.(5).

The flow net includes streamlines, equipotential lines, speed. Vectors indicating prevailing Land stream (seepage) and phreatic line representing the Hemrin dam's seepage behavior.

From the Characters It has given an idea that the equipotential and stream lines at rise 92m and 104.5m are typical to one another, which complies with leakage hypothesis. However, at the height 107.5m it appears to be unsatisfied and the channels of the dams are not powerful at higher lake level.
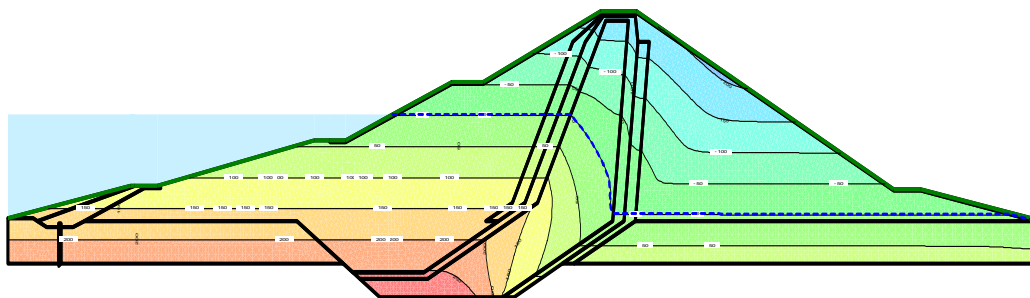

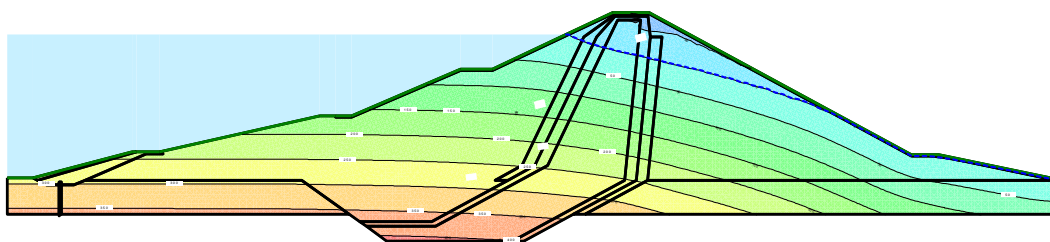**Fig. 3.** Flownet for section (Pond level = 92m)

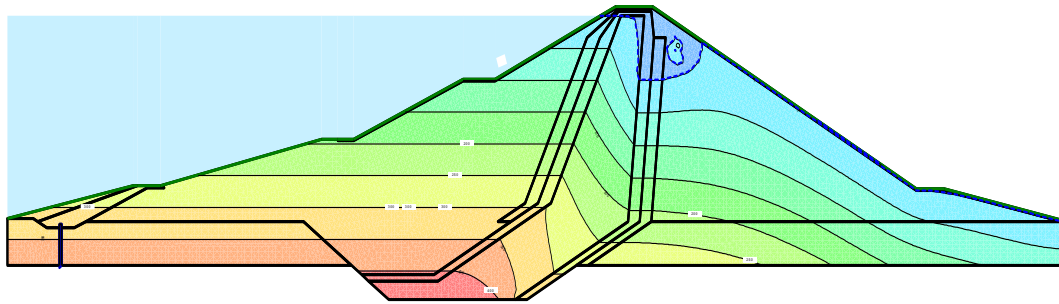**Fig. 4.** Flownet for section (Pond level = 104.5m)

Fig. 5. Flownet for section (Pond level = 107.5m)

4.3 Pore pressure, exit. gradient, and seepage flux

Utilizing the SEEP/W. software, the pore pressure, the seepage. flux and exit. gradient for the whole lake level situations and in the segment chosen are registered; Such are the recorded in Table.2. At the most minimal lake level least pore pressure happens; that is of the order of (-50.11 kpa); at highest pond level maximum pore pressure occurs in the selected section; and which is of the order of (115.95 Kpa). A graphical correlation of pore pressure versus elevations is also shown in Figure (6) Nearly for all the situations a direct pattern is watched. What's more, it is likewise understood that the exit gradient is inside as far as possible for all the situations and at the chose segment for study; in this way it likewise acclimates to wellbeing the dam requirements. Figure (7) offers graphics connection for exit gradient.as the capacity in heights individually. Right now first a decrease in the estimation of exit gradient with the increment lake level, until spans to the normal elevation (104.5m); after that exit gradient rises exponentially as the lake level increments until arrives at the most extreme worth (0.559) at the greatest rise (107.5m) as appeared in Table 2 for the chose area.

On the other hand, the SEEP / W analysis shows that the seepage flux reaches its minimum value at the maximum elevation (107.5 m), i.e. in the case of the flood level of the same selected section, as the minimum seepage flux order to (2.90E-09 m3/Sec/m2) because the water level at the upstream of Hemrin earth dam reaches almost the same height as the core of the embankment. This causes water filtered over the core and collected in the downstream area along the potential seepage face as shown above in the Fig. (5). At this level where water can escape from any part of the downstream area, because the phreatic line is along potential seepage face, which may lead to seepage failure. Fig. (8) explain a graphics relation for seepage. flux as a function. of elevations respectively.

Table2 Computed pore pressure, seepage flux and exit gradient for different pond levels in Hemrin earth dam

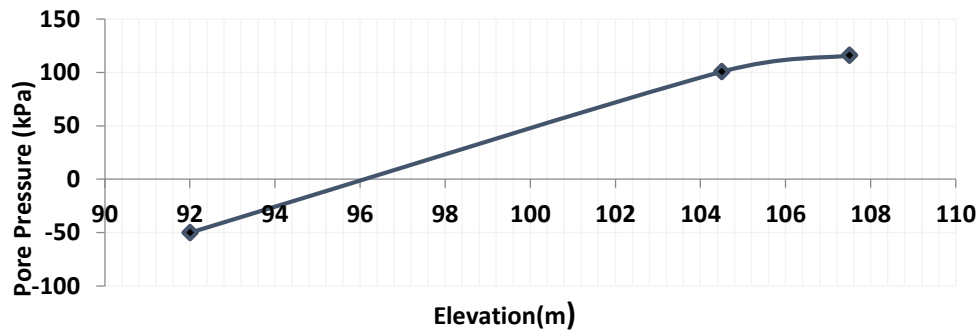| Parameter	Upstream Pond Levels		
	Minimum 92(m.)	Normal 104.5 (m.)	Maximum 107.5 (m.)
Pore pressure (KPa)	-50.11	100.81	115.95
Exit gradient	0.459	0.316	0.559
Seepage flux (m^3/sec/m^2)	3.78E-09	2.22E-06	2.90E-09

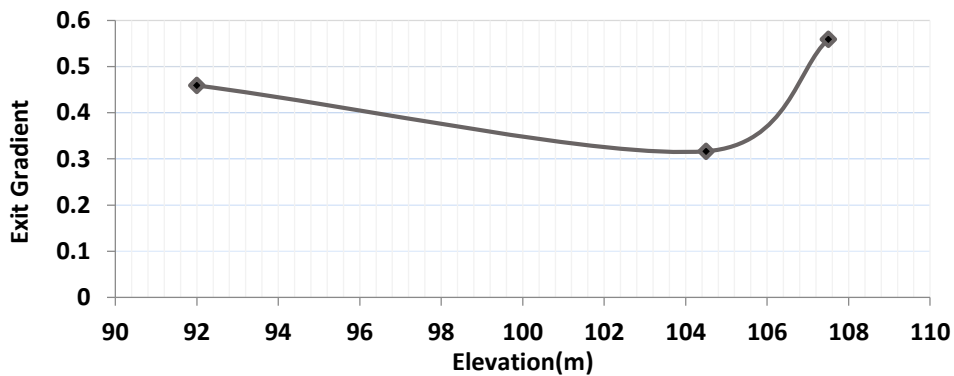**Fig. 6.** Pore pressure vs. elevation (head of water)

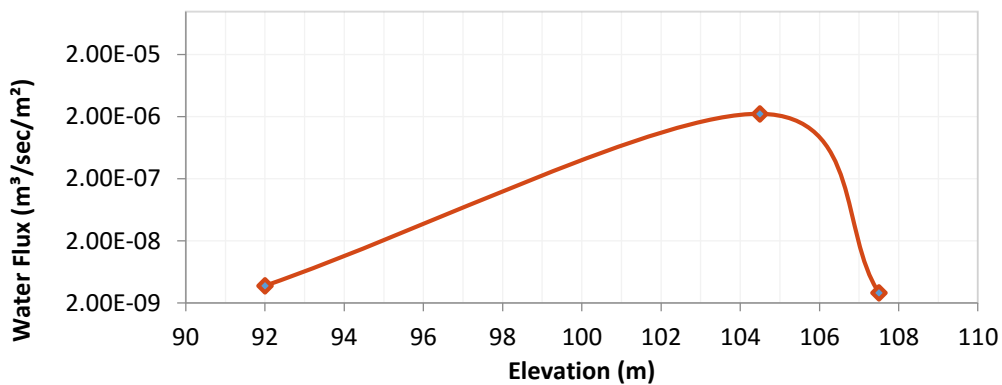**Fig. 7.** Exit gradient vs. elevation (head of water)

Fig. 8. Water flux vs. elevation (head of water)

To avoid seepage failure, there are two proposals. The first is that the water level of the upstream should not exceed normal elevation to avoid problems that may occur in the event if water reach the flood level. As for the second proposal, it is to add a horizontal drain filter on the downstream side using the hidden drilling technique to maintain the safety of the dam in the event if the water level exceed normal level during flood times. Figures (9,10,11) below showing seepage analysis by utilizing the SEEP/W program in the case of adding a horizontal drain filter in the downstream side of the earth dam: -
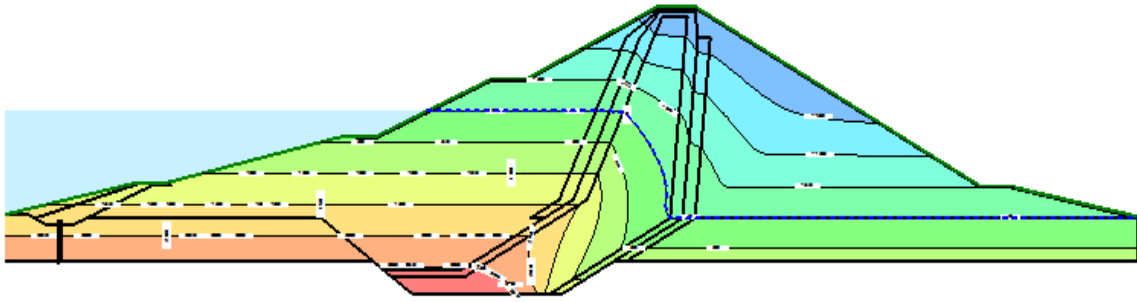
Fig. 9. Flownet for section with horizontal drain filter (pond level = 92m)
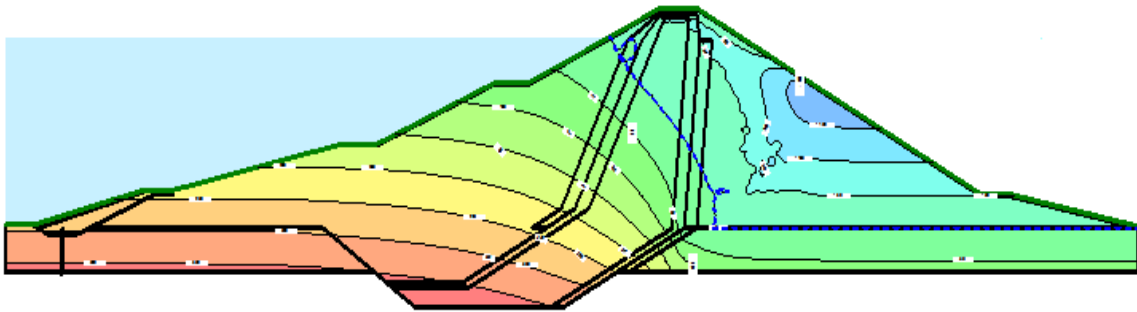

Fig. 10. Flownet for section with horizontal drain filter (pond level = 104.5m)
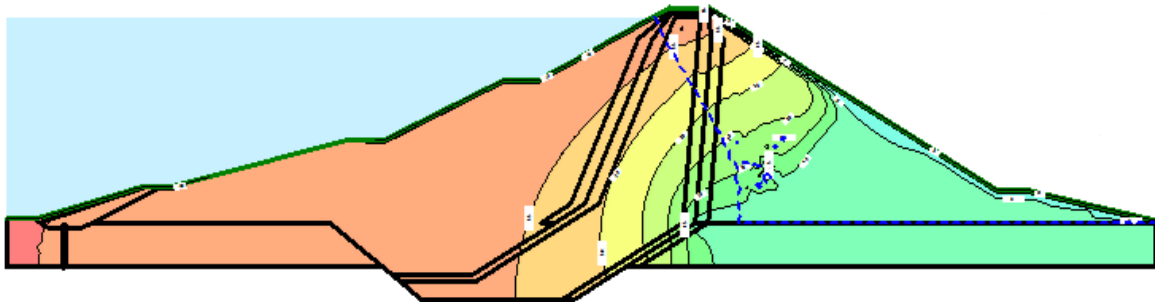

Fig. 11. Flownet for section with horizontal drain filter (pond level = 107.5m)

So, the results of the pore pressure, the seepage flux and exit gradient by using SEEP/W software for all elevations scenarios and segment selected with horizontal drain filter are calculated; these are listed in Table 3.

The graphics below Figures (12,13,14) show a comparison of the results obtained in the case of the horizontal drain filter with the previous results:

Table 3 Computed pore pressure, seepage flux and exit gradient for different pond levels with horizontal, drain filter in Hemrin earth dam

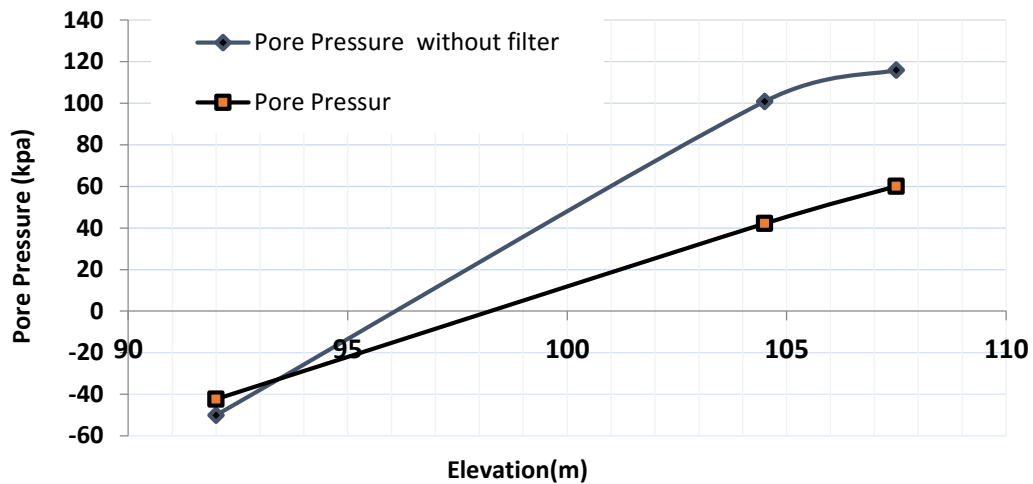| Parameter	Upstream Pond Levels		
	Minimum 92(m.)	Normal 104.5 (m.)	Maximum 107.5 (m.)
Pore pressure (kPa)	-42.31	42.16	60.11
Exit gradient	0.53	0.96	1.55
Seepage flux (m3/sec/m2)	4.54E-09	9.09E-06	1.11E-05

Fig. 12. Comparison pore pressure vs. elevation (head of water) in two cases with and without horizontal drain
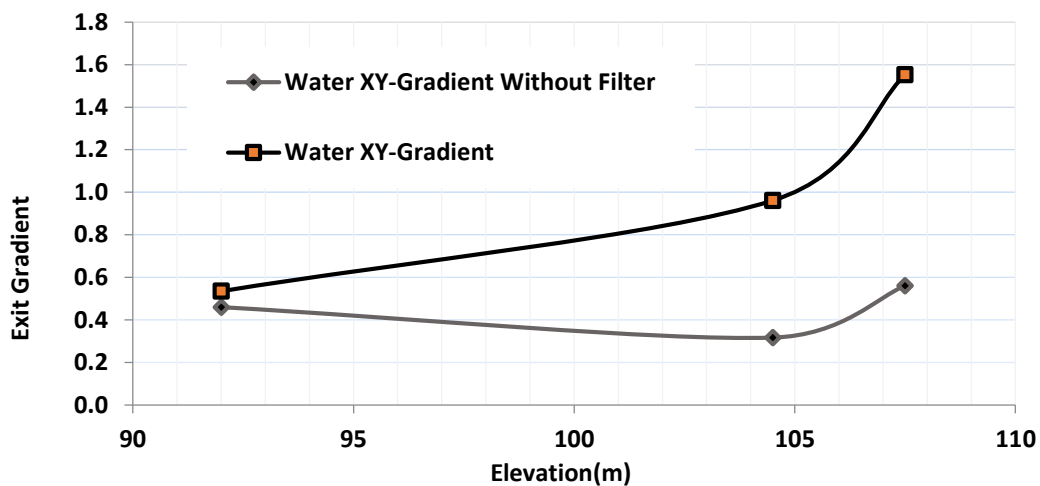

Fig. 13. Comparison exist gradient vs. elevation (head of water) in two cases with and without horizontal drain

4.4. Analysis of stability of the slope of SLOPE/W

The SLOPE/W software is utilized to get slope stability analysis for the upstream, downstream slope for various scenarios and checked by using spencer analysis method accordingly. The analysis is carried out in terms of effective stresses. Pore pressures for various loading conditions and for different elevations of water head are estimated as subsequently described. For each case analysis the critical slip surface, yielding the minimum safety factor is found by rigorous search. The section at which the dam height become maximum is selected for stability analysis, because this is the critical section for stability as compared to other and will give the minimum factor of safety. From SLOPE/W simulations it may be noted that the minimum safety factors on all loading cases where having a critical surface near outer faces only, and location of the critical slope surface along with the safety factors obtained by using Spencer method. Shown in Figure (15) and Figure (16).
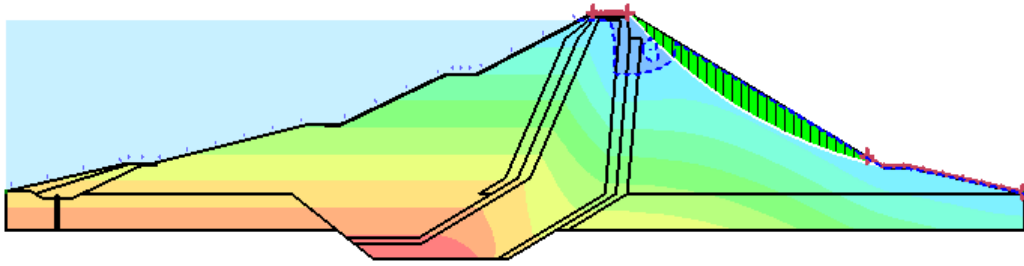
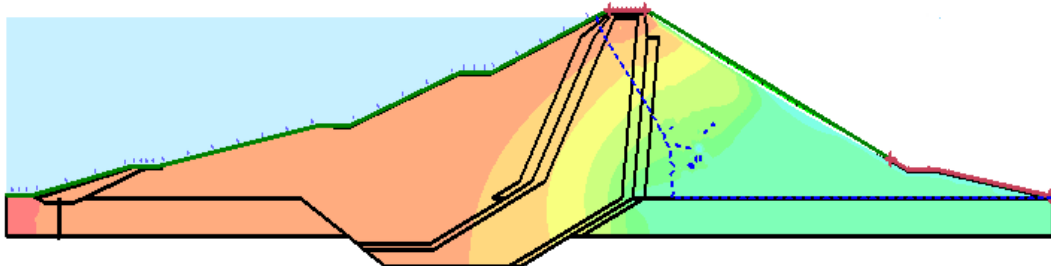**Fig. 15.** Slip surface for minimum safety factor (pond level = 107.5m)

Fig. 16. Slip surface for minimum safety factor (pond level = 107.5m) with horizontal drain filter

Table 4 Computed safety factor for different pond levels in hemrin earth dam without and with horizontal drain filter

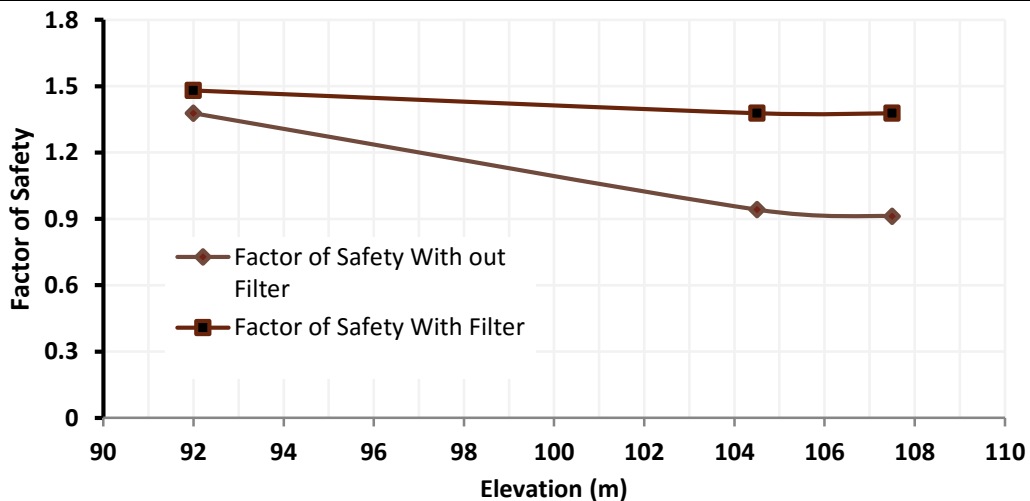| Parameter	Upstream Pond Levels		
	Minimum 92 (m.)	Normal 104.5 (m.)	Maximum 107.5 (m.)
Safety Factor	1.37	0.94	0.91
Safety Factor With Horizontal Drain Filter	1.48	1.37	1.37

Fig. 17. Comparison safety factor vs. elevation (head of water) in two cases with and without horizontal drain

From graphical Figure 17 and Table 4 above noticed that minimum safety factor obtained at a maximum elevation of water head for two cases without and with horizontal drain filter.

5. Conclusion and recommendations

In the present study using the Geo-Slope software, seepage and slope stability analysis in the Hemrin earth dam was studied. SEEP/W

software was used to compute seepage, while SLOPE/W was used for computation minimum safety factor.

1- Minimum pore pressure exists at the lowest pond level; that is of the order of (-50.10 kpa); maximum pore pressure occurs at the maximum pond point in the chosen segment; and which is of the order of (115.95 kpa). therefore, the loss of water in the dam ultimately increases.

2- The exit gradient value for the minimum, normal and maximum elevation less than 1.0 a decrease in value of exit.gradient with the increase pond level until reaches to the normal elevation(104.5m) ; after that exit gradient is rising exponentially as the depth of the pond increases until reaches the maximum value (0.55) at the maximum elevation (107.5m) .

3- The seepage flux reaches its minimum value at the maximum elevation (107.5 m), i.e. in the case of the flood level of the same selected section, as the minimum seepage flux order to (2.90E-09 m3/Sec/m2) because the water level at the upstream of Hemrin earth dam reaches almost the same height as the core of the embankment. This causes water filtered over the core and collected in the downstream area along the potential seepage face. At this level where water can escape from any part of the downstream area, because the phreatic line is along potential seepage face, which may lead to seepage failure.

4- To avoid seepage failure, recommended that keep the water level on the upstream not exceed normal elevation to avoid problems that may occur in the event if water reach the flood level. Or, it is to add a horizontal drain filter on the downstream side using the hidden drilling technique to maintain the safety of the dam in the event if the water level exceeds normal level during flood times.

5- The SLOPE/W program is utilized for getting slope stability analyzes for upstream and downstream slope for various scenarios of selected section in different elevation and checked by using spencer analysis method accordingly and computed safety factor noticed that minimum safety factor obtained at a maximum elevation of water head for two cases without and with horizontal drain filter.

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