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# Computation of Seepage and Exit Gradient through a Homogeneous Earth Dam without Filter Drain by using Geo-Slope (SEEP/W) Software

**Imran Arshad[1]*, Muhammed Muneer Babar[2]**

[1]SAA Technical & Specialized Services Establishment, Abu Dhabi, United Arab Emirates.
[2]Institute of Water Resources Engineering & Management (USPCASW), MUET, Pakistan.

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***Corresponding author:**
Imran Arshad;
**Email:**
engr_imran1985@yahoo.com



**Abstract**

In this study, SEEP/W was used to develop a finite element model of a homogenous earth dam and for this purpose Hub dam was selected. Two different cases i.e. (i) with filter drain and (ii) without filter drain was studied to check the behavior of the dam in terms of seepage flux and exit gradient respectively. The software was also used to simulate the phreatic line behavior for both cases. The FE model was comprised of four different types of elements i.e. triangular, square, rectangular and trapezoidal. For case (i) the domain is discretized into a mesh by 12,346 elements through placement of nodal points 12,495 and for case (ii) 12,305 elements and 12,399 nodal points was used. The outcome of the simulated results showed that the dam is safe against piping, at its original design as the installation of a filter drain found working effectively in reducing internal water pressure within the dam and its foundation. For case (i), the phreatic line showed a normal trend as it is falling into the filter drain with overall minimum seepage flux of 2.513 x $10^{-4}$ $ft^3$/sec/ft and exit gradient at downstream toe 0.351 respectively. However, for case (ii) the dam showed an irregular behavior as the phreatic line trend was found abnormal as it cuts the downstream slope of the dam and about (65.419% – 71.085%) more exit gradient was recorded for each scenario.

**Keywords:** Homogeneous Dam, Seepage Flux, Exit Gradient, Phreatic Line, SEEP/W, Geo-Slope Software.

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## INTRODUCTION

It is well known fact that excessive seepage in any type of a dam is one the root cause to destabilize the dam structure and thereby bring economical havoc (Baghalian *et al.,* 2012). This mainly happens due to the potential head difference between the upstream face and downstream face, as water through soil pores or rock fissures finds its way by eroding away the fine soil particles and cause piping within the dam. The amount of water seeps through and under the foundation of a dam, along with the distribution of pore water pressure, can be analyzed by using a theory of flow through porous medium (Arshad *et al.,* 2014). The computed amount of seepage is useful in estimating the loss of water from the reservoir, while the pore water pressure distribution gives a rough idea to observe a trend of hydraulic gradient (phreatic line) at a point of seepage discharge respectively (Al-Damluji *et al.,* 2004). Phreatic line within the dam body is the line having negative hydrostatic pressure at above the line and positive hydrostatic pressure below the line respectively (Moayed *et al.,* 2012).

It is necessary to find out the trend of phreatic line as it will allow us to recognize a divide line between dry and submerged soil. The phreatic surface should be kept at or below the downstream toe to avoid piping and control exit gradient (Doherty, 2009). The trend of phreatic line can be well controlled by designing a dam with proper filter drain. The purpose of the filter drain is to restrict the phreatic line almost in upstream side of the dam. The filter prevent passing of fine particles into the drain, while drain allows the removal of surplus amount of internal water to control pore water pressure within the dam body respectively (Garg*,* 2006). Nowadays, before the implementation of a mega structural work, finite element method is used to analyze the behavior of complex structures, as it will give an idea to an engineer about its stability and durability (Arshad *et al.,* 2017). In present research work, by using FEM technique a homogeneous section of an earthen dam (Hub dam) was selected to simulate phreatic line for homogeneous section with and without horizontal filter drain; and to compare the results of seepage flux and exit gradient for different scenarios respectively.

## MATERIALS AND METHODS

### Hub Dam Description

The Hub dam is a rolled earthfill structure 156 ft high over the deepest foundation, with crest length of 15,640 ft. it is located at about 35 km, northwest of Karachi city. The top of the dam at elevation 352 ft is 28.66 ft wide width 26.5 ft clears width of road exclusive of the parapet wall. The reservoir occupies a broad undulating valley between the western slopes of Kirthar and eastern slopes of Pub ranges of mountains which narrows down in upstream direction. The water spread area of the reservoir surface is 24,939 acres or 38.96 square miles at maximum water level which has been fixed at elevation 346. Gross storage at full reservoir level EL 346 will be 857,000 acre-feet of water. The minimum operational level, at the sluice invert EL 270 ft, established by the relative levels of the irrigable command area and design of main canal, corresponds to 760,000 acre-feet of the live storage and 97,000 acre-feet of dead storage. The allocated annual supplies from the reservoir have been fixed as 193,000 acre-feet of water, thereby the reservoir will provide for a large carry-over capacity amounting to more than 3 years supplies.

The upstream face of the dam has 2 berms each 10 ft wide at EL 270 and 318 ft respectively. The slope varies from 4.5 to 1 upto elevation EL 270 ft, 3 to 1 between elevations EL 270 and 318 ft, 2.5 to 1 between elevation 318 to 342 ft and 2 to 1 between elevations 342 to 352 ft the top of the dam. The downstream face of the dam from its crest elevation EL 352 ft down to elevation EL 318 ft is sloped 2 to 1, from the flattening to 2.5 to 1 down to berm at elevation EL 270, thereafter the slope has been kept as 3 to 1 respectively. Slope protection consists of random fill of river run sand and gravel. The dam has a zoned earthfill section in the river portion consisting of a central core of impervious material with pervious fill on either side. On both flanks of river the dam has a homogenous semi-impervious section. Embankment drains at the downstream termination of the horizontal filter blanket (filter drain) are located at the toe running parallel to dam axis (WAPDA, 2009).

### Steps for Modeling of Hub Dam

In the preliminary step a cross section for a homogenous section was selected to generate FEM mesh. According to the given conditions the upstream and downstream boundary conditions are assigned as Dirichlet and Neumann boundary nodes respectively. The nodes at the bottom of the foundation of dam are considered with zero-flux (Nuemann) condition (Arshad *et al.,* 2016). After assigning the boundary conditions the flux section in middle of the dam was assigned respectively. The material properties according to the type of material used in the dam section were then calibrated. Finally, the FE model, is verified by using SEEP/W and computation of seepage flux, exit gradient and phreatic line trend for different scenarios of water levels is carried out accordingly.

### Selection of Cross Sections for FEM Modeling

Since the main dam is composed of different kinds of reaches, therefore in this research only homogenous section was selected. Due to variable ground level elevations, the foundation level of the dam was kept at EL 250 ft, while the crest elevation level was kept at EL 352 respectively. The dimension of selected homogenous cross section was elaborated in Figure 1.

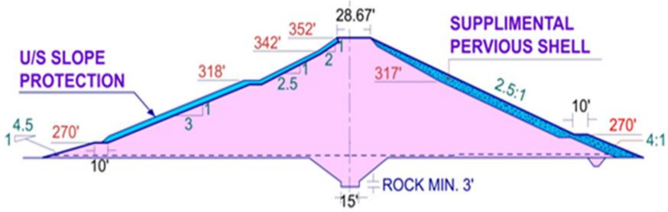


**Fig. 1. Geometry of Homogeneous Section.**

**FEM Mesh Formation and Its Verification by Using SEEP/W Software**

The FEM mesh has been developed by using salve program of Geo-Slope software i.e. (SEEP/W). The cross sections were developed for 2 cases i.e. (i) homogeneous section with filter drain, and (ii) homogeneous section without filter drain respectively. The hydraulic conductivities of the materials used in mesh development of the cross sections and dimensions remain same except for filter drain. The meshes are generated by using triangular, square, rectangular and trapezoidal type of elements (Arshad *et al.,* 2018). For case (i) the domain is discretized into a mesh by 12,346 elements through placement of nodal points 12,495 and for case (ii) 12,305 elements and 12,399 nodal points was used (Arshad *et al.,* 2015). Figure 2 describes the typical mesh formation of homogeneous section.

Computations were carried out for three different scenarios i.e. maximum (346 ft), minimum (270 ft), and normal pool level (339 ft) respectively. At upstream fill level and downstream toe boundary conditions are considered as Dirichlet boundary conditions and at foundation upstream face and bottom level Neuman boundary conditions (zero flux) had been assigned for all the water level scenarios in both cases respectively. The verification of FEM mesh and computation of results was done through SEEP/W respectively.

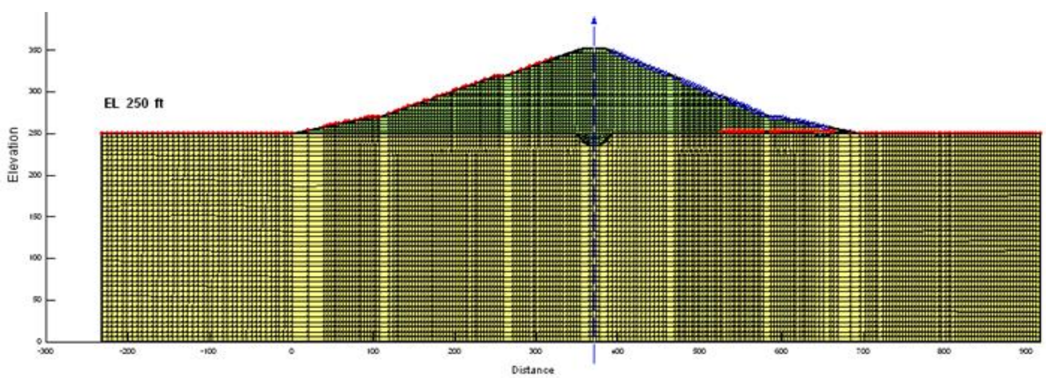


**Fig. 2. Typical Mesh formation for homogeneous section.**

## RESULTS AND DISCUSSION

### Calibration of Material Properties (Hydraulic Conductivity) of an Earth Dam

In order to calibrate the material properties of the earth dam, initially identical guess values of hydraulic conductivities for all the materials used in the section were first specified and then assigned. Calibration of the hydraulic conductivities was made on the basis of trial and error, while comparing observed hydraulic heads with the simulated ones. These guess and calibrated hydraulic conductivities (material properties) values for different types of materials used in the earth dam are elaborated below in Table 1 respectively.

**Table 1. Guess and Calibrated Values of Material Properties for Homogeneous Section**

| S. No. | Material type | Hydraulic conductivity (ft/sec) | |
|---|---|---|---|
| | | * Guess Values | Calibrated Values |
| 01 | Foundation | $10^{-4}$ to $10^{-6}$ | $3.225 \times 10^{-6}$ |
| 02 | Shell | $10^{-5}$ to $10^{-6}$ | $2.000 \times 10^{-5}$ |
| 03 | Filter Drain | $10^{-2}$ | $3.280 \times 10^{-2}$ |

* Source: WAPDA

### Seepage Flux and Exit Gradient

SEEP/W was used to compute the behavior of seepage flux and exit gradient for two different cases i.e. (i) with filter drain and (ii) without filter drain through a homogenous dam and its foundation respectively. The seepage and exit gradient was computed at three different pond level scenarios. The SEEP/W software gives output in terms of flownet which comprises of streamlines, equipotential lines, velocity vectors showing dominant flow (seepage) field and phreatic line depicting seepage behavior of the earth dam. The results revealed that the existence of filter drain has a positive effect on seepage and exit gradient. The main role of the filter drain installation at the downstream of the dam was to control the phreatic line trend by removing the excess internal water to control pore water pressure within the dam body and filter prevent the passage of fine particles into the drainage conduit respectively. Therefore, the chances of phreatic line to cut the downstream slope face of the dam become minimum and controllable. The behavior of phreatic line within the dam for both cases at different pond levels elaborated in respectively in (Figure 3a – Figure 3b).

It is an evident from Figure 3a that at minimum pond level the presence of filter blanket has a direct effect on phreatic line as it is falling into the filter drain with seepage flux of order 2.513 x $10^{-4}$ $ft^3$/sec/ft and exit gradient at the downstream toe 0.351 respectively. Figure 3b showed some different behavior of phreatic line at minimum pond level with no filter drain. As the velocity vectors after comes out from the foundation with seepage flux of order 3.381 x $10^{-4}$ $ft^3$/sec/ft and joins the downstream shell and increases the pore water pressure respectively. Furthermore, due to unavailability of filter drain the high velocity vectors comes out from downstream shell nearly at the toe region with high exit gradient of 1.015 which may adversely affect the behavior of the dam. These results are according to the findings of (Aasma, 2015), who also computed the seepage flux through an earthen dam with and without filter drain using Geo-Slope software.

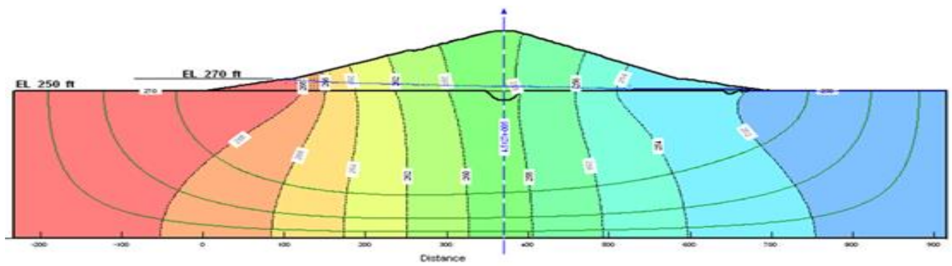


**Fig. 3a. Flownet for Homogeneous Section with Filter Drain (Pond level = 270 ft)**

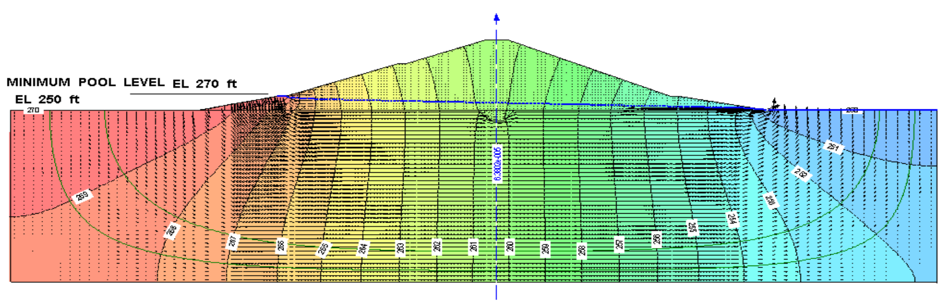


**Fig. 3b. Flownet for Homogeneous Section without Filter Drain (Pond level = 270 ft)**

Likewise, Figure 4a at normal pond level showed a regular movement of pore water from upstream to the downstream face of the dam is as phreatic line is dropping into the filter drain having seepage flux of order 3.571 x $10^{-4}$ $ft^3$/sec/ft and exit gradient at the downstream toe 0.414 respectively. The streamlines and equipotential lines were normal to each other and the movement of velocity vectors was towards filter drain which conforms; the seepage theory.

Figure 4b showed an abnormal behaviour of phreatic line at normal pond level without filter drain. The simulated result indicated that the phreatic line cuts the downstream slope of the dam at a distance of 566 ft and an elevation 275 ft due to which dam may suffer from a slope failure. Furthermore, due to excessive pore water movement and pressure within the dam an exit gradient at the downstream toe of order 1.264 was observed; which is beyond the permissible limit with seepage flux 4.988 x $10^{-4}$ $ft^3$/sec/ft respectively. Therefore, we can consider that a homogenous dam without filter drain is not safe against piping as there is a possibility of internal erosion due to seepage. Similar results were reported by (Osuji *et al.,* 2015), who also computed the quantity of seepage and exit gradient for the case of Jebba dam with and without filter drainage system within the dam.

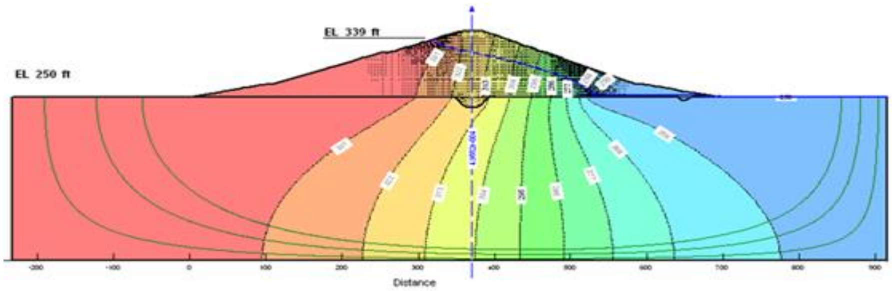


**Fig. 4a. Flownet for Homogeneous Section with Filter Drain (Pond level = 339 ft)**

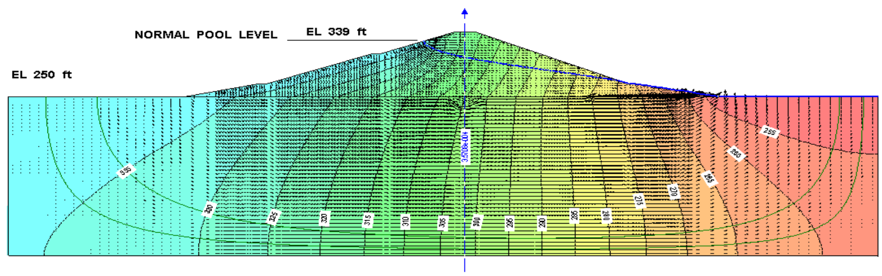


**Fig. 4b. Flownet for Homogeneous Section without Filter Drain (Pond level = 339 ft)**

Similarly seepage flux and exit gradient for the maximum pond level was computed for both cases. Figure 5a showed that at maximum pond level the homogenous dam with filter drain is having seepage flux of order 3.961 x $10^{-4}$ $ft^3$/sec/ft and exit gradient 0.517 respectively. The trend of phreatic line was relatively similar as observed in normal and minimum pond levels and the streamlines and equipotential lines were also normal to each other which conforms; the seepage theory. These results are according to the findings of (Gokmen *et al.,* 2005), who also observed the variation of phreatic line within the dam body along with high exit gradient for the case of Jeziorsko earthfill dam in Poland.

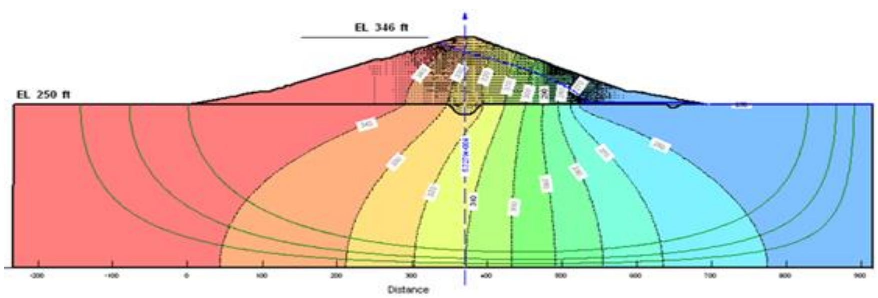


**Fig. 5a. Flownet for Homogeneous Section with Filter Drain (Pond level = 346 ft)**

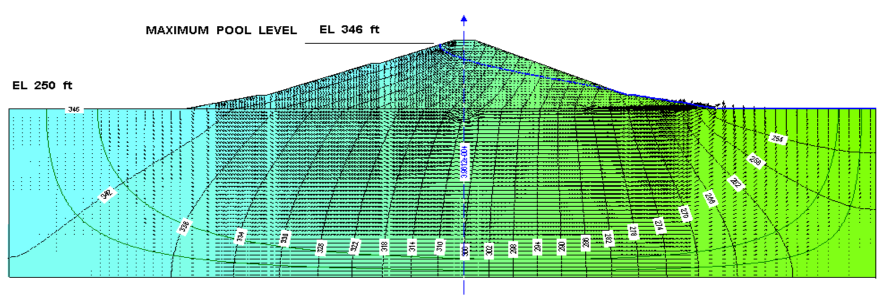


**Fig. 5b. Flownet for Homogeneous Section without Filter Drain (Pond level = 346 ft)**

Once again the dam showed an irregular behaviour of phreatic line at maximum pond level without filter drain as mention in Figure 5b. The simulated result indicated that the phreatic line cuts the downstream face of the dam at a distance of 562 ft and an elevation 277 ft due to which possibility of internal erosion may occur which tends to a slope failure. Furthermore, the velocity vectors comes out from the foundation with seepage flux of order $5.728 \times 10^{-4}$ $ft^3$/sec/ft and joins the downstream shell and increases the pore water pressure respectively. Extremely high exit gradient of order 1.788 was recorded in this case which indicates that dam is not safe against piping. Complete analysis results were elaborated in Table 2 respectively. Similar results were observed by (Khattab, 2010), during the case study of Mosul dam, who also computed seepage flux and exit gradient along with phreatic line behaviour for different scenarios.

**Table 2. Computed seepage flux and exit gradient at homogeneous section with and without filter drain for different pond levels**

| **Parameters** | **Upstream Pond Levels** | | | | | |
|---|---|---|---|---|---|---|
| | **With Filter Drain** | | | **Without Filter Drain** | | |
| | **Minimum** | **Normal** | **Maximum** | **Minimum** | **Normal** | **Maximum** |
| | **270 (ft.)** | **339 (ft.)** | **346 (ft.)** | **270 (ft.)** | **339 (ft.)** | **346 (ft.)** |
| Seepage flux ($ft^3$/sec/ft) | $2.513 \times 10^{-4}$ | $3.571 \times 10^{-4}$ | $3.961 \times 10^{-4}$ | $3.381 \times 10^{-4}$ | $4.988 \times 10^{-4}$ | $5.728 \times 10^{-4}$ |
| Exit gradient | 0.351 | 0.414 | 0.517 | 1.015 | 1.264 | 1.788 |

Figures 6 and 7 showed a graphical relationship between seepage flux and exit gradient at different pond levels when the dam is with or without filter drain respectively. The graphs showed that seepage flux through the dam and its foundation was found (25.672% – 30.848%) more when there is no filter drains on the downstream face of the dam. This is due to the continuous movement of the water within the dam especially in the downstream shell is more, as there is no free passage to pass internal pore water to the drain collectors, the water from upstream shell and foundation finds its way moving towards the downstream shell and cuts the shell to make its way out respectively. On the other hand, the absence of filter drain increases the exit gradient for about (65.419% – 71.085%) due to which at the downstream high exit gradient was recorded. Though in both cases for exit gradient non-linear behavior was observed but due to excessive water pressure within the dam without filter drain, the exit gradient at the downstream toe abruptly changed during different scenarios. For the case of Hub dam, if the homogeneous section of the dam is without filter drain then it can face the piping problem as the phreatic line pattern does not follow the standard design criterion and due to excessive exit gradient internal erosion may occur, which may tends to a slope failure. The results are according to the findings of (Nasim, 2007) and (Arshad *et al.,* 2017), who also observed same trend for seepage flux and exit gradient for Al-Adhaim and Hub dam respectively.

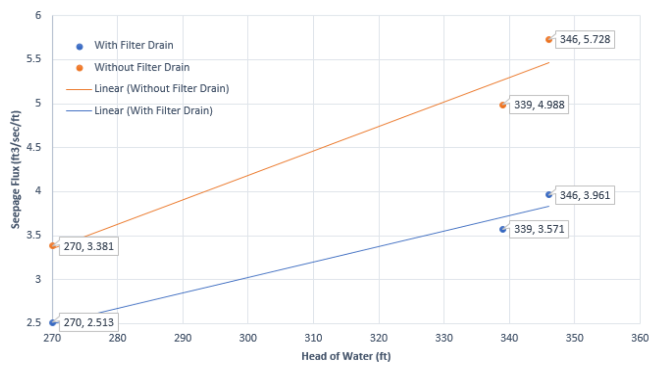


**Fig. 6. The relationship between seepage flux at different pond levels when the dam is with and without filter drain.**

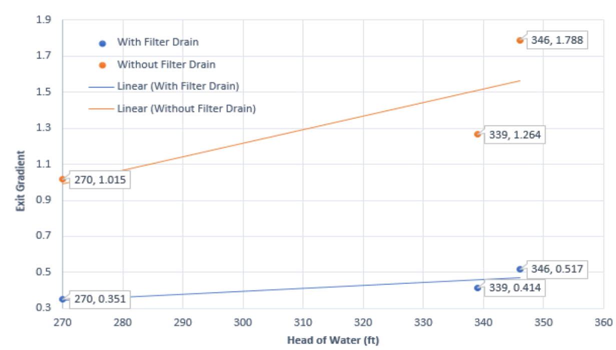


**Fig. 7. The relationship between exit gradient at different pond levels when the dam is with and without filter drain.**

## CONCLUSION

In present research work, the sub program of Geo-Slope Software (SEEP/W), was used to develop a homogenous earth dam and for this purpose Hub dam was selected. Two different cases i.e. (i) with filter drain and (ii) without filter drain was studied to check the behavior of the dam in terms of seepage flux and exit gradient respectively. The software was also used to simulate the phreatic line behavior for both cases. The outcome of the simulated results showed that the dam is safe against piping, at its original design as the presence of filter drain has a positive effect on reducing internal water pressure within the dam. For case (i), the phreatic line showed a normal trend as it is falling into the filter drain with overall minimum seepage flux of 2.513 x $10^{-4}$ $ft^3$/sec/ft and exit gradient at downstream toe 0.351 respectively. In addition to this for each scenario the equipotential lines and stream lines are also found normal to each other. However, for case (ii) the dam showed an abnormal behavior as an extremely high exit gradient was observed for all the scenarios. The phreatic line trend was also found abnormal as it cuts the downstream slope of the dam. Hence, it can be concluded that filter drain especially in earth dams plays a key role to control the phreatic line trend and exit gradient by reducing the internal pore water pressure within the dam body and to save the dam from downstream slope failure respectively.

## ACKNOWLEDGEMENTS

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## CONFLICT OF INTEREST

All the authors have declared that no conflict of interest exists.

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