psm Journals

International Journal of
Alternative Fuels and Energy

Research Article 2023 | Volume 7 | Issue 1 | 1-14

The Impact of Cut-off Wall Length on Seepage Characteristics of a Non-Homogeneous Earth Dam Evaluated with a Geo-Slope Finite Element Software

Imran Arshad*

SAA Technical & Specialized Services Establishment, Abu Dhabi, United Arab Emirates.

Open Access
Article Information

Received: April 11, 2023

Accepted: April 21, 2023

Published: April 30, 2023

Keywords
SEEP/W model,
Phreatic-line,
Cut-off wall,
Finite Element Analysis,
Hub Dam.

How to cite
Arshad, I., 2023. The Impact of Cut-off Wall Length on Seepage Characteristics of a Non-Homogeneous Earth Dam Evaluated with a Geo-Slope Finite Element Software. Int. J. Altern. Fuels. Energy., 7(1): 1-14.

***Correspondence**
Imran Arshad
Email:
engr_imran1985@yahoo.com

Possible submissions
Submit your article

Abstract:
Embankment dams have better stability than homogeneous earth dams, resulting in a slimmer design in volume. The core zone, which serves as an impermeable zone, is where embankment dams are weak. Zonal core embankment dams are a composite of several material characteristics. Due to the intricacy of the geometry, the material parameters, and the boundary conditions, drainage and geometric design will have an impact on seepage and phreatic line properties. In this study three geometric models of a non-homogenous earth dam (Hub dam) depict along with three different scenarios i.e. (i) original design, (ii). Dam with a partial cutoff wall, (iii). Dam with a full cutoff wall was numerically analyzed by using Geo-Slope (SEEP/W) software. The results indicate that the cutoff wall at its original shape and design performs better as the minimum seepage value of order 2.2117 x 10^{-4} (ft^3/sec/ft) with an exit gradient of (0.099) and minimum seepage velocity 1.0020 x 10^{-6} (ft/sec) at 270 ft reservoir level. Any increment in the length of cutoff wall will be uneconomical as it does not make much difference to minimize seepage flux, seepage velocity, and exit gradient. For the majority of flow characteristics, the cutoff wall's length plays a very limited role therefore, it can be said that the Hub Dam has operated efficiently since its construction in accordance with its original form and design.

Scan QR code to visit this journal.

INTRODUCTION

Dams are built all over the world to contain water in large quantities, protect homes from flooding, alter the course of streams, create hydroelectricity, hold water back for agriculture during the dry season, and other purposes (Kamanbedast *et al.,* 2012). Embankment dams have better stability than homogeneous earth dams, thus enabling a leaner physical design in volume. The core zone of the embankment dam, which serves as an impermeable zone, is where the dam's weakness rests. An embankment dam with a zonal core composed of different material qualities (Al-Damluji *et al.,* 2004). The geometric design of the dam will influence seepage and phreatic line properties that occur due to the complexity of geometry, material parameters and boundary conditions. Thus, the calculation is not as simple as in a homogeneous soil fill dam. Reservoir inundation is a critical stage in an embankment type dam. At this stage, the embankment material will change due to the influence of additional water loads in the reservoir (Arshad *et al.,* 2019).

A non-homogenous type of dam that has an impermeable core in the form of a layer of clay standing upright in the middle of the dam body. The dam was built through a process of stockpiling several materials in the form of gravel, rock, sand and soil which were formed with a certain slope and height so that they could inhibit or raise the water level in the upstream (Irzooki, 2016). Dams with the type of embankment are very susceptible to collapse due to hydrostatic water pressure, pore-water pressure and earthquake loads received as well as from the geometry of the dam itself (Moayed *et al.,* 2012). Therefore, slope stability and water seepage discharge in the dam body need to be analyzed so that the dam construction is safe from potential landslides.

The dam structure must be analyzed in such a way as to produce an optimal design to withstand the loads acting on the structural elements (Malekpour *et al.,* 2012). Calculation of these loads must be calculated using a numerical method, namely the finite element method. In principle, the finite element method divides a continuum into smaller parts called elements, so that the solution in each small part can be solved more simply. The results of the analysis will show the possibility of landslides or erosion in parts / areas of the dam body, either upstream or downstream (Alnealy *et al.,* 2012). Thus, it is necessary to analyze seepage and stability with pre-construction loading conditions, minimum water level, and maximum water level analysis. The problem of the destruction of the dam structure can be caused because the structure is not strong enough to withstand horizontal and vertical loads around it (Mansuri *et al.,* 2013).

Researchers around the globe have proposed a various range of remedies to decrease the failure caused by seepage. A zonal earth dam's supply of a clay core, clay blanket, and chimney filter can control the seepage through the dam body (Osuji *et al.,* 201). A common practice around the world is to provide a cutoff wall made of an impermeable substance to lower the seepage through the foundation. Installation of a cutoff wall or sheet pile can be used to control the reduction of exit gradient and seepage flux (Parsaie *et al.,* 2018). A thorough study is still absent, even though numerous studies have been considered so far to decrease seepage utilizing vertical cut off walls (Arshad *et al.,* 2017). To analyze the seepage flow, exit gradient, and maximum seepage velocity through the body and the foundation of a non-homogeneous earth dam, a detailed numerical research has been carried out in this study.

MATERIALS AND METHODS

Location of the Dam

The present research work is undertaken for seepage modeling of the (Hub dam) earth dam, which located on the Hub River 35 km, northwest of Karachi city, Sindh-Pakistan. The profile of the dam axes is elaborated in Fig 01(WAPDA, 2009).

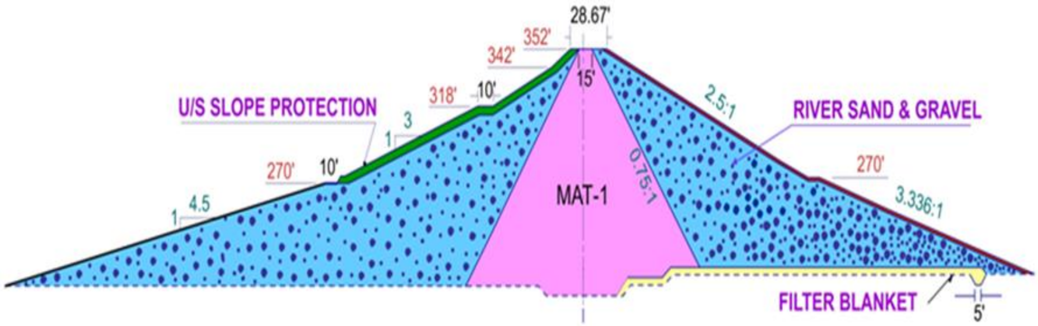

Fig. 1. Cross-section of Non-Homogeneous Section of Hub dam.

Numerical Model

For numerical analysis, three geometric models of a non-homogenous earth dam (Hub dam) depict along with three different scenarios i.e. (i) original design, (ii). Dam with a partial cutoff wall, (iii). Dam with a full cutoff wall respectively. The numerical model was created using Geo-Slope (SEEP/W) software and the steady state analysis was selected to simulate the hydraulic conditions beneath the dam foundation (Arshad, 2018). The geometry of the dam in the SEEP/W model is presented in (Figure 2a – 2c). The model's sections were divided into segments (elements) using a quad and triangle meshing method. A mesh of 957 nodes, 901 elements, and an approximate global element area size of 20ft. was created. These meshing approaches select to give accurate analysis for the soil elements underneath dam foundation (Stark, 2017). A saturated case was selected for the model in regards to construction and soil materials; it was chosen because it was ideal for a steady state analysis and was a domain that would remain saturated for the duration of the simulation (Khattab, 2010).

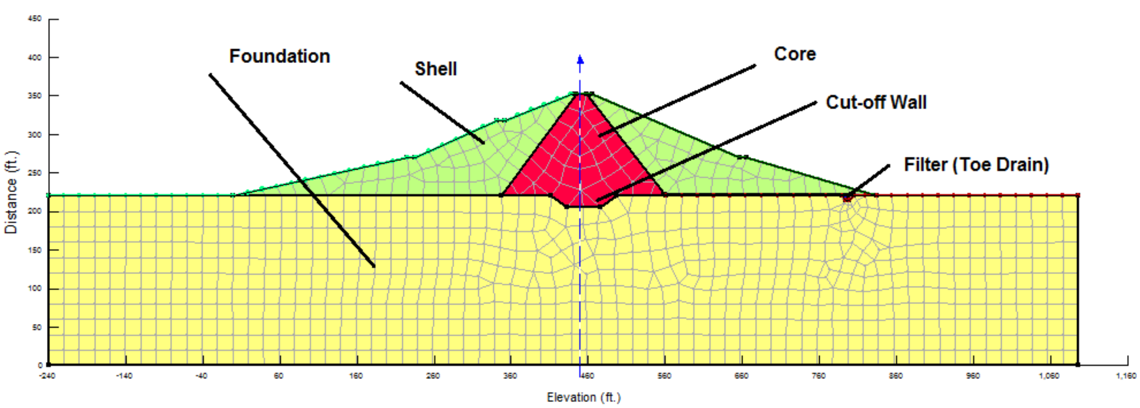

Fig. 2a. The SEEP/W Mesh for a non-homogeneous section of a Hub Dam (original design).

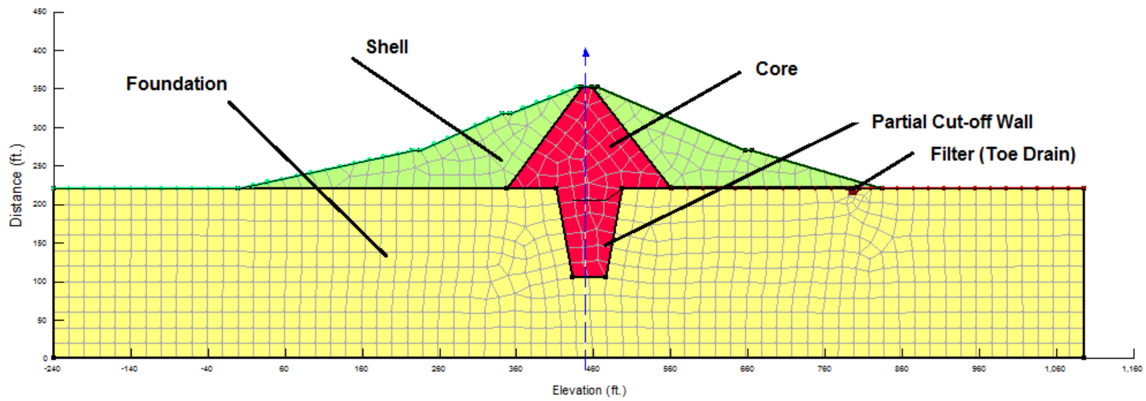

Fig. 2b. The SEEP/W Mesh for a non-homogeneous section with Partial Cutoff Wall

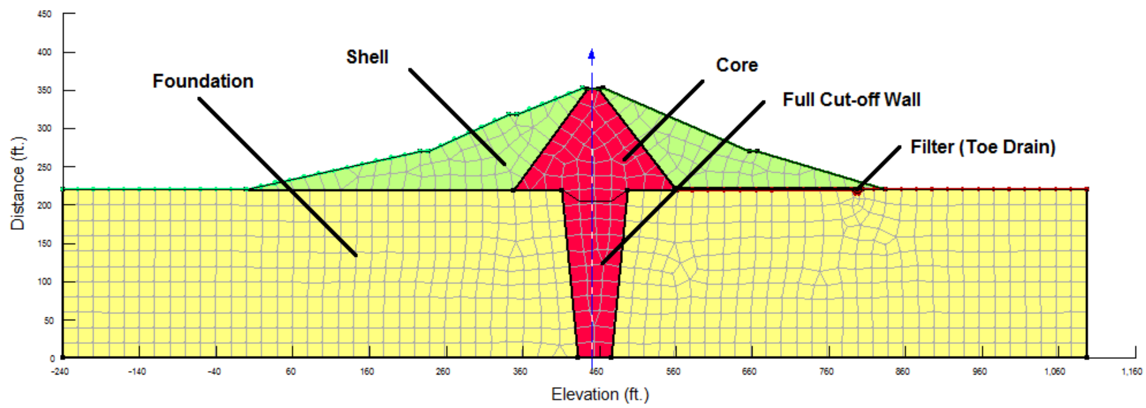

Fig. 2c. The Seep/W Mesh for a Non-Homogeneous Section with Full Cut-Off Wall

In order to formulate the model various coefficient and parameters were entered into the software respectively. The interface materials used for conductivity equaled zero (the dam structure and cutoff wall). A Dirichlet and Neumann boundary node was assigned on the upstream and downstream slope of the dam (Arshad *et al.,* 2014). Free water means the upstream side are open and the increasing in water quantity are expected. The performance of dam was studied for three different scenarios i.e. (i) original design, (ii). Dam with a partial cutoff wall, (iii). Dam with a full cutoff wall at various reservoir levels i.e. EL 270 ft., 339 ft., and 342 ft., respectively. The comparison of numerical simulations is discussed for cutoff wall accordingly (Baghalian *et al.,* 2012). Figure 2(a) represents an earth dam at its original shape and design. Figure 2(b) represents an earth dam with a partial cutoff wall and figure 2(c) represents an earth dam with a full cutoff wall. The core of the dam comprised of a silt-clay and the foundation of the dam consists of fine sand, coarse sand, gravel, and impervious rock respectively (Nasim, 2007). The cutoff wall was also filled with the same material as of a clay-core respectively. For analytical purposes, the saturated condition of the earth dam is considered. Table 1 contains the hydraulic conductivities of materials. All the cases, mentioned above, are performed separately.

Table 1. Hydraulic Conductivities used for Modeling.

Type of Material Used in Modeling	Hyd. Conductivity (ft/sec)	
	***Guess Values**	**Calibrated Values**
Foundation	1×10^{-6}	3×10^{-6}
Shell	1×10^{-6}	2×10^{-5}
Core	1×10^{-7}	2×10^{-8}
Cutoff wall	1×10^{-7}	2×10^{-8}
Filter Drain	1×10^{-2}	3×10^{-2}

*Source: Water and Power Development Authority - Pakistan

Governing Equations used by SEEP/W Software

1. Darcy's Law

Darcy's law should be applied as follows, in case saturated and unsaturated flow conditions occur.

$$q = Aki \quad (1.1)$$

$$v = \frac{q}{A} = ki \quad (1.2)$$

where;

q = a specific discharge;

A = a cross-section area;

k = a permeability; and

i = a hydraulic gradient.

Further, a differential equation (i.e., Laplace's equation) should be used to estimate seepage flow two-dimensionally in steady state analyses as follows.

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial H}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_x \frac{\partial H}{\partial y}\right) + Q = \frac{\partial \theta}{\partial t} \quad (1.3)$$

Where;

H = a total head,

Kx = a horizontal conductivity,

Ky = a vertical conductivity, and

Q = flux.

2. Basic Finite Element Equation

The basic finite element equation (i.e., the general finite element method) should be applied to SEEP/W simulation models as follows.

$$[k]\{H\} = \{Q\} \quad (1.4)$$

Where;

K = a node's material properties,

H = a node's total head, and

Q = water flow at a node.

3. Definitions of Total Head (H)

SEEP/W formulates in terms of total head, and boundary conditions are specified according to this value. This parameter should be calculated as follows.

$$H = \frac{u}{rw} + h \quad (1.5)$$

Where;

H = total head;

U = pressure head; and

h = elevation head.

Total head (H) = pressure head (*u*) + elevation head (*h*).

RESULTS AND DISCUSSION

Flow-net, equipotential lines, phreatic line, and velocity vectors

The SEEP/W program is utilized for seepage analysis for a hub dam embankment and its establishment for various reservoir level situations to obtain invasive information (Arshad *et al.,* 2014). For this reason, utilizing the product flow net has been drawn to the chosen area and for various rises as appeared in Fig. (3a) to – Fig. (5f). The performance of dam was studied for three different cases i.e. (i) original design, (ii). Dam with a partial cutoff wall, (iii). Dam with a full cutoff wall at different reservoir levels i.e. maximum (346 ft.), normal (339 ft.) and minimum (270 ft.) respectively. The comparison of numerical simulations is discussed for cut-off wall (Doherty, 2009). The flow net includes streamlines, equipotential lines, speed. Vectors representing prevailing land stream (seepage) and phreatic line representing the Hub dam's seepage behavior. It is evident from the results that seepage is occurring through the dam foundation, so a proper remedial measure is required to eliminate the seepage through the dam body.

Case I. Non-Homogeneous Section at original shape and design

The behavior of the dam at the time of its construction for different scenarios i.e. reservoir level (270 ft.), (339 ft.), and (346 ft.), the phreatic line and flow direction of the water shows a non-linear behavior. The phreatic line (blue colour line) after passing the central core suddenly drops where the filter drain is provided. The seepage flux of order 2.2117 x 10^{-4} (ft^3/sec/ft), 5.6064 x 10^{-4} (ft^3/sec/ft), and 5.7477 x 10^{-4} (ft^3/sec/ft) with an exit gradient of 0.099, 0.188, and 0.317 was observed for a reservoir levels corresponding to 270 ft., 339 ft., and 346 ft. respectively. Likewise, the maximum seepage velocity at various reservoir levels i.e. 270 ft., 339 ft., and 346 ft. was found 1.002 x 10^{-6} (ft/sec), 2.4900 x 10^{-6} (ft/sec), and 3.0240 x 10^{-6} (ft/sec) respectively. At different water levels, the pore water pressure decreased almost linearly, indicating that steady state flow takes place in all parts of the dam body. Water level fluctuations affected the upstream of the dam more rapidly and reduction of pressure occurred at a higher rate. Due to the low velocity of water drainage inside the clay core materials, the least change in the amount of pore water pressure occurred within the core (Omofunmi *et al.,* 2017).

The obtained results were consistent with the studies of (Aasma, 2016) [22]. At all points in the downstream slope, the exit hydraulic gradient was less than unity therefore; the dam is safe against piping. The different color contours represent that the total head will be same at any node. The flow paths (green colour lines) are an imaginary droplet of water which follows from the entrance to exit accordingly (Arshad *et al.,* 2019). In a flow net, the amount of flow between each flow line was observed the same; i.e. the amount of flow is the same in each flow channel. Figure (3a–3f), describes the SEEP/W simulated results for the case (I) at different reservoir levels.

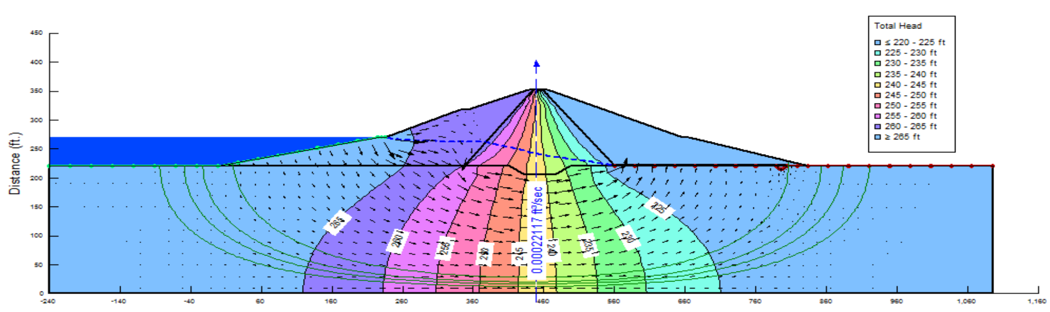

Fig. 3a. SEEP/W model results for Non-Homogeneous Section (Reservoir level = 270 ft).

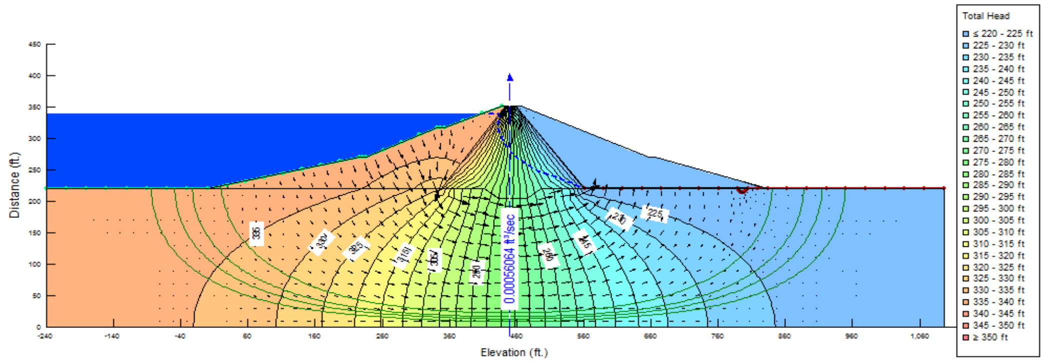

Fig. 3b. SEEP/W model results for Non-Homogeneous Section (Reservoir level = 339 ft).

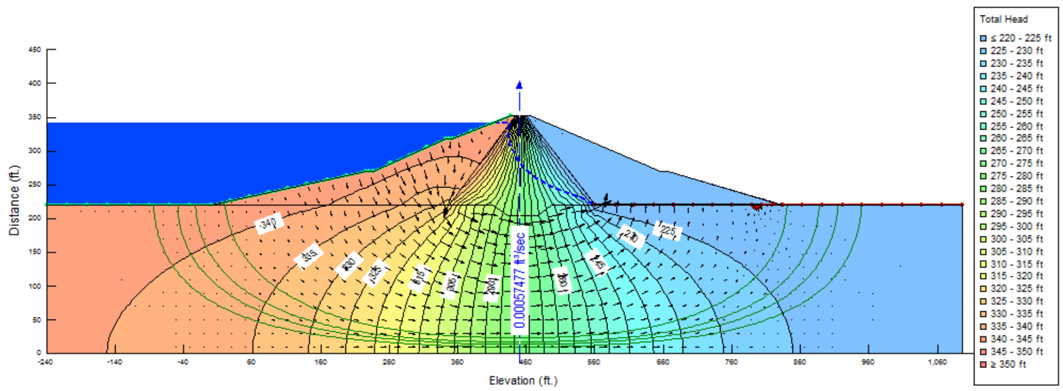

Fig. 3c. SEEP/W model results for Non-Homogeneous Section (Reservoir level = 346ft).

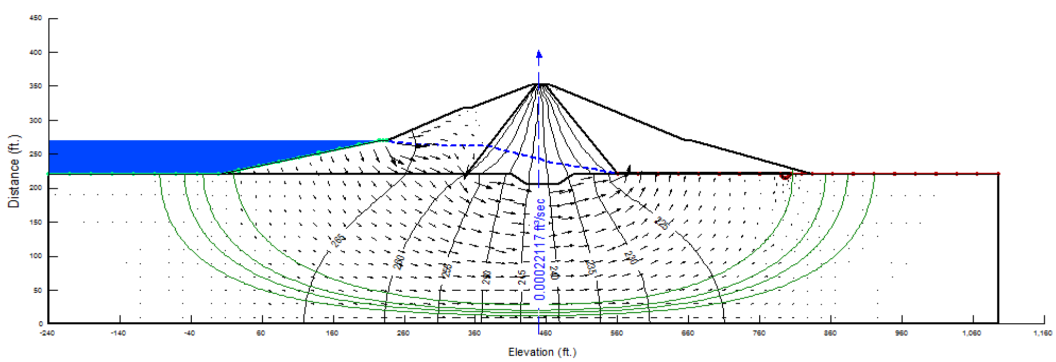

Fig. 3d. Phreatic Line behaviour for Non-Homogeneous Section (Reservoir level = 270 ft).

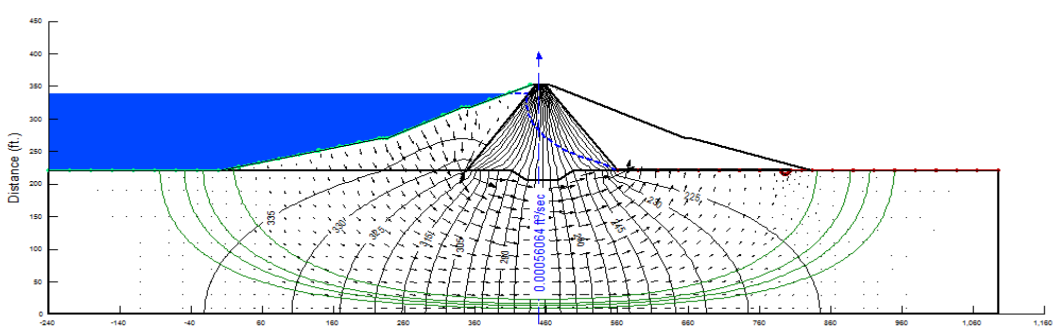

Fig. 3e. Phreatic Line behaviour for Non-Homogeneous Section (Reservoir level = 339 ft).

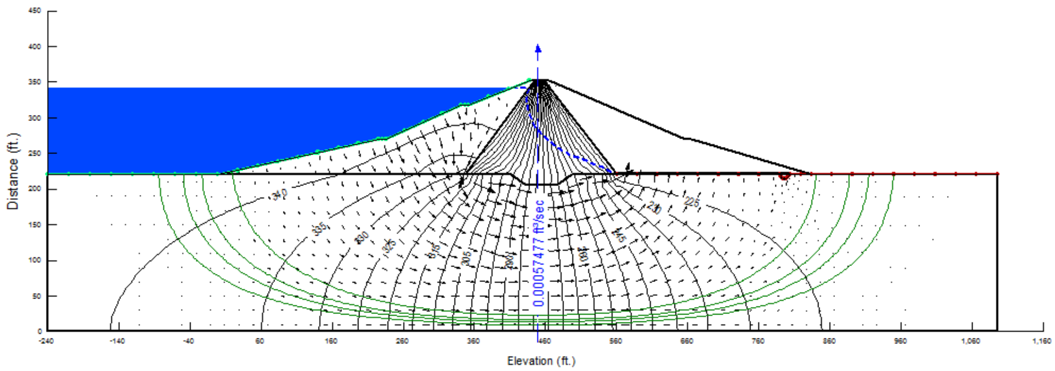

Fig. 3f. Phreatic Line behaviour for Non-Homogeneous Section (Reservoir level = 346ft).

Case II. Non-Homogeneous Section with a partial cutoff wall

Likewise, the seepage analysis was performed for a non-homogeneous section with a partial cutoff wall under steady-state condition for a different water reservoir levels. The results showed that for each water reservoir level (270 ft., 339 ft., and 346 ft.) the seepage flux of order 1.5441×10^{-4} (ft^3/sec/ft), 3.8143×10^{-4} (ft^3/sec/ft), and 3.9105×10^{-4} (ft^3/sec/ft) with an exit gradient (0.089), (0.157), and (0.299) was observed respectively. Likewise, the maximum seepage velocity at various reservoir levels i.e. 270 ft., 339 ft., and 346 ft. was found 0.911×10^{-6} (ft/sec), 2.251×10^{-6} (ft/sec), and 2.899×10^{-6} (ft/sec) respectively (Jamel, 2016). Figure (4a–4f), describes the SEEP/W simulated results for the case (III) at different reservoir levels.

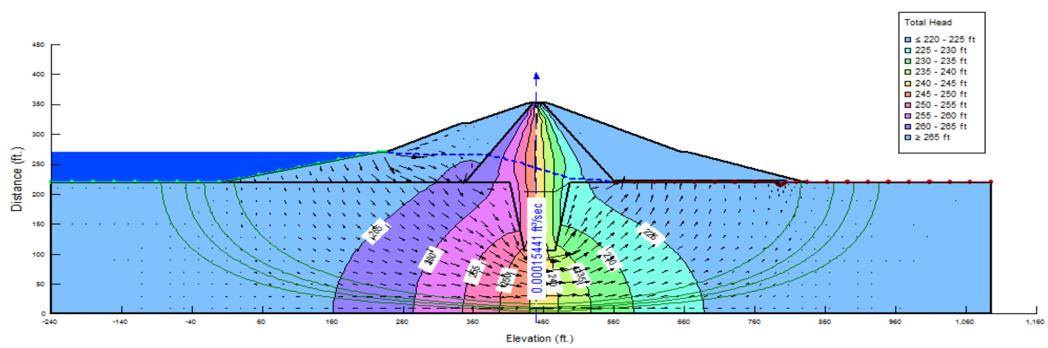

Fig. 4a. SEEP/W model results for Non-Homogeneous Section with Partial cut-off wall (Reservoir level = 270 ft).

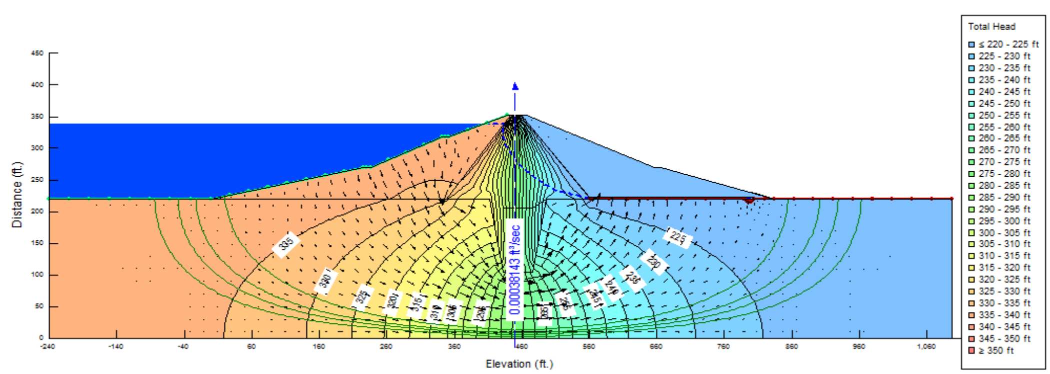

Fig. 4b. SEEP/W model results for Non-Homogeneous Section with Partial cut-off wall (Reservoir level = 339 ft).

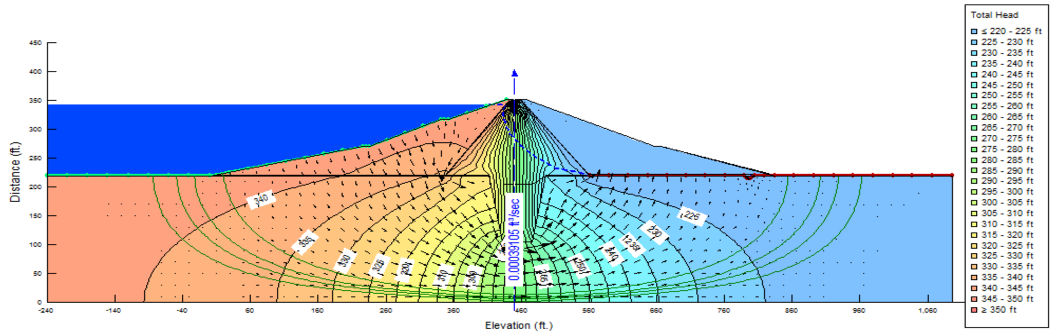

Fig. 4c. SEEP/W model results for Non-Homogeneous Section with Partial cut-off wall (Reservoir level = 346ft).

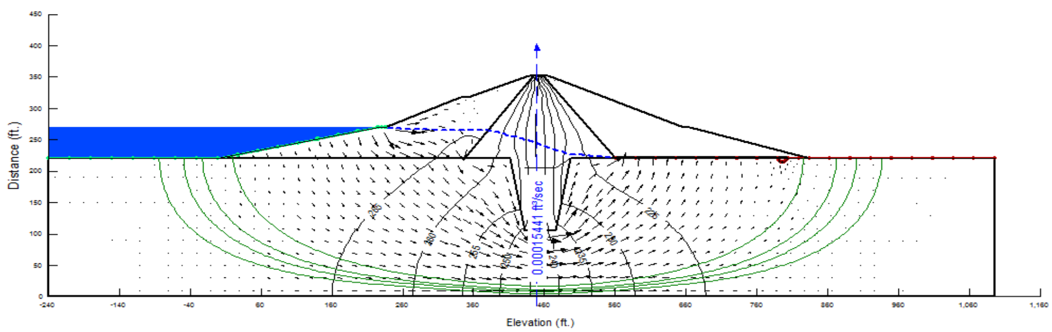

Fig. 4d: Phreatic Line behaviour for Non-Homogeneous Section without partial Cut-off wall (Reservoir level = 270 ft).

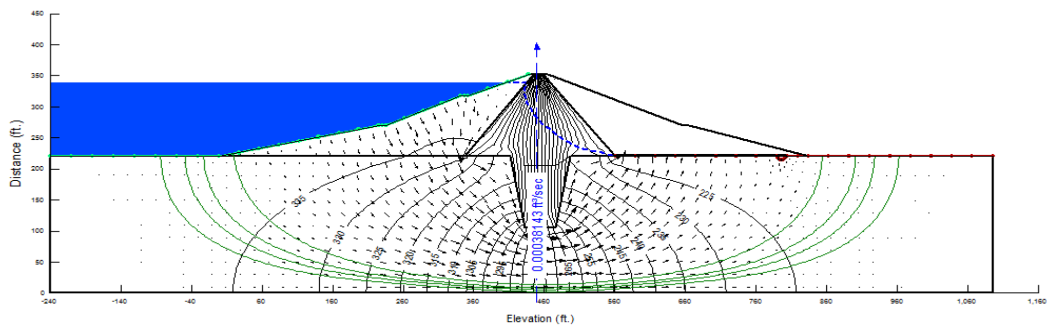

Fig. 4e: Phreatic Line behaviour for Non-Homogeneous Section without partial Cut-off wall (Reservoir level = 339 ft).

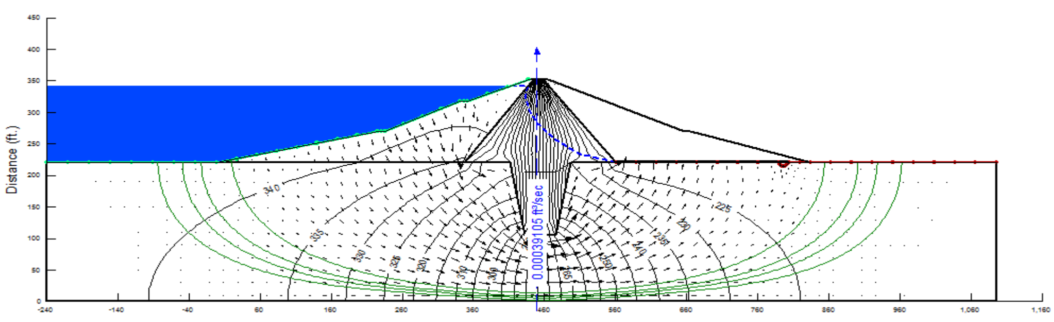

Fig. 4f: Phreatic Line behaviour for Non-Homogeneous Section without partial Cut-off wall (Reservoir level = 346 ft).

Case III. Non-Homogeneous Section with a full cutoff wall

Similarly, the seepage analysis was performed for a non-homogeneous section without cutoff wall and a filter drain under steady-state condition for a different water reservoir levels. The results showed that for each water reservoir level (270 ft., 339 ft., and 346 ft.) the seepage flux of order 0.20689 x 10^{-4} (ft^3/sec/ft), 0.49549 x 10^{-4} (ft^3/sec/ft), and 0.50798 x 10^{-4} (ft^3/sec/ft) with an exit gradient (0.081), (0.141), and (0.285) was observed respectively. Likewise, the maximum seepage velocity at various reservoir levels i.e. 270 ft., 339 ft., and 346 ft. was found 0.7899 x 10^{-6} (ft/sec), 1.859 x 10^{-6} (ft/sec), and 2.353 x 10^{-6} (ft/sec) respectively.

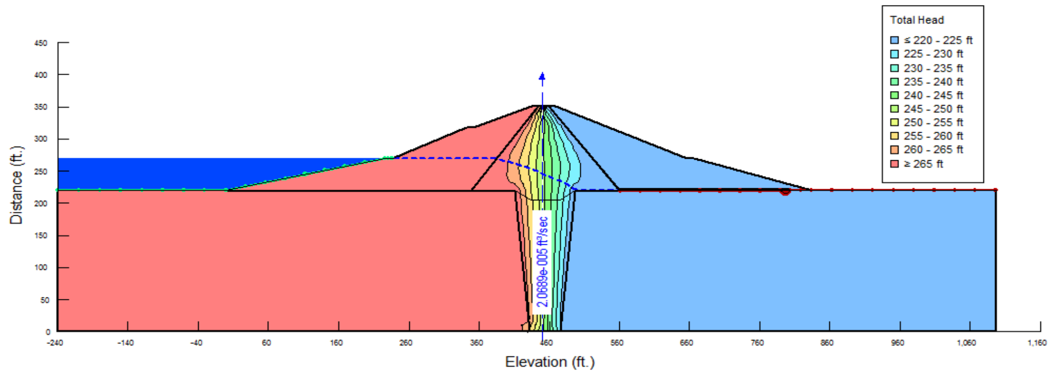

Fig. 5a. SEEP/W model results for Non-Homogeneous Section with full cut-off wall (Reservoir level = 270 ft).

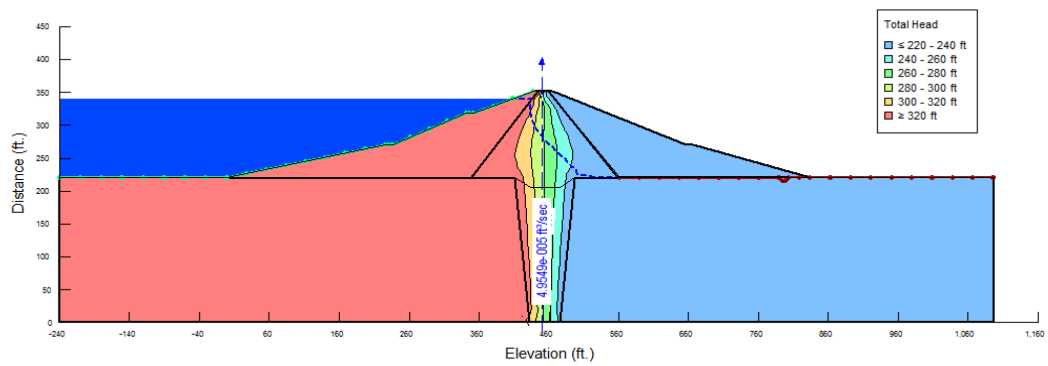

Fig. 5b. SEEP/W model results for Non-Homogeneous Section with full cut-off wall (Reservoir level = 339 ft).

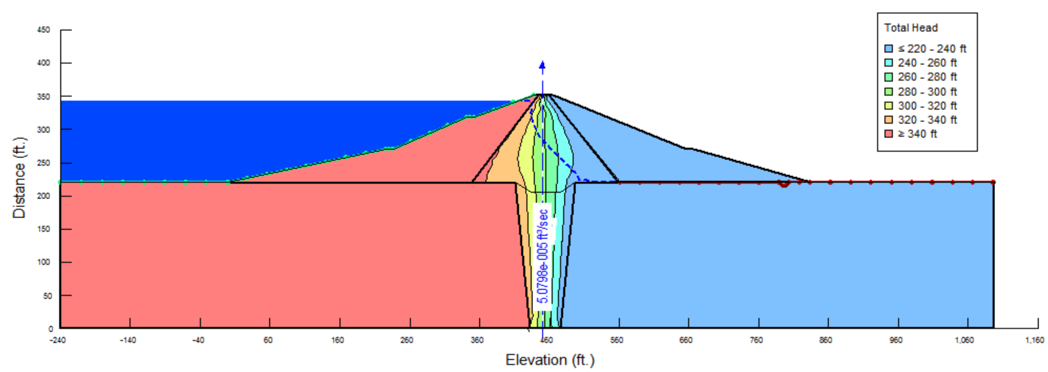

Fig. 5c. SEEP/W model results for Non-Homogeneous Section with full cut-off wall (Reservoir level = 346ft).

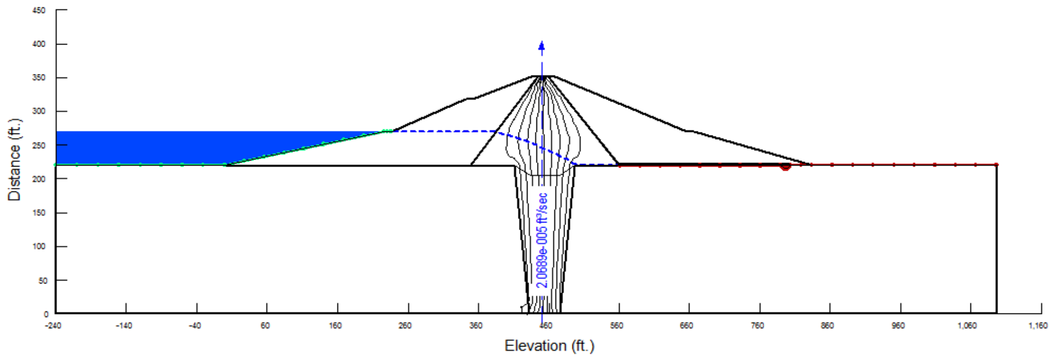

Fig. 5d. Phreatic Line behaviour for Non-Homogeneous Section without full Cut-off wall (Reservoir level = 270 ft).

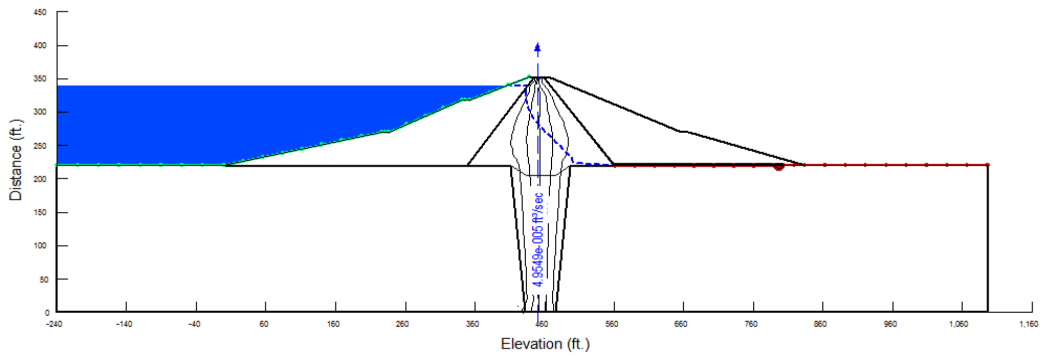

Fig. 5e: Phreatic Line behaviour for Non-Homogeneous Section without full Cut-off wall (Reservoir level = 339 ft).

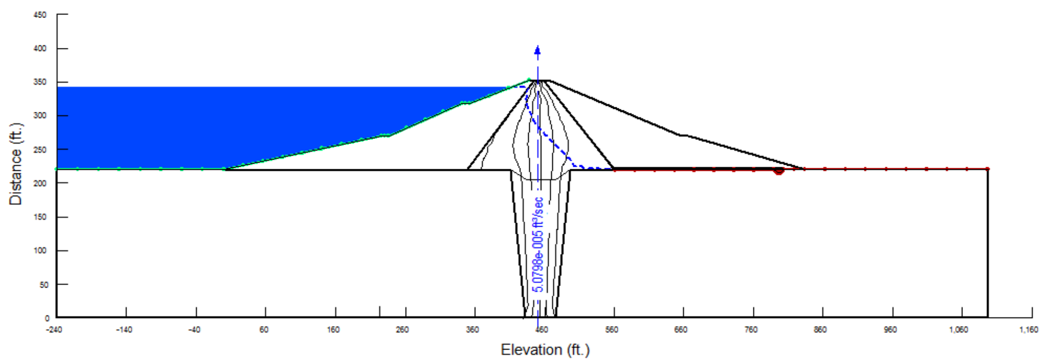

Fig. 5f: Phreatic Line behaviour for Non-Homogeneous Section without full Cut-off wall (Reservoir level = 346 ft).

The comparison of all three scenarios showed that partial and full cutoff wall does not make much difference to minimize seepage and exit gradient respectively. Therefore, it indicates that there is no possibility found for a downstream slope failure (Issam *et al.,* 2020). In addition to this, the seepage flow line behavior for all the scenarios were found normal as it passes the core and falls into the filter drain respectively. Similar results were obtained by (Aasma *et al.,* 2016) for the case non-homogeneous earth dam. Figure (5a–5f), describes the SEEP/W simulated results for the case (**III**) at different reservoir levels.

Table 2. The SEEP/W model results of Hub dam for different water levels in reservoir.

Parameters	**Upstream Reservoir levels**								
	Dam with original design			**Dam with partial cut-off wall**			**Dam with full cut-off wall**		
	270 (ft.)	**339 (ft.)**	**346 (ft.)**	**270 (ft.)**	**339 (ft.)**	**346 (ft.)**	**270 (ft.)**	**339 (ft.)**	**346 (ft.)**
Seepage flux x 10^{-4} (ft3/sec/ft)	2.2117	5.6064	5.7477	1.5441	3.8143	3.9105	0.2069	0.4955	0.5080
Exit gradient	0.0990	0.1880	0.3170	0.0890	0.1570	0.2990	0.0810	0.1410	0.2850
Max. Seepage Velocity x 10^{-6} (ft/sec)	1.0020	2.4900	3.0240	0.9110	2.2510	2.8990	0.7899	1.8590	2.3530

For the current case it seems that partial cutoff wall and full cutoff wall doesn't make much difference in lowering the seepage and exit gradient as the same trend was observed for all the scenarios. Figure (6a – 6c) explains a graphical relationship for seepage flux, exit gradient and maximum seepage velocity as a function of elevations, respectively (Arshad *et al.,* 2020).

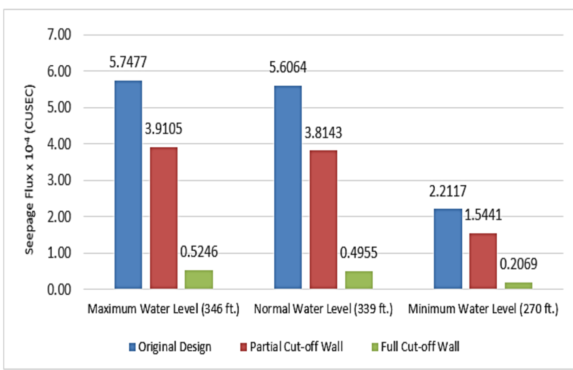

Fig. 6a. Relationship between water level in reservoir vs. seepage flux for various scenarios.

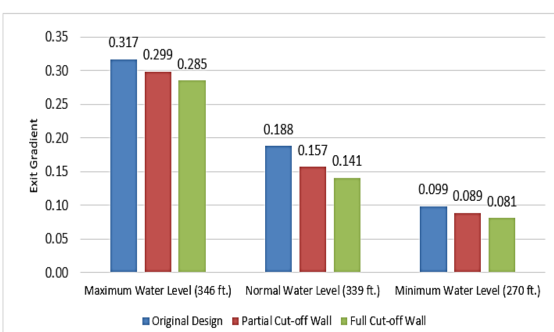

Fig. 6b. Relationship between water level in reservoir vs. exit gradient for various scenarios.

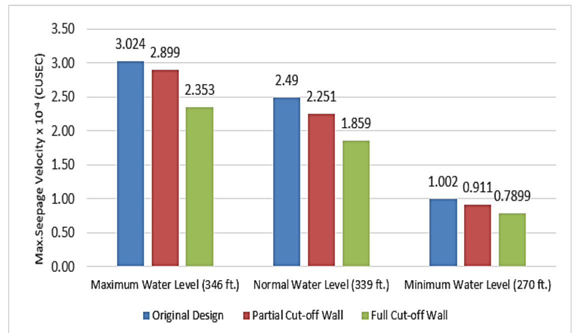

Fig. 6c. Relationship between water level in reservoir vs. Maximum Seepage Velocity for various scenarios.

CONCLUSION

The analysis of the finite element method of the non-homogeneous dam results in the conclusion that the Geo-Slope (SEEP/W) software is capable to produce flow parameters i.e. velocity, discharge, total head, and a free surface line (seepage flow line). In addition, the analysis carried out on each element is recommended using the results of the calculation of the flow-net diagram method. Based on results obtain, it could be concluded that the length of the cutoff wall plays an essential role to protect the dam from the seepage problem. Use of partial cut-off and full cut-off wall may not contribute much to lower the various flow parameters respectively. These results also indicate that the cutoff wall at its original shape and design performs better and any increment in the length of cutoff wall will be economical. The role of the length of the cutoff wall is almost negligible for most of the flow parameters. Hence, it can be concluded that Hub dam performed effectively since its construction at its original shape and design.

ACKNOWLEDGMENT

The authors wish to express their gratitude to WAPDA Pakistan (Water and Power Development Authority) officials deputed at Hub dam especially to the Resident Engineer, Mr. Arif and all other individuals who have been source of help throughout the research period.

CONFLICT OF INTEREST

The authors declare that this article's content has no conflict of interest.

REFERENCES

Aasma, A.J.J., 2016. Analysis and Estimation of Seepage through Homogenous Earth Dam without Filter. Diyala J. Eng. Sci., 9(2): 83-94.

Al-Damluji, O.A., Fattah, M., Al-Adthami, R.A., 2004. Solution of Two-Dimensional Steady-State Flow Field Problems by the Boundary Element Method. J. Eng. Tech., 23(12): 750-766.

Alnealy, H.K.T., Alghazali, N.O.S., 2015. Analysis of Seepage Under Hydraulic Structures Using Slide Program. Amer. J. Civ. Eng., 3(4): 116-124.

Arshad, I., Babar, M.M., 2020. Finite Element Analysis of Seepage and Exit Gradient through a Homogeneous Earth Dam without Cut-Off Walls by using Geo-Slope (SEEP/W) Software. PSM Biol. Res., 5(3): 117-125.

Arshad, I., Babar, M.M., Vallejera, C.A., 2019. Computation of Seepage and Exit Gradient through a Non-Homogeneous Earth Dam without cut-off walls by using Geo-Slope (SEEP/W) Software. PSM Biol. Res., 4(1): 40-50.

Arshad, I., Babar, M.M., Vallejera, C.A., 2019. Numerical Analysis of Seepage and Exit Gradient through a Non-Homogeneous Earth Dam without Impervious Core by using Geo-Slope Software. Int. J. Altern. Fuels. Energy., 3(1): 1-12.

Arshad, I., 2018. Finite Element Analysis of Seepage and Exit Gradient underneath Jinnah Barrage Weir Foundation by Using Geo-Slope (Seep/W) Software. Published in Int. J. Altern. Fuels. Energy., 2(1): 1-13.

Arshad, I., Babar, M.M., Javed, N., 2017. Numerical Analysis of Seepage and Slope Stability in an Earthen Dam by Using Geo-Slope Software. PSM Biol. Res., 2(1): 13-20.

Arshad, I., Baber, M.M., 2014. Finite Element Analysis of Seepage through an Earthen Dam by using Geo-Slope (SEEP/W) software. Int. J. Res., 1(8): 612-619.

Arshad, I., Baber, M.M., 2014. Comparison of SEEP/W Simulations with Field Observations for Seepage Analysis through an Earthen Dam. Int. J. Res., 1(7): 67-79.

Arshad, I., 2013. Finite Element Analysis of seepage through Hub Dam by using Geo-Slope Software. M.E Thesis, (IWREM), MUET Jamshoro, Pakistan.

Baghalian, S., Nazari, F., Malihi, S.S., 2012. Analysis and Estimation of Seepage Discharge in Dams. Int. J. Eng. App. Sci., 4(3): 49-56.

Doherty, D., 2009. Design and Construction of Earth Dams: A Primer on Dam Design. Retrieved from http://www.earthactionmentor.org/categories/earthworks_landform, October 03.

Issam, R., Bachir, B., Abdelaziz, R., Arshad, I., 2020. Computation of Seepage through a Non-Homogeneous Earth Dam by Using (SEEP/W) Software. PSM Biol. Res., 5(4): 137-146.

Irzooki, R.H., 2016. Computation of Seepage through Homogenous Earth Dams with

Horizontal Toe Drain. Eng. and Tech. J., 34(3): 430-440.

Jamel, A.A.,2016. Analysis and Estimation of Seepage through Homogeneous Earth Dam without Filter. Diyala J. of Eng. Sci., 9(2): 38-49.

Kamanbedast, A., Delvari, A., 2012. Analysis of Earth Dam: Seepage and Stability Using Ansys and GeoStudio Software. World App. Sci. J., 17(9): 1087-1094.

Khattab, S.A.A., 2010. Stability Analysis of Mosul Dam under Saturated and Unsaturated Soil Conditions. Al-Rafidain Eng. J., 18(1): 95-102.

Moayed, R.Z., Rashidian, V.R., Izadi, E., 2012. Evaluation of Phreatic Line in Homogenous Earth Dams with Different Drainage Systems. Civ. Eng. Dept. Imam Khomeini Int. Uni. Qazvin, Iran.

Malekpour, A., Farsadizadeh, D., Dalir, A. H. Sadrekarimi, J., 2012. Effect of horizontal drain size on the stability of an embankment dam in steady and transient seepage conditions. Turk. J. of Eng. and Environ. Sci.,36(2): 139-152.

Mansuri, B., Salmasi, F., 2013. Effect of Horizontal Drain Length and Cutoff Wall on Seepage and Uplift Pressure in Heterogeneous Earth Dam with Numerical Simulation. J. of Civ. Eng. and Urban., 3(3): 114-121.

Nasim, S., 2007. Seepage Analysis of Earth Dams by Finite Elements. M.Sc. Thesis, Collage of Engineering, University of Kufa, Iraq.

Omofunmi, O. E., Kolo, J. G., Oladipo, A. S., Diabana, P. D., Ojo A. S., 2017. A Review on Effects and Control of Seepage through Earth-fill Dam. J. of App. Sci. and Tech., Vol. 22(5): 1-11.

Osuji, S.O., Adegbemileke, S.A., 2015. Phreatic Line and Pore Pressure Stresses in Zoned Rockfill Dam. Asian J. Sci. Tech., 6(5): 1447-1454.

Parsaie, A., Haghiabi A.H., 2018. Prediction of side weir discharge coefficient by radial basis function neural network. J. of Civ. Eng., 4(2): 143-151.

Stark, T.D., Jafari, N.H., Zhindon J.S.L. Baghdady A., 2017. Unsaturated and Transient Seepage Analysis of San Luis Dam. J. of Geotech. and Environ. Eng., 143(2): 112-121.

WAPDA., 2009. 4th Periodic Inspection Report of Hub Dam. Published by ACE – WAPDA.