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Seepage Analysis through an Earth Dam (KHASA-CHAI Dam) as a Case Study

***Abstract**- In this research KHASA-CHAI Dam that consists of zoned embankment was investigated by using finite element method. The finite element computer software SEEP/W was used. Experimental works were done to the soils that enters in the construction of the dam to obtain the different parameters that SEEP/W software need in order to complete the analysis. The dam at its actual design was investigated by considering the water in the reservoir to be at maximum, minimum and half filled with water. Then the control of seepage and exit gradient through the dam were investigated by studying the effect of changes in the construction of the dam. It was concluded that the core in the dam has an important effect on decreasing the seepage quantity through the dam body. The presence of filters in the dam has small effect on increasing seepage quantity, but they have great effect on decreasing exit gradient.*

***Keywords**: Seepage Analysis; Embankment Dams; Finite Element; Khasa-Chai Dam.*

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1. Introduction

One of the main causes of failures for an earth dam is the seepage, which can cause weakening in the dam's structure and followed by sudden failure due to piping or sloughing. Based on the information reported by the National Performance of Dams Program (NPDP) as a study for a workshop on seepage through earth dams, embankment dams often experience seepage problems at the filling stage of the reservoir. Furthermore, seepage damages increases as the age of the structure increase because of corrosion . As the NPDP stated, up to 162 incidents in the dams included either penetrations or outlets. The first 54% of the incidents in the dams were occurred in the last two centuries and the second 46% of the incidents were happened during the last century. The seepage or piping has caused up to 65 incidents and 57 incidents occurred because of corrosion. About 41 dam incidents related seepage with distortions in conduits and generally this rate was considered to be low [1].
A team at University of New South Wales (UNSW) has analyzed another set of data and summarized that up to 50% of the identified failures in the embankments are because of the seepage. Up to 30% of these failures are related with the conduits within the body of the dam [2].
Moreover, the State Dam Safety Programs directed an inspection on conduits for the International Commission on Large Dams (ICOLD). In this study, 14 states were involved and about 1115 dams having conduits were required repairs. About b591, 2b5n6 and 223 dams were made out of corrugated metal pipes, steel and concrete respectively [3].
Seepage that might cause failure to the dam could happen through different positions such as the body of the dam, foundation or from the dam body towards the foundation, from a previous statics Up to 1986 as a study prepared by Foster, et al., on large dams he found that the historical annual probability of failure was (4.5×10-4) per dam-year and this value will be reduced to (4.1×10-4) dam-year if the construction failures are removed from considerations, Table 1 presents the failure of large dams up to year 1986 [4]. The probability of failure had reduced from (10-4) to (10-5) over a period of 30-40 years [5]. In the period from (1831-1930) in Great Britain the probability of failure which causes loss of lives was (3×10-4), and since the introduction of reservoir safety legislation during the 1930 and up to day no failures have occurred which causes loss of lives in Britain [6].
Internally, the development of the erosion could break up to several stages such as erosion initiation and extension, advancement of the erosion to cause piping and finally creation of a crack **[7]**. Many researchers concentrated on studying the problem that could happen to the dams due to seepage.

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Table 1: Probability of failure up to 1986 [4]

Cause of Failures	% of Total Failures
Overtopping	46
Piping through Embankment	31
Piping through Foundation	15
Piping from Embankment to Foundation	2
Slope Instability	4
Earthquake	2

Table 2: Results from experimental works

Type of Experiments	Results	Type of Specifications
Sieve Analysis	Coefficient of curvature Cc=2.35	ASTM D-421
	Coefficient of uniformity Cu =50	
Compaction	Max. Dry density = 2.2 (gm/cm3)	ASTM D-4254
	Optimum moisture content=6%	
Permeability	At (20 ºC) = 1×10-7(m/s)	ASTM D-2434
Specific gravity	At (20 ºC) = 2.69	ASTM C-127

Internally, the development of the erosion could break up to several stages such as erosion initiation and extension, advancement of the erosion to cause piping and finally creation of a crack **[7]**. Many researchers concentrated on studying the problem that could happen to the dams due to seepage:

Yousif [8] studied the seepage analysis through Al-Adhaim dam by using the finite elements Geo-Slope software, he studied different parameters that could control the seepage and exit gradient in the dam by removing the core, changing the core location, changing filters locations and thicknesses.

Ismaeel and Noori [9] studied the seepage and stability of Duhok dam using SEEP/W software. This software was used 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.

Tatewar and Pawade [10] studied the analysis carried out on Bhimdi earth dam which is a 21 m high (Maharashtra State) by changing different parameters such as changing berm width, position of filter drains by using Geo-Slope software.

The aim of this research is to study the seepage through KHASA-CHAI dam a zoned earth dam by varying different conditions related to the dam geometries and the results were presented using SEEP/W a finite element software.

2. Experimental Program

This section is aim to study the soil parameters that the dam constructed from and then use these parameters in Geo-Slope software SEEP/W program to simulate the seepage through the dam.

I. Shell samples

The soil used in the construction of KHASA-CHAI shell was sub-base soils class B that is a local soil available in large quantities near the construction area of the dam. The experimental works' results can be seen in Table 2.

II. Core samples

The soil used in the construction of the core was silty-clay soils, which are local soils available near the construction area in large quantities. The physical properties determined by the experimental works could be seen in Table 3.

Table 3: Results from experimental works

Type of Experiments	Results	Type of Specifications
Sieve Analysis	Soil with 76% clay	ASTM D-421
	Soil with 24 % silt	
Compaction	Max. Dry density = 1.8 (gm/cm^3)	ASTM D-4254
	Optimum moisture content=18.8%	
Liquid limit	49%	ASTM D-4318
Plastic limit	34%	ASTM D-4318
Permeability	At (20 ºC) = 5.3×10^{-9}(m/s)	ASTM D-4254
Specific gravity	At (20 ºC) = 2.58	ASTM C-128

III. Fine Filter samples

The soil used in the construction of fine filters in the dam was crushed and natural sand material. The experimental works' results can be seen in Table 4.

IV. Coarse Filter samples

The soil used in the construction of coarse filters on the downstream side was gravel material, which is available in quarries near the construction area, the soil experiments done are as shown in the Table 5.

3. Seepage Analysis

I. General

The steady state seepage through the dam is analyzed using SEEP/W software, which is one of Geo-Slope tools that uses finite element methods to model pore water pressure distribution and the movement of water within the porous media (soil and rock). This software is a general seepage analysis program it could model both saturated & unsaturated flow and this allows SEEP/W to handle a great range of real problems than other seepage software products.

II. Case Study: KHASA-CHAI Dam

This dam is a multipurpose project. Figure 1 presents the cross section of the dam, the right side of it located at Coordinates (E 452041, N 3934306) and the left side of it located at coordinates (E 452441, N 3933254) the dam was constructed on the river KHASA-CHAI, the seasonal tributary of Zaghaitun River, which is in turn flowing into Al-Adhaim dam reservoir (10 km) northeast of Kirkuk near Kuchuk village. A (58 m) high with total length of 2.36 km, zoned earth dam with silty clay core dam was constructed for which a Lake would be developed and used as a reservoir with active and dead storages of (80 and 5.15 Mm^3) respectively. The dam contains many instruments for monitoring and inspection to be sure that the dam will be in safe condition during the operation periods; these instruments will be responsible for observing the settlement, movement and the increase in the pore water pressure inside the dam body [11].

Table 4: Results from experimental works

Type of Experiments	Results	Type of Specifications
Sieve Analysis	Coefficient of curvature Cc=0.94 Coefficient of uniformity Cu =6.67	ASTM D-421
Compaction	Max. Dry density = 1.95 (gm/cm^3) Optimum moisture content=6.2%	ASTM D-4254
Permeability	At (20 ºC) = 5.6×10^{-3} (m/s)	ASTM D-2434
Specific gravity	At (20 ºC) = 2.55	ASTM C-127

Table 5: Results from experimental works

Type of Experiments	Results	Type of Specifications
Sieve Analysis	Coefficient of curvature Cc=0.89 Coefficient of uniformity Cu =2.2	ASTM D-421
Compaction	Max. Dry density = 2.2 (gm/cm^3) Optimum moisture content=5.4%	ASTM D-4254
Permeability	At (20 ºC) = 1×10^{-2} (m/s)	ASTM D-2434
Specific gravity	At (20 ºC) = 2.6	ASTM C-127

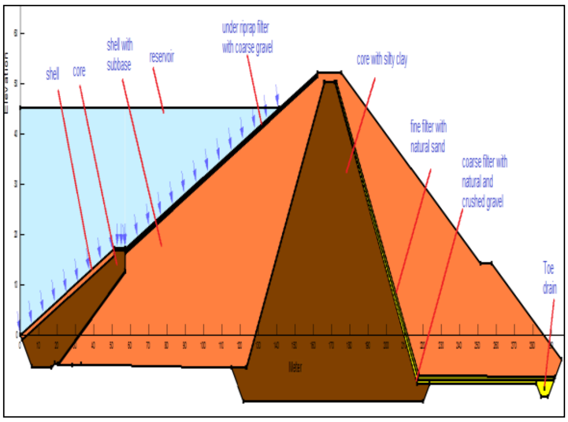

Figure 1: Cross section of the dam

III. Computer Program

Geo-Slope software is a geotechnical program that is based on finite element and can solve many types of analysis like stress-strain, slope stability, earthquake analysis, dynamic and permenant deformation analysis. SEEP/W software is one Geo-Slope programs that uses finite element methods to model pore water pressure distribution and the movement of water within the porous media (soil and rock). It could model both saturated and unsaturated flow and this allows SEEP/W to handle a great range of real problems than other seepage software products [12].

IV. Seepage Formulation

The finite element mesh used for the analysis is shown in Figure 2 with quads and triangles elements, the number of elements are (1936) and the number of nodes is (1998).

The upstream boundary conditions are designated to be:

1. Upstream reservoir level with total head H (m) which represent the height of the water in the reservoir.

The downstream boundary conditions are designated to be:

1. Potential seepage face located on the downstream face. Point of the toe drain with pressure head constant equal to (0 m).

2. The analysis is carried out by considering the water in the reservoir to be at maximum water level at height (49.17 m), minimum water level at height (18.43 m) and half filled with water at height (33.81 m). The results from the basic analysis are taken at the point of the toe drain and presented in Table 6.

4. Seepage Control

I. Effect of changing the permeability of the shell

In this point three cases will be considered by changing the permeability of the shell with respect to the permeability of the core and draw the effect of these changes on seepage line, seepage value and exit gradient:

a) The permeability of the shell equals to (1000) the permeability of the core.

$K_{shell} = 1000\times5.3\times10^{-9} = 5.3\times10^{-6}$ m/s

b) The permeability of the shell equals to (10,000) the permeability of the core.

$K_{shell} = 10000\times5.3\times10^{-9} = 5.3\times10^{-5}$ m/s

c) The permeability of the shell equals (100,000) the permeability of the core.

$K_{shell} = 100000\times5.3\times10^{-9} = 5.3\times10^{-4}$ m/s

Figure 3 presents the effect of changing (k_{shell}/k_{core}) on seepage quantity; Figure 4 presents the effect of changing (k_{shell}/k_{core}) on exit gradient. It can be summarized the effect of the ratio of (k_{shell}/k_{core}) on seepage quantity and exit gradient:

- The exit gradient decrease when this ratio increases.
- The increase of this ratio will lead to an increase in the permeability of the shell and this will lead to an increase in the seepage quantity through the embankment.

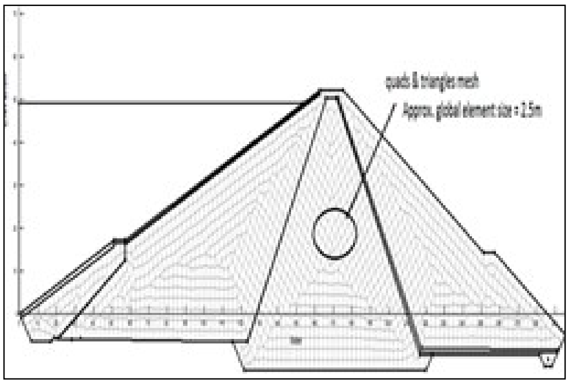

Figure 2: Finite element mesh for the problem

Table 6: Results from the basic analysis

Height of water (m)	Max.(49.17)	Average(33.81)	Min.(18.43)
Seepage (m^3/sec)	1.344×10^{-7}	8.83×10^{-8}	3.79×10^{-8}
Exit gradient(x)	4.07×10^{-5}	2.27×10^{-6}	1.3455×10^{-6}
Exit gradient(y)	12×10^{-5}	4×10^{-7}	1×10^{-8}
Maximum velocity(x)(m/s)	1.14×10^{-9}	1.16×10^{-9}	2.5×10^{-10}
Maximum velocity(y)(m/s)	2.88×10^{-9}	7×10^{-10}	4.04×10^{-11}

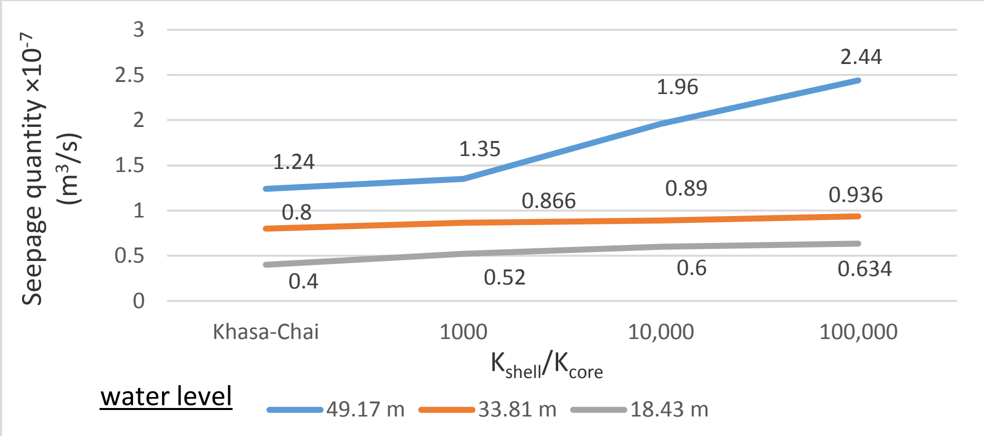

Figure 3: The effect of changing (k_{shell}/k_{core}) on seepage quantity

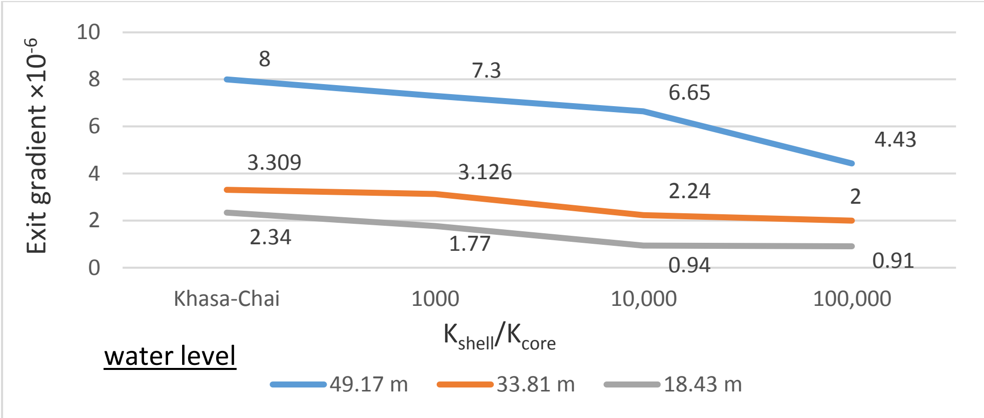

Figure 4: The effect of changing (k_{shell}/k_{core}) on exit gradient

II. Effect of the Core in the Dam body

This is the central part for most earth fill dams and consists mainly from impermeable material to stop water passing through the dam. Cores may be constructed from soil, steel, concrete or wood depending on the availability of materials and on the construction difficulties. Two cases are studied here:

a) Studying the importance of core existence on seepage quantity and exit gradient.

Figs. 5 and 6 present the relationship between the seepage quantities and exit gradients with the various head of water when the dam is with & without core.

It can be summarized the effect of the core on seepage quantity and exit gradient:

- Decrease seepage quantity by 94%.

Decrease exit gradient by 45%.

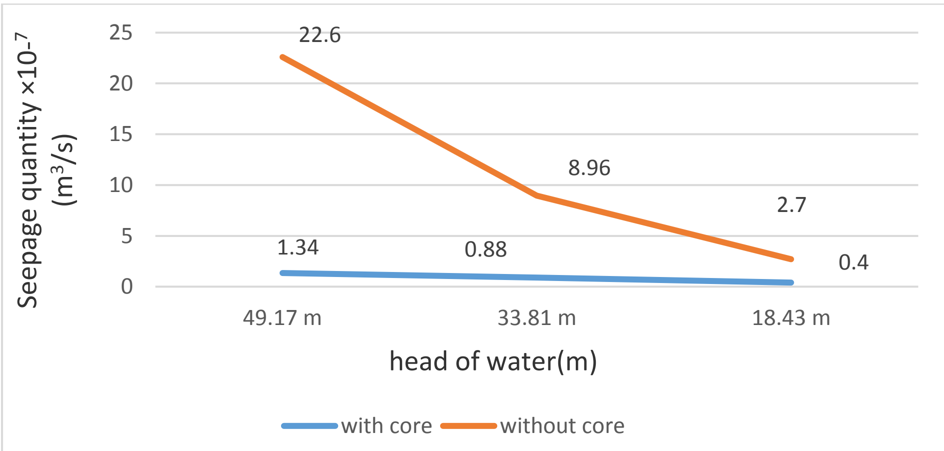

Figure 5: Relationship between seepage quantity & head of water

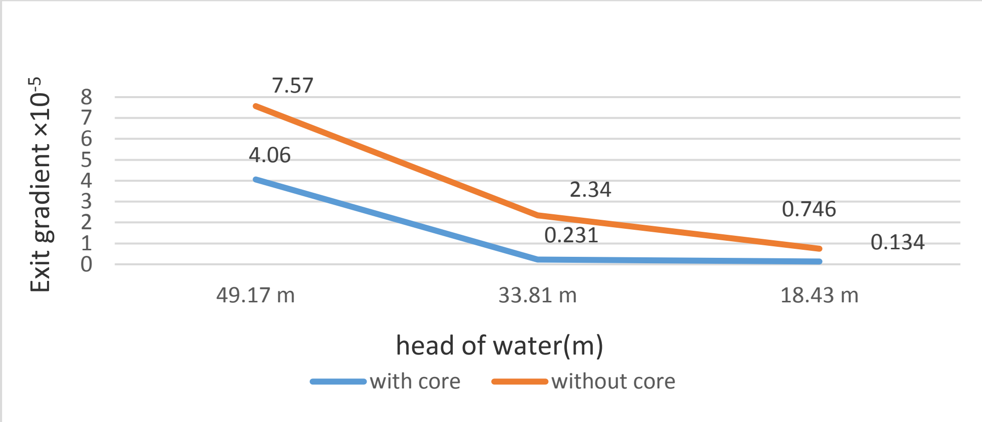

Figure 6: Relationship between exit gradient & head of water

b) Studying the effect of core thickness on seepage quantity and exit gradient.

The thickness mentioned here located on the ground line at elevation zero. The thickness of the core in the dam as build at zero elevation is (85 m), three cases were taken by reducing the thickness of the core (5 m) from each side (upstream & downstream) sides to keep the core in all cases as a symmetric as the original state.

Figures 7 and 8 present the relationship between the quantity of seepage and exit gradient with the various change in the thickness of the core at different reservoir levels.

The effect of decreasing the core thickness on seepage quantity and exit gradient can be summarized by:

- Increasing seepage quantity by (8-34 %) for every time decreasing the core thickness by 10 m.
- Increasing exit gradient by (10-93 %) for every time decreasing the core thickness by 10 m.

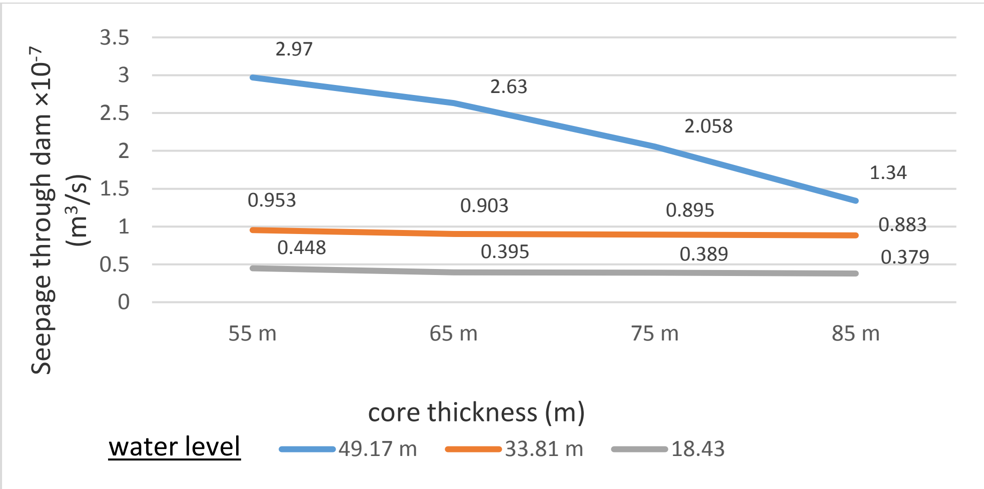

Figure 7: Relationship between seepage quantity and core thickness

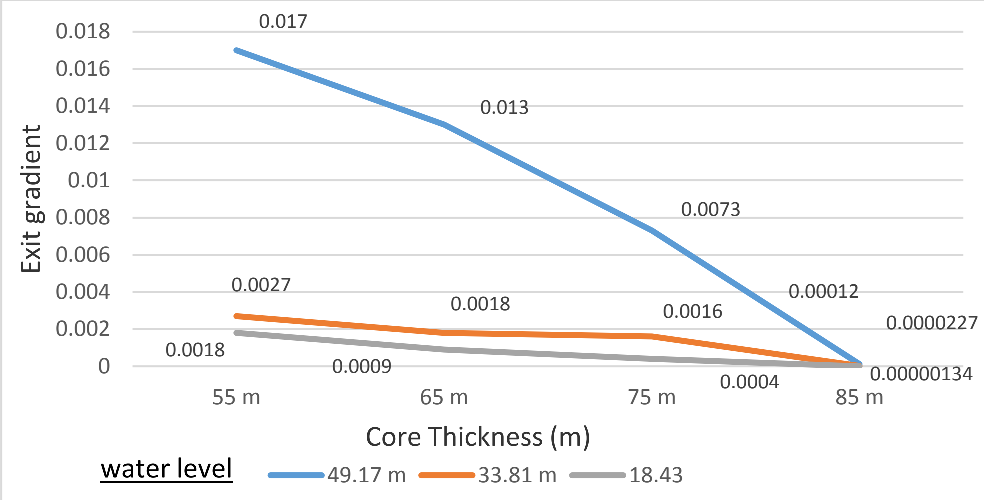

Figure 8: Relationship between exit gradient and core thickness

III. The effect of filters in the dam

Filters in earth fill dams are made of coarser-grained soils located within or adjacent to the dam body. Filters are usually classified according to the particle size distribution, it should have adequately small sizes in compared to the soil grain size in order to prevent the erosion of the soil in addition, it should be sufficiently coarse enough to allow the drainage of water [13].

To have these functions the perfect filters should be [14]:

- Not segregate during processing, handling, compaction…etc.
- Have the capability not to change to cement by standing strong against both physical and chemical actions.
- Not change in gradation during processing, handling, and compaction.
- The particles should have the internal stability property to prevent separation from filter as the seepage flow proceeds.
- The permeability should be enough to discharge the seepage flows and prevent the development of excess pore water pressure.
- To overcome the erosion that might happen in the shell of the dam by concentrated leak, backward erosion...etc.

Three cases are studied here:

a) Removing the upstream filters

The effect of the upstream filters on seepage and exit gradient can be summarized by:

- Increasing seepage quantity by (3-17 %) for the different reservoir levels.
- Increasing exit gradient by (5-36 %) for the different reservoir levels.

Figs. 9 and 10 present the relationship between the quantities of seepage and the exit gradient with the removing of upstream filters during the change in the reservoir levels.

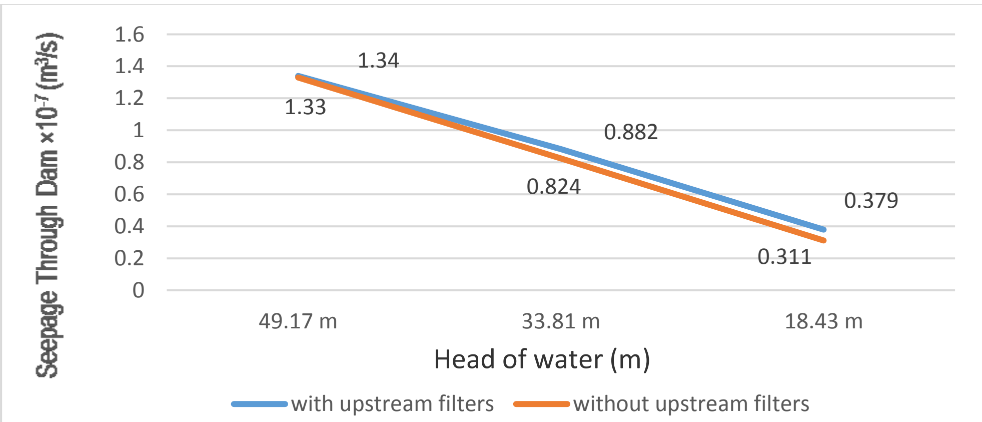

Figure 9: Relationship between seepage quantity and head of water

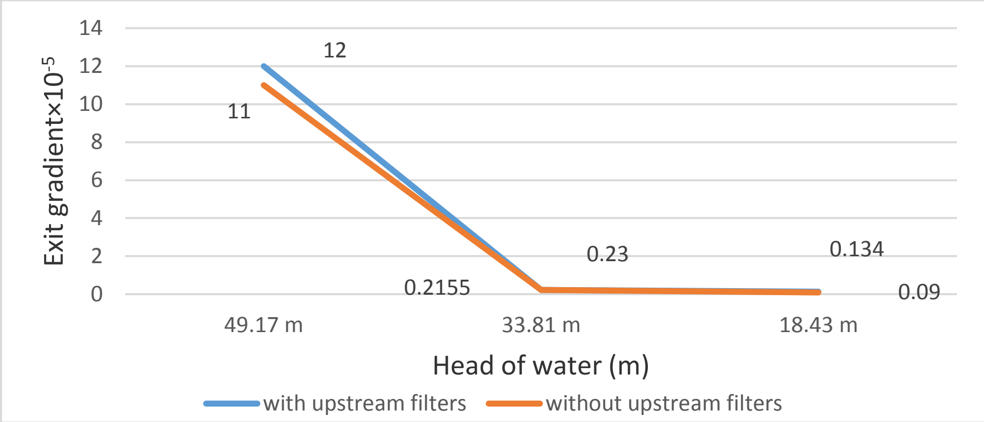

Figure 10: Relationship between exit gradient and head of water

b) Removing the downstream filters

The effect of downstream filters on seepage quantity and exit gradient can be summarized by:

- Increasing seepage quantity by (10-22 %) for the different reservoir levels.
- Decreasing exit gradient by (100 %) for the different reservoir levels.

Figure 11 and 12 present the relationship between the quantity of seepage and the exit gradient with the removing of downstream filters during the change in the reservoir levels.

c) Removing upstream and downstream filters

The effect of presence upstream and downstream filters on seepage quantity and exit gradient can be summarized by:

- Increasing seepage quantity by (12-22 %) for the different reservoir levels.
- Decreasing exit gradient by (100 %) for the different reservoir levels

Figures 13 and 14 present the relationship between seepage quantities and exit gradient with the head of water in the reservoir when the dam is with and without all filters.

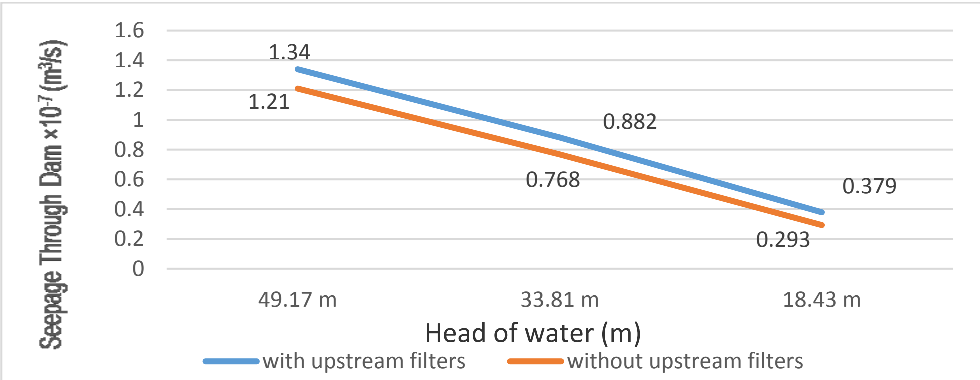

Figure 11: Relationship between seepage quantity and head of water

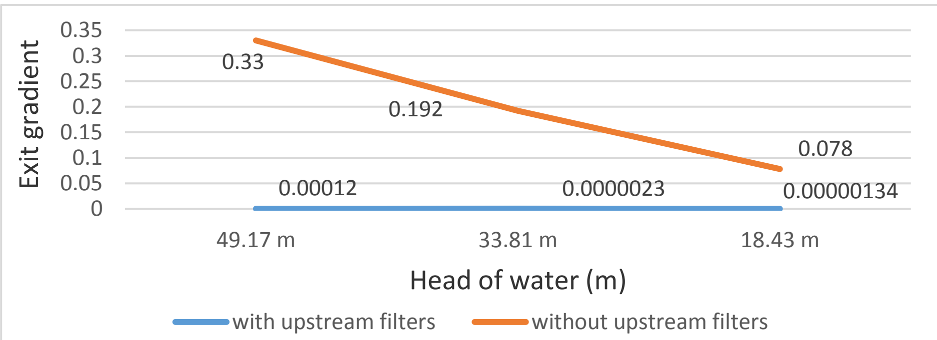

Figure 12: Relationship between exit gradient and head of water

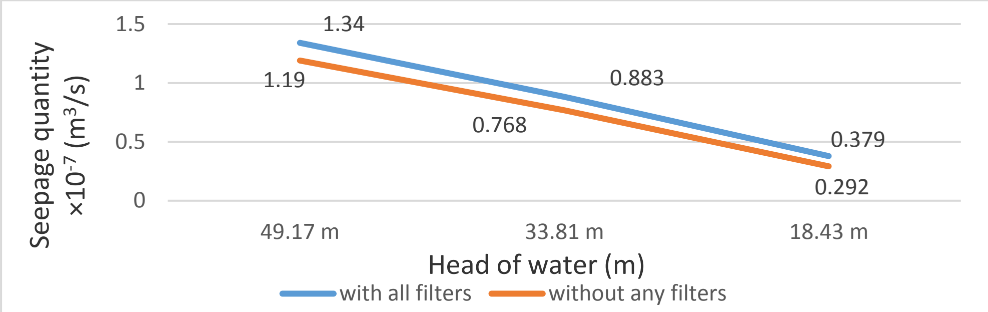

Figure 13: Relationship between seepage quantity and head of water

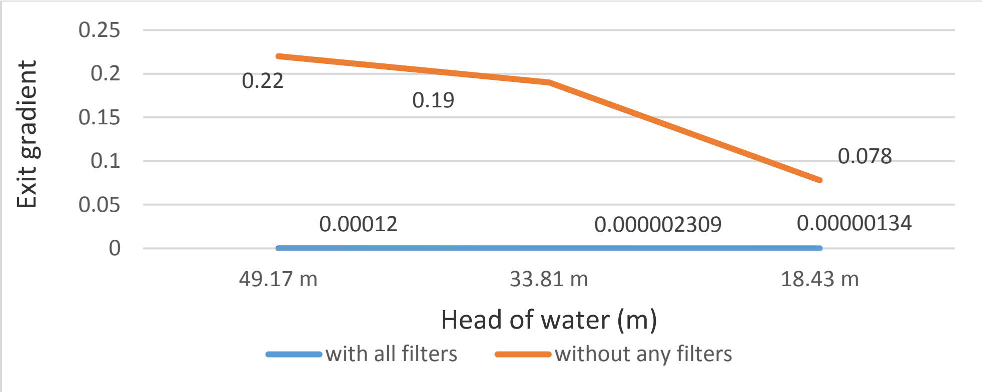

Figure 14: Relationship between exit gradient and head of water

Conclusions

1. The three conditions of water levels in the reservoir (49.17 m), (33.81 m) and (18.43 m) which represent the maximum, half-filled and minimum reservoir levels respectively show that exit gradient is always less than (1.0) which means that the dam is safe against failure by boiling.
2. The changing in the ratio of (K_{shell}/K_{core}) has an effect on both exit gradient and seepage quantity. When this ratio increases, the exit gradient will decrease and the seepage quantity will increase.
3. The design ratio of (K_{shell}/K_{core} =10,000) is the best ratio since it provides a reasonable amount of seepage and exit gradient.
4. The core in the dam has an important effect on the seepage quantity through the dam where it could increase and reach (94 %) when the core removed from the dam. In addition, the exit gradient could increase in order of (45 %) when the core removed from the dam body.
5. Reduction the thickness of the core by 10 m may increase seepage quantity in order of (35 %) and the exit gradient may increase in order of (34 %).
6. The upstream filters have no considerable effect on both the quantity of seepage and exit gradient.
7. The downstream filters has very small effect on seepage quantity, while the exit gradient may decrease in order of (100 %) when they exists.
8. The effect of all filters can be summarized by increasing the seepage quantity in order of (12-22 %). On the other hand, the presence of these filters may decrease exit gradient in order of (100 %).

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