# Effect of Different Core Slopes and Filters on Seepage for Horan Dam, Iraq

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## Abstract

A dam failure results in losses in terms of economy and infrastructure, in addition to the loss of many lives and assets. Inadequate seepage control procedures are typically the cause of seepage failure in earth-fill dams. For an earthen dam to be waterproof and to minimize seepage, non-homogeneous dams with a clay core are one kind of embankment dam used. As water moves through the dam's core, friction causes it to lose a lot of energy. Both vertical and inclined cores can be used in the design and construction of zoned embankment dams. As a result, choosing the proper materials and dimensions for the earth dam's core is critical. The main objective of this study is to investigate different seepage control strategies for an earth dam (HORAN DAM) using the Finite Element Method (FEM). We modeled and analyzed nine cases of various seepage control techniques that have been modeled and analyzed using SEEP/W, a FEM-based software. The modeling results show using chimney filters reduces pore water pressure more effectively than using toe rock and horizontal filters. Regarding seepage, trapezoidal cores perform better than inclined cores, and the milder slope is preferred over steeper core slopes. The results show when the core permeability decreases, the seepage quantity also decreases. Toe rock decreases seepage more than horizontal filters and chimney filters. Additionally, it has been shown that using a toe rock filter together with a trapezoidal core with a mild slope performs better than using a different filter and a different internal clay core shape.

**Keywords:** Clay, Earth Dam, Geo-Studio, Horizontal Filter, Rock Toe, Seepage, and Slope.

# تاثير اختلاف منحدر القلب والمرشح على التسرب لسد حوران في العراق

ضحى جبار قاسم وهيثم علاء حسين وأمانويل زيدوبيلو

**الخلاصة**

يؤدي فشل السد الى خسائر اقتصادية وبنية تحتية بالاضافة الى خسائر العديد من الارواح والممتلكات.عادة ما تكون إجراءات التحكم في التسرب غير كافية هي السبب في فشل السدود الترابية .لكي يكون السد الترابي مقاوما للماء ويقلل من التسرب. تستخدم السدود غير المتجانسة ذات النواة الطينية. فعندما تتحرك المياه عبر قلب السد، يتسبب الاحتكاك في فقدانه الكثير من الطاقة. ويمكن استخدام كل من النوى الرأسية والمائلة في تصميم وبناء سدود الترابية الغير متجانسة. ونتيجة لذلك.الهدف من هذه الدراسة هو تطبيق طريقة العناصر المحدودة لدراسة استراتيجيات التحكم في التسرب لسد ترابي(سد حوران) باستخدام برنامج التسرب الارضي وهوة برنامج قائم على طريقة العناصر المحدودة .واظهرت نتائج التحليل العددي ان استخدام مرشحاتchimney يقلل من ضط الماء المسامي بشكل أكثر فعالية من استخدام المرشحات الصخريةtoe rock والافقية .من حيث التسرب ويكون أداء النواة شبه المنحرفة افضل من النواة المائلة، ويفضل المنحدر الاكثر اعتدالا على المنحدرات الاساسية الاكثر انحدارا، تقلل صخور الأصبع التسرب أكثر من المرشح الافقي ومرشح chimney. تظهر النتائج أنه عندما تنخفض نفاذية اللب، تنخفض أيضًا كمية التسرب.بالاضافة الى ذلك ،فقد تبين ان استخدام مرشح toe rock مع قلب شبه منحرف مع منحدر معتدل يؤدي بشكل أفضل من استخدام مرشح مختلف وشكل قلب مختلف من الطين.

# 1. Introduction

A dam is constructed to compound or store water for different purposes such as water supply, irrigation, flood control, and hydroelectric power generation [1]. An embankment dam may fail for different reasons, mainly seepage and overflooding. Seepage can cause piping and embankment body sloughing or sliding, which causes dam failure.

Dam failure is a big issue especially when the dam is built of earth material. Therefore, to minimize the dam failure, it is essential to control the seepage water within the dam body and its foundation. Because of seepage, water loss, and minimization of dam stability [2]. There are two methods for managing seepage in an earth dam. In the first method, seepage is reduced by the construction of anti-seepage elements like sheet piles, cutoff walls, slurry trenches, clay sealing, u/s impervious blankets, etc. In the second method, a safe water outlet is created by the installation of filters, sand drains, stone columns, relief walls, etc. [3].

The quantity of seepage loss through a homogenous earth dam without a filter located on an impermeable base was analyzed by [4]. They used GeoStudio, SEEP/W for the analysis. The study proposed an equation and it is compared with an artificial neural network (ANN) that yields results with less than three percent error and SEEP/W results show that there is less than two percent error. Also, the result is compared with Dupuit's and Casagrande's, and its value is twenty and fifty percent error respectively.

Additionally, [5] analyzed the seepage and slope stability analysis in the Ilam earth fill dam using SEEP/W software. Four different mesh sizes (coarse, medium, fine, and unstructured mesh) were taken to analysis the dam cross-section to assess the type and size of mesh on the flow rate and total water head. The average seepage flow rate for the various mesh sizes for the earth fill dam was found to be 0.836 liters per second of the whole length of the dam. These programs were also adopted [6] to simulate seepage and analyze the slope stability of Banha University's prototype earth-fill dam using finite element modeling. The analysis results reported in this study validate the earth dam safety with combined seepage and slope stability under normal and different scenarios.

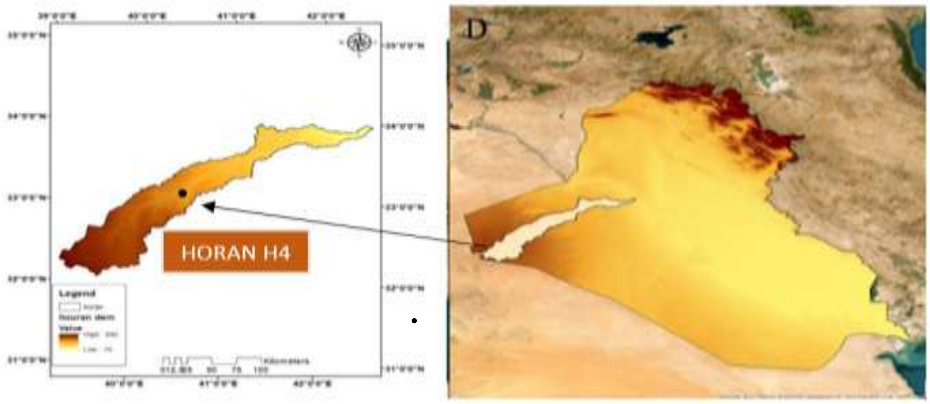
An earth dam needs a core to prevent seepage and be waterproof. Therefore, it is essential to select the proper materials and proportions for the earth dam's core. While a thick clay core makes sense for waterproofing, the clay's low shear strength would compromise the dam's stability. A stable safety factor, sufficient waterproofing, and affordability would all make up the perfect core. [7] studied the steady-state seepage conditions with optimum size for the clay core of the Alavian dam near Maragheh City. They used the Geo-Studio software for embankment modeling. To find the optimal core thickness, eleven additional models of the dam with different core sizes were analyzed combined with seepage and slope stability for embankment dams. An earth dam with a thicker clay core will have less seepage and a lower hydraulic gradient since clay has a low permeability. This is a suitable state. On the other hand, a larger clay core reduces the upstream slope safety factor against sliding since clay has a low shear strength. Results show that the Alavian dam core is 35% less than it is now when the dam clay core is in its optimum state.

Using SLIDE V.5.0, a finite element method-based computer program, other researchers, including [8] analyzed the zoned earth dams' pressure head, hydraulic gradient, exit gradient, and seepage volume (Khassa Chai dam in Iraq). When a clay core is present, the quantity of seepage and the exit gradient increase, which has a significant impact on both of these measurements. Since it permits appropriate amounts of seepage, k core = $1x10^{-10}$ is the optimal core permeability value. The dam core is still necessary to reduce the phreatic line, pressure head, and seepage quantity, even when its thickness is decreasing.[9] conducted research on the features of seepage analysis through earth dams with varying filter media. Utilizing SEEP/W, a geo studio sub-program, the numerical analysis has been examined. The result represents the seepage characteristics with the coefficient of permeability of the materials employed in the filter media determined. The horizontal filter has a high discharge. In the chimney filter and rock toe, there is less discharge.[10]uses both the Limit Equilibrium Method and Finite Element Method to analyze the clay core impacts on seepage and stability of earth dams.[11] numerically compared seepage responses to different zoned dam and core properties. [12] investigated the hydrodynamic and geometrical parameters of the dam, horizontal filters, and the center impervious core to determine their effect on seepage. In a hydraulic flume, 21 models of a homogeneous dam were constructed with and without a horizontal filter material, as well as a central impervious core of varying width. Studies show that increasing the thickness of the clay core lowers seepage. The inclusion of a downstream filter prevented the phreatic line from cutting the earth dam's downstream face. [13] studied 200 models with two different central core shapes: rectangular and wedge. Analyzing the models with GeoStudio software reveals a significant decrease in seepage discharge quantity for trapezoidal core shapes compared to rectangular core shapes, by more than 50%. Although different studies have been reported in the literature for minimizing the seepage flow and investigation for seepage analysis by providing the effect of increasing core slope with different types of filters is still missing

While different research on seepage control has been published in the literature, there hasn't yet been a thorough examination of seepage analysis that considers the impact of increasing core slope with various filter types. In this paper, seepage analysis has been carried out using three different slopes of core (1H:4.33V), (1H:1V), and core with slope(incline) at upstream (1H:1V) downstream (0. 5H:1V). There are three types of filters in each core slope: chimney, horizontal, and toe rock filters. Under these different conditions, the position of the phreatic surface, seepage quantity, pore water pressure, and hydraulic gradient are examined. Additionally, a thorough investigation of the impact of the interior clay core's shape has been conducted. The Horan earth dam modeling has been carried out using the finite element -based software SEEP/W and the modeling results have been reported and discussed.

## 2. Description of the Study Area

The Horan embankment Dam is located in Wadi Horan valley (18 km) northeast of Rutba town in Iraq and its location as shown in **Fig. 1**. It is located at the coordinate at Latitude 33.0333°, Longitude 40.2500° and also, it's roughly halfway between Damascus and Baghdad, near the town of Rutba. From the Iraq–Saudi border to the Euphrates River near Haditha, it stretches for 350 kilometers [14]. The phrase "Wadi Horan" is frequently used to describe the wider physical region that includes the wadi itself, the hills that surround it, and any smaller wadi that split from it. The valley is the lowest in Iraq, with high walls enclosing it and a depth that varies from 150 to 200 meters. Even though the valley is mostly dry, there are oases there that, during rainy seasons, can turn into watercourses.




**Figure(1):** Location of Horan Dam [15]

## 3. Salient Features of Wadi Horan Dam

The dam is (24.4 m) high above the riverbed, (8 m) wide, and (395 m) long. A four-meter-wide berm is constructed on the upstream sides of the dam at the elevation of 15 m. The overall mass volume of the embankment dam is 485,000 m³, of which 95,000 m³ is the impervious zone, including protective pitching on the crest and slopes. In riverbanks, the dam is founded on limestone, compact, cavernous, and mostly permeable, a 2 m cut off deep into the bedrock is provided[16].

## 4. Software Used

For this study, GeoStudio 2018 was implemented to carry out the seepage analysis of the Wadi Horan dam. Only one of the eight GeoStudio-2018 suite products is used. Seepage analysis is conducted using SEEP/W.

## 5. Seepage Analysis

In this research, the Finite Element Method computer program – SEEP/W from Geo-slope International is used to model the embankment. SEEP/W is a mathematical model of a real physical process of water flowing through a soil medium [17].

The SEEP/W uses a partial differential equation shown in eq. (1) (PDE) as the governing equation used for modeling.

$$[\frac{\partial}{\partial x}\left(kx\frac{\partial H}{\partial x}\right)+\frac{\partial}{\partial y}\left(ky\frac{\partial H}{\partial y}\right)=0] \quad \text{…….. (1)}$$

Where: - kx, ky = coefficient of permeability in (x, y) directions.

Ht = total head of water.

## 6. Material Used for Analysis

Materials used for various dam components are regarded as being in saturated condition in this study, which ignores complexity; unsaturated conditions are not taken into account. Table 1 lists the materials utilized for the various dam components in this investigation.SEEP/W governs the Mohr-Coulomb model for soil behavior [2]. The model has different parameters, such as horizontal Kx and vertical coefficient of permeability Ky, saturated and unsaturated unit weights, γ, Young's Modulus, E, Poisson's Ratio, ʋ, Cohesion, c, Friction angle, $\phi$, and the Dilatancy angle, ψ. As shown in **table 1**.

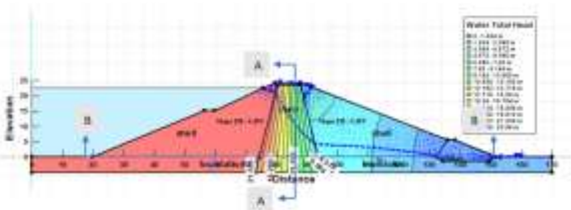
**Table (1):** Soil material data set used for Horan Dam[18]

| **Part** | **Unit Weight (kN/$m^3$)** | **Cohesion (kN/$m^3$)** | **Angel of Friction $\emptyset^{\circ}$** | **Elastic modules E (kN/m²)** | **Poisson's ratio (v)** | **Coefficient of permeability (m/s)** |
|---|---|---|---|---|---|---|
| Core | 20 | 20 | 15 | 20000 | 0.35 | $2.25\times 10^{-10}$ |
| Foundation | 22 | 50 | 31 | 20000 | 0.45 | $1\times 10^{-10}$ |
| Shell | 21 | 0 | 32 | 45000 | 0.45 | $1.25\times 10^{-5}$ |
| Filter | 13 | 0 | 32 | 20000 | 0.48 | $1.25\times 10^{-2}$ |

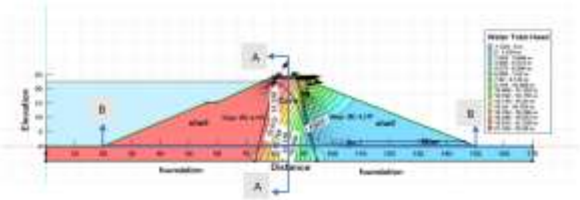
## 7. Case Study

For seepage analysis we have used nine different scenarios or cases as shown in **Fig. 2** these are: -

**Case 1:** Seepage when the dam max water level (22.6 m), at steady state with core slope 1:4.33 with toe rock.
**Case 2:** Seepage when the max water level (22.6 m), at steady state. with core slope 1:4.33 with filter horizontal.
**Case 3:** Slope when the dam max water level (22.6 m), steady state. with core slope 1:4.33 with chimney filter.
**Case 4:** Seepage when the dam max water level (22.6 m), steady state. with core slope 1:1 with toe rock.
**Case 5:** Slope when the max water level (22.6 m), steady state, and rapid drawdown with minimum water level of (4.5 m) after ١٦ days with core slope 1:1 with horizontal filter.
**Case 6:** Seepage when the dam max water level (22.6 m), steady state, with core slope 1:1 with chimney filter.
**Case 7:** Seepage when the dam max water level (22.6 m), steady state, with core slope 1:1 U/S 0.5:1 D/S with toe rock.
**Case 8:** Slope when the max water level (22.6 m), steady state, with core slope 1:1 U/S 0.5:1 D/S with horizontal filter.
**Case 9:** Seepage when the dam max water level (22.6 m), steady state with core slope 1:1 U/S 0.5:1 D/S with chimney filter.



(A)



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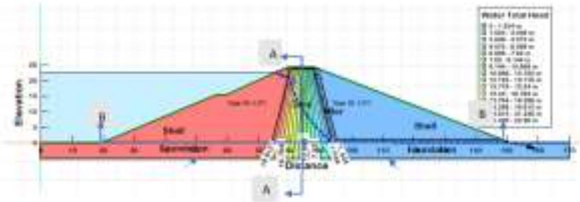
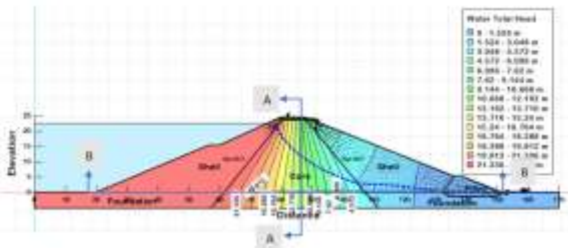


(C)



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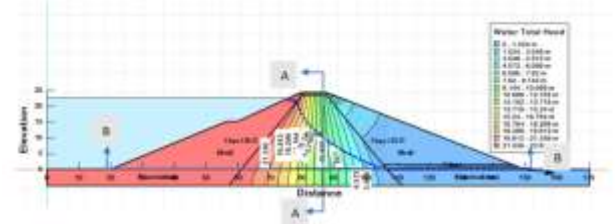

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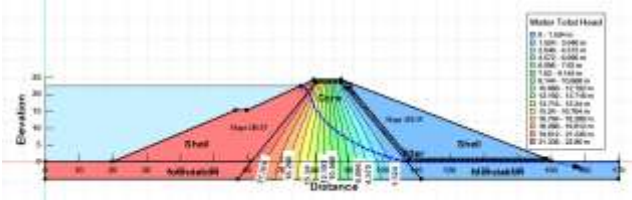

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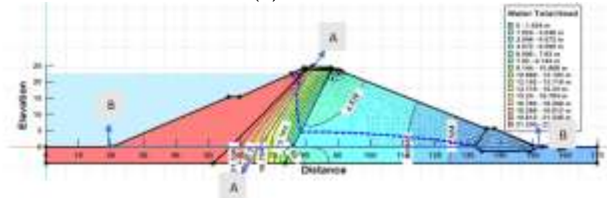

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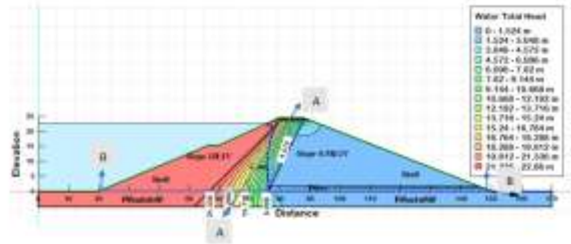
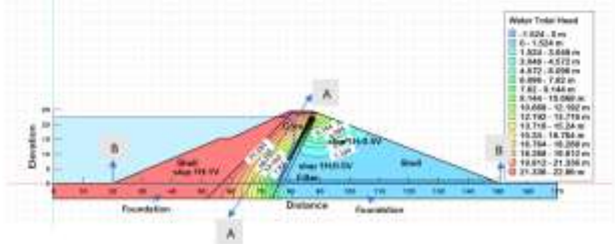


(H)



(I)

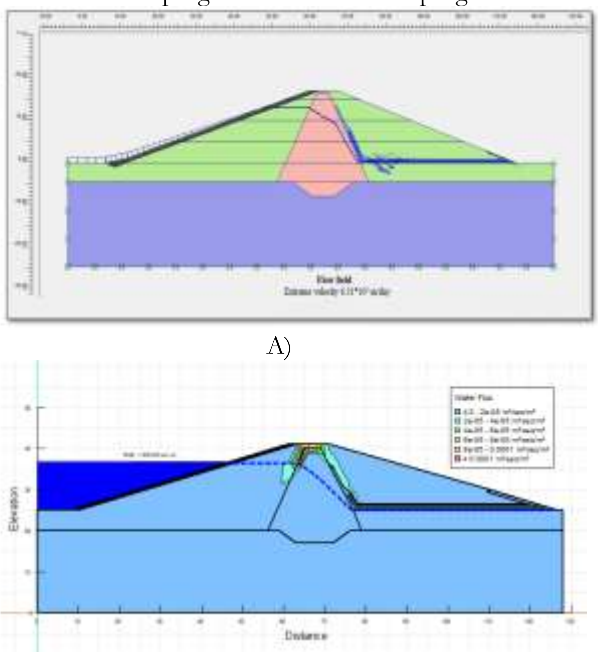
**Figure (2):** Phreatic line, total head, velocity vectors, flow path ,and sections on Horan earth dam, A. case 1 B. case 2 C. case 3 D. case 4 E. case 5 F. case 6 G. case 7 H. case 8 I. case 9

## 8. Seepage Analysis

The maximum quantity of active storage in this impoundment state is 22.6 meters. The reservoir's water level fluctuates during impoundment for a variety of causes. This could be the primary cause of significant evaporation, seepage losses, and seasonal variations in inflow. SEEP/W is used to analyze the seepage quantity, phreatic line, exit gradient and flow velocity.

### 8.1. Validation of program

The seepage analysis is based on the finite element-based GeoStudio, SEEP/W program. For the validation of the model or to verify and assess the suitability of the software utilized in this investigation, it is compared to another program. The PLAXIS program for the Koga earth dam is contrasted with the seepage rate calculated by GeoStudio. The seepage quantity results computed by GeoStudio closely match the PLAXIS prediction. The seepage analysis through the dam body underwent thorough analysis with PLAXIS 2D software. Within the dam body, the seepage water measures at (equivalent to $1.89*10^{-4}$ $m^3/s/m$) [19]. There is an interesting disparity between these results and those from GeoStudio, where the seepage quantity for the same cross-section registers at $1.6815*10^{-4}$ $m^3/s/m$. A comparison of obtained results shows a good agreement between PLAXIS and GeoStudio results. The following **fig.3** shows the location of seepage/phreatic line at normal pool level in the PLAXIS program and GeoStudio program.



A)

B)

**Figure (3): A)** Seepage/Phreatic line Location for normal pool level in PLAXIS **B)** Seepage/Phreatic line, flow paths, and seepage rate through the dam using GeoStudio

### 8.2. Phreatic Line and Seepage Quantities

The seepage line's location varies as shown in Table 2; the seepage line is located under the downstream toe in cases 1, 4, and 7, under the downstream horizontal filter in cases 2, 5, and 8, and under the downstream transition filter in cases 3, 6, and 9 Fig. 2. illustrates the impact of core shape on the Euphrates flowline. The internal clay core causes a decrease in the Euphrates flowline within the dam body. According to analysis, the flowline rapidly drops when a chimney or horizontal filter is present. The phreatic line location under the downstream transition filter shows a more controlled seepage path, suggesting enhanced stability and effectiveness of the filter design in cases 3, 6, and 9. In this study, the effect of seepage on core slope is considered for three different slope cores with three different filters. Note that the value of seepage discharges the seepage quantity ranges from approximately $2.865*10^{-5}$ to$1.1015*10^{-4}$ $m^3/s/m$. As shown in Table **2**, shows that as the core slope increases, the seepage discharge increases as well because the core's area decreases since the core permeability coefficient is significantly lower than the shell's. Table 2 also shows that the maximum value of seepage is obtained by the inclined core with a core slope upstream (1H:1V) and downstream (0. 5H:1V) and lower value when using a trapezoidal core with a slope (1H:1V) and an increase with an increase core slope to (1H:4.33V). (this topic is supported by the investigation of[10] [20]**.** It is noted that the toe rock has a lower value of discharge than the horizontal filter and the horizontal filter has less than the chimney filter for the core with a slope of (1:1).

### 8.3. Water Pressure/Pore

A maximum water pressure (Pore) distribution is observed at two distinct values as illustrated in **Table 2**: 263.34142 kPa, and 191.52104 Kpa. A higher pore pressure of 263.34142 kPa is found in Cases 1, 4,5 and 7 whereas the lower value of 191.52104 KPa appears in Cases 3, 6, and 9. The variability in minimum pressure, particularly the presence of positive minimum pressures in some cases, suggests different conditions or configurations affecting the dam's stability and pressure distribution. Cases with chimney filters (cases3, 6, and 9) have positive minimum pressures Negative pore pressure increases the effective stress in the dam body (soil), enhancing it's the shear strength of the material. Effective stress means the difference between the pore water pressure and total stress. This increased shear strength helps in stabilizing slopes and improving the bearing capacity of foundations. Negative pore pressures typically occur in unsaturated soils where the voids are empty. Based on the seepage analysis, Cases 3, 6, and 9 seem to be the most favorable. It has a relatively lower maximum pore pressure distribution of 191.52104 Kpa compared to other cases, which mostly exhibit a higher pore pressure of 263.34142 kPa.

**Table (2):** Seepage quantities and location of the phreatic line

| ***Case*** | ***Type of filter*** | ***Seepage quantity ($m^3/s/m$)*** | ***Location of seepage line*** | ***Maximum Pore pressure distribution around the U/S shell material (Kpa)*** | ***Minimum Pore pressure distribution around the D/S shell material (Kpa)*** |
|---|---|---|---|---|---|
| **Core slop (1:4.33)** | | | | | |
| ***Case 1*** | Toe rock | $3.2721*10^{-5}$ | Under the downstream toe | 263.34142 | -119.70065 |
| ***Case2*** | Horizontal filter | $1.0124*10^{-4}$ | Under the downstream horizontal filter | 239.4013 | -143.64078 |
| ***Case3*** | Chimney filter | $1.0133*10^{-4}$ | Under the downstream transition filter | 191.52104 | -191.52104 |

| | | | | | |
|---|---|---|---|---|---|
| ***Core slop (1:1)*** | | | | | |
| ***Case4*** | Toe rock | $2.865*10^{-5}$ | Under the downstream toe | 263.34142 | -119.70065 |
| ***Case5*** | Horizontal filter | $8.6473*10^{-5}$ | Under the downstream horizontal filter | 263.34142 | -119.70065 |
| ***Case6*** | Chimney filter | $9.2035*10^{-5}$ | Under the downstream transition filter | 191.52104 | -191.52104 |
| ***Core slop u/s (1:1) d/s (1:0.5)*** | | | | | |
| ***Case7*** | Toe rock | $3.2903*10^{-5}$ | Under the downstream toe | 263.4013 | -143.64078 |
| ***Case8*** | Horizontal filter | $1.0653*10^{-4}$ | Under the downstream horizontal filter | 191.52104 | -191.52104 |
| ***Case9*** | Chimney filter | $1.1015*10^{-4}$ | Under the downstream transition filter | 191.52104 | -191.52104 |

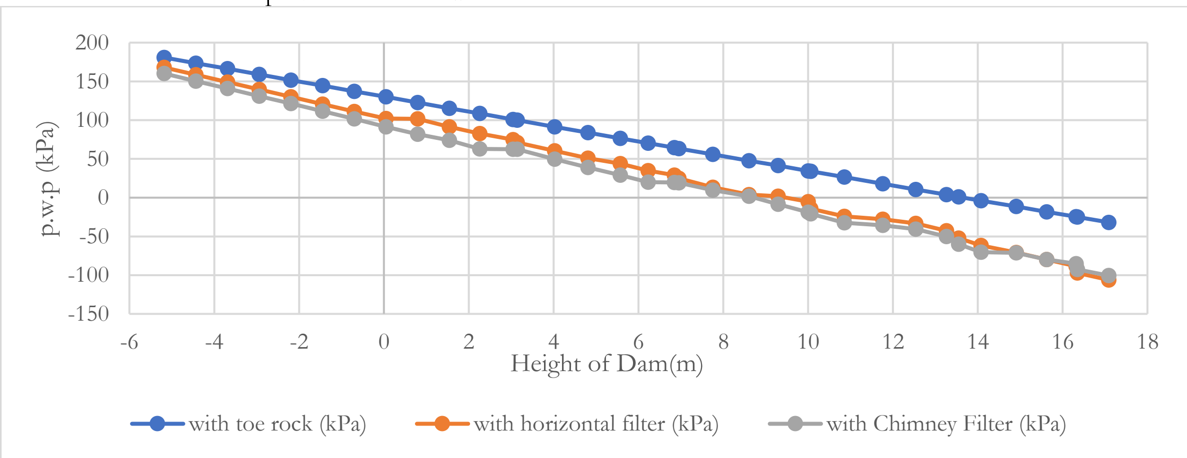
**8.3.1 Effect of different slopes of core and filter on water pressure (Pore)**

The following **Fig.4** shows the evaluation between three different core slopes with three different filters. For **fig.4**( a, b, and c ) demonstrates the variations in pore water pressure with dam height. From the **fig.4**, it was observed that the pore water pressures flowing through the body decreased as drainage length increased. Protection of the downstream slope is crucial for the dam's safety .According to the graph, the pore water pressure is highest when the toe rock filter is utilized. Pore water pressure drops when used with horizontal and chimney filters. (this topic is supported by the investigation of [21].

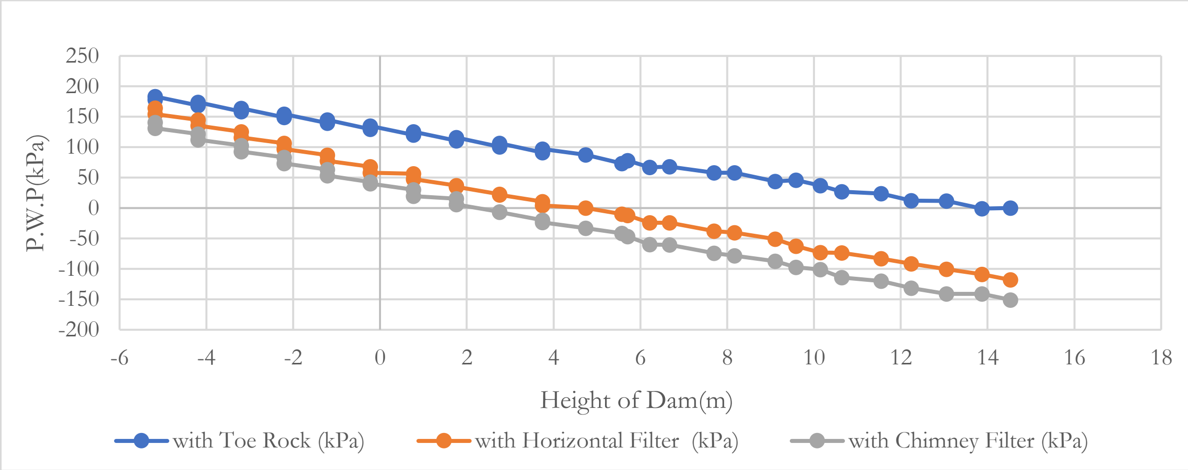
**8.4. Hydraulic gradient**

The main problems with a dam's behavior are changes in the exit gradient and how these affect the dam (seepage and slope stability). In drawdown analysis, the hydraulic gradient is the difference between the dam and reservoir (reserved water) increases. The erosion problems arise with the migration of soil particles in the direction of flow due to increased seepage stresses [22].

The computation of hydraulic gradient, **fig. 5,** shows the hydraulic gradient along section B-B. The maximum seepage gradient is found to be 3.2 **Fig. 5** (I) where along the downstream face of the core when the core slope is inclined. This implies the resulting gradient can induce a problem that is called internal hydraulic fracturing. The hydraulic gradient decreases with a reduced slope of the core by about 1.2 for a dam with core slope (1H:4.33V). A lower value of hydraulic gradient represents a dam with a gentle slope of core (1H:1V) with toe rock, as shown in **fig. 5**(D). As the slope of the core decreases, the equipotential lines in the core get closer together; therefore, the drop of water potential per unit width of the core increases. As a result, the hydraulic gradient in the core increases. Based on the seepage analysis, Cases 4,5, and 6 seem to be the most favorable compared to other cases, which mostly exhibit a hydraulic gradient.




**(A)**

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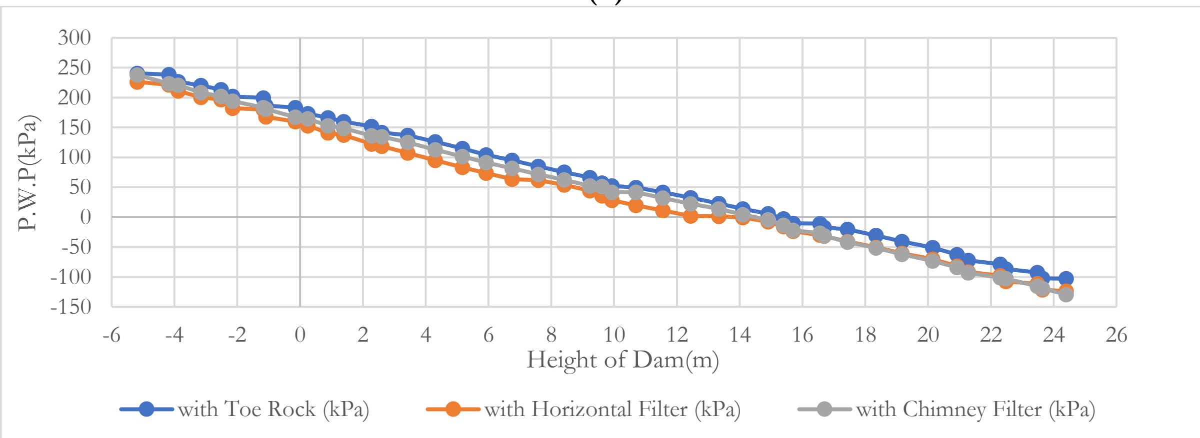


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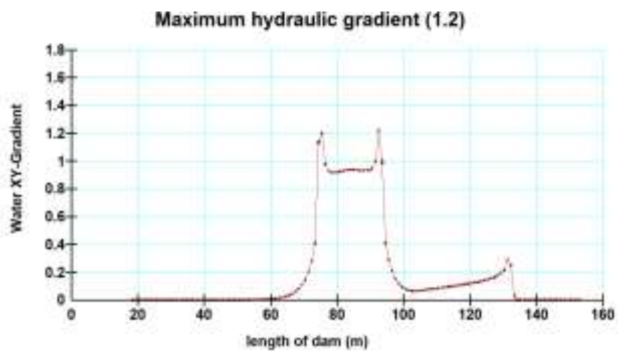
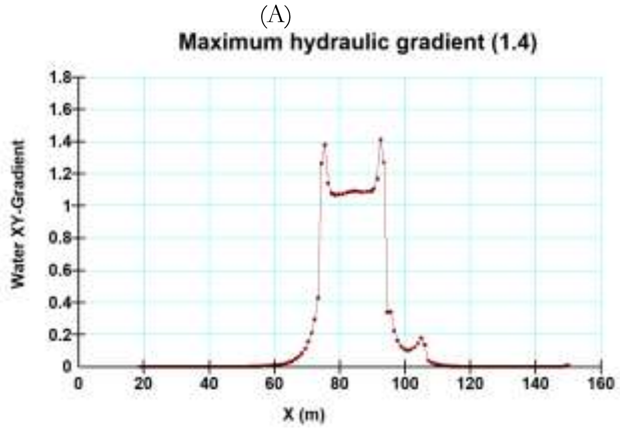
**Figure (4):** Comparison of Water Pressure Between three Filter A) with Core Slope(1:4.33) B)with Core slope(1:1) C)with Core Slope u/s (1:1) d/s (0.5:1).

### 8.4.1 Change in Hydraulic Gradient with Different Core Slope

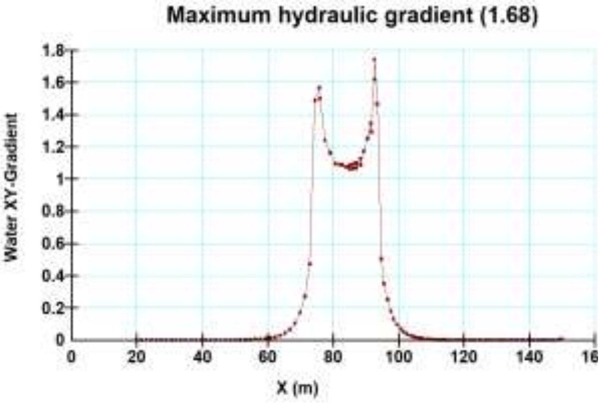
The graph **Fig.6** illustrates the variation in hydraulic gradient with different core slopes along section (B-B). It is evident that steeper core slopes result in greater changes in the hydraulic gradient. For instance, the core with an upstream slope of 1H:1V and a downstream slope of 0.5H:1V exhibits the highest and sharpest peaks, indicating areas of significant water pressure changes. These steep gradients suggest zones of potential concern for structural issues or internal erosion. In contrast, the core with a slope of 1H:4.33V shows fewer peaks and less fluctuation, though it still presents noticeable gradient changes that could affect dam stability. This steeper slope leads to a shorter seepage path, causing the head loss to occur over a smaller distance and thus increasing the hydraulic gradient. On the other hand, the core with a 1H:1V slope demonstrates the smoothest and least variable gradient profile. As a gentler slope, it provides a longer seepage path, which allows the hydraulic head to dissipate more gradually, resulting in a lower and more stable hydraulic gradient. Overall, these findings highlight how core geometry significantly influences seepage behavior and potential structural performance in embankment dams.



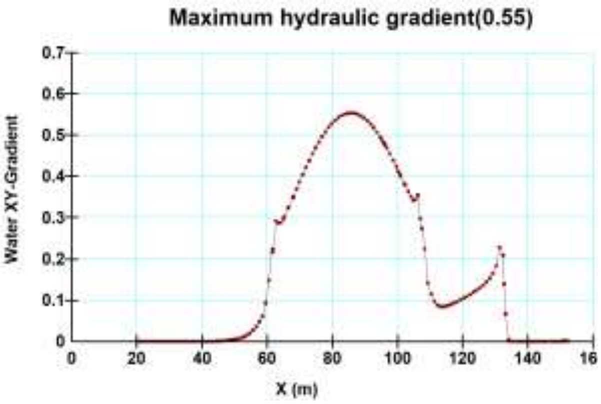

(A)




(B)




(C)

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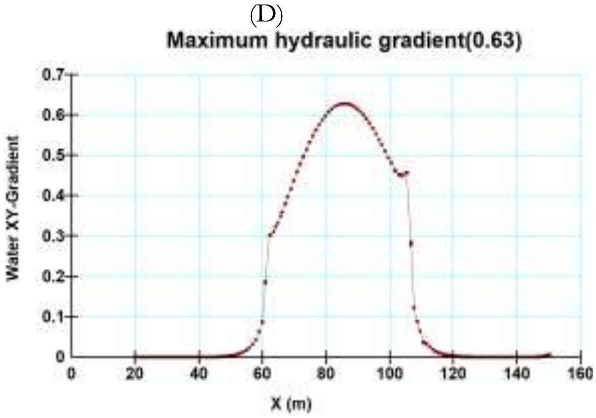


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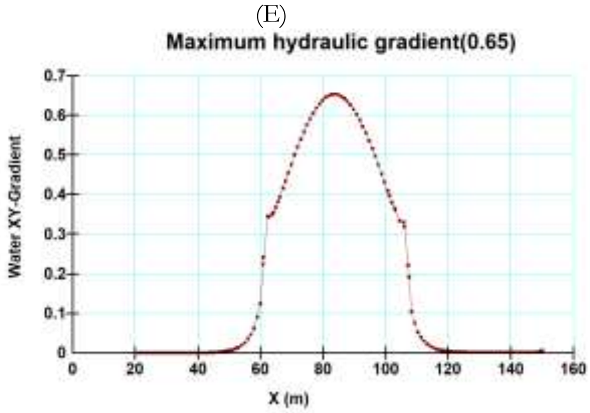


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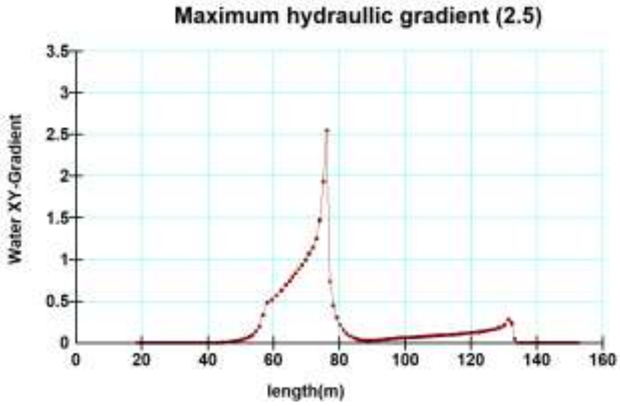
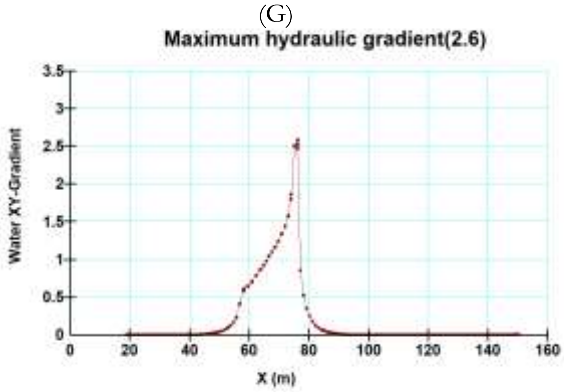
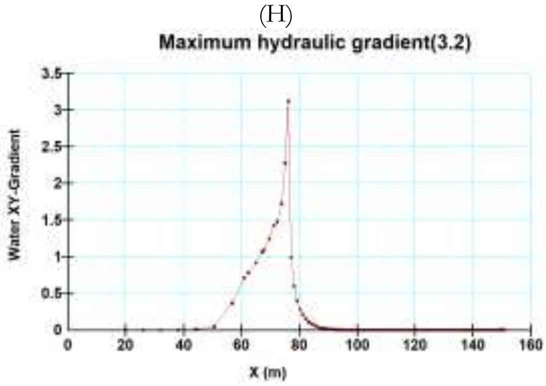



(G)




(H)

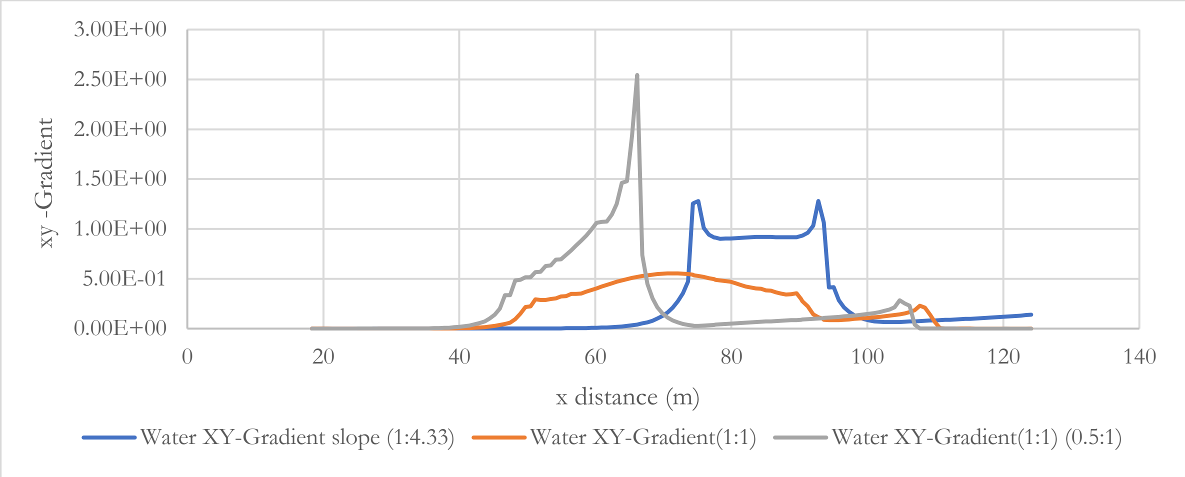



(I)

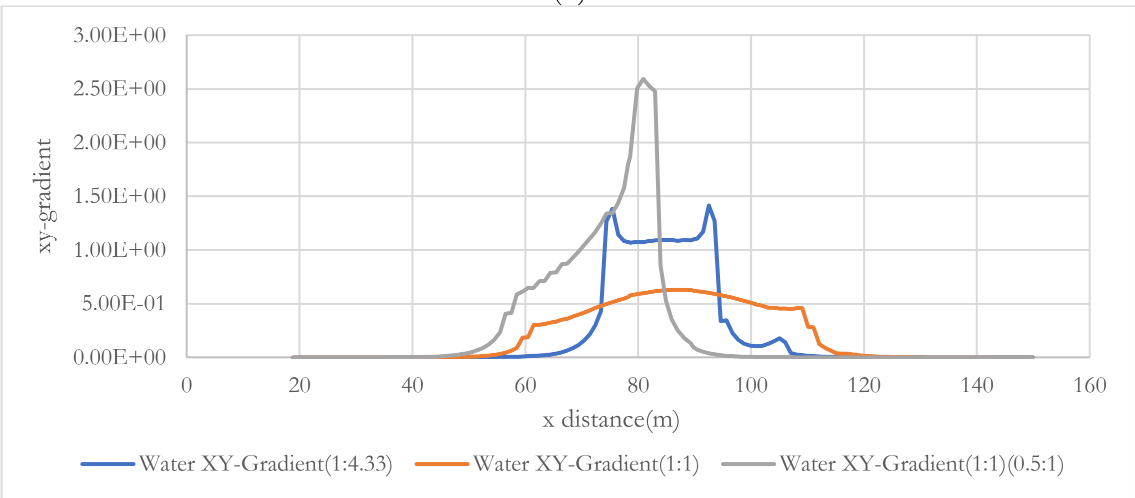
**Figure (5):** The hydraulic gradient and the distance (X) relationship on the dam bottom A. case 1 B. case 2 C. case 3 D. case 4 E. case 5 F. case 6 G. case 7 H. case 8 and I. case 9

## 9.Effects of filter and core slope selection on cost and material availability

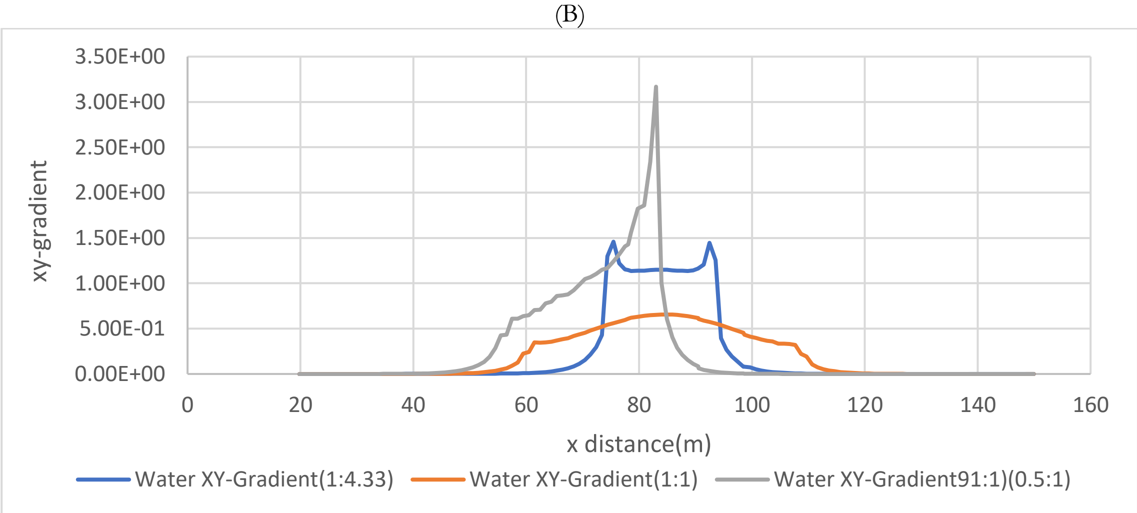
To demonstrate the financial effects on seepage behavior and safety factor of various core slopes and filter types (horizontal, chimney, and toe rock). In reality, even though they use less material, steep core slopes like 1:4.33 are riskier and more difficult to build, particularly on weak foundations. Despite their effectiveness in lowering pore pressure and seepage, chimney filters are more expensive and complex due to their precise construction methods and premium materials. Conversely, horizontal and toe rock filters are less expensive and simpler to install, but they might not be as effective at preventing seepage, which could result in more frequent maintenance over time. Additionally, even though they increase stability and seepage control, gentle core slopes require more room and building materials, which affects their viability and cost. Therefore, even though the simulation results favor configurations like flatter cores and chimney filters, actual implementation must carefully balance cost, long-term maintenance considerations, construction feasibility, and performance.




(A)




(B)



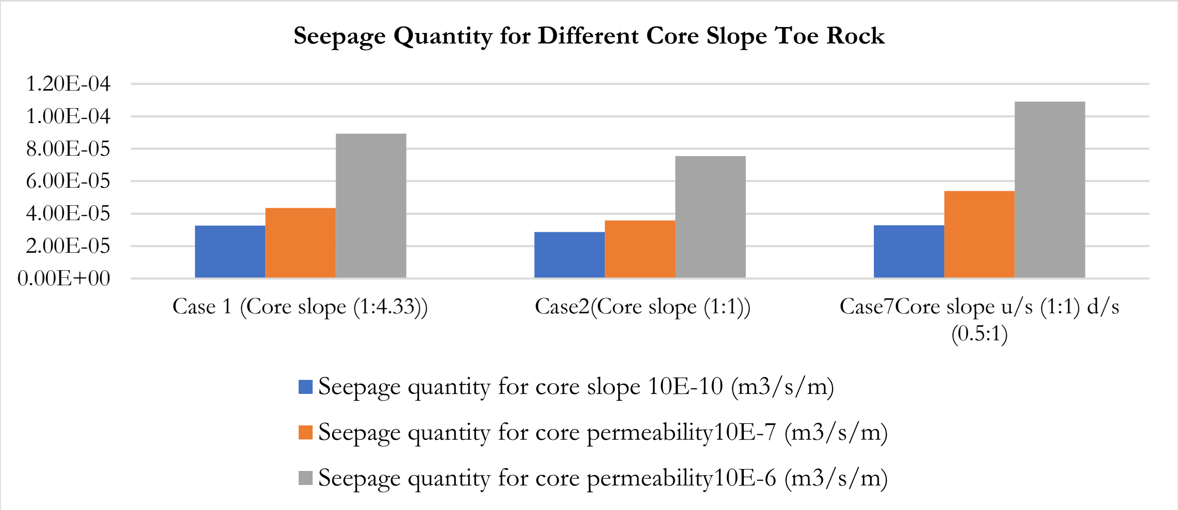

(C)

**Figure (6)**: x y-gradient vs length of the dam for three slopes of core (1:4.33), (1:1) and core slope u/s (1:1) d/s (1:0.5) A) with toe rock B) with horizontal filter C) with chimney filter

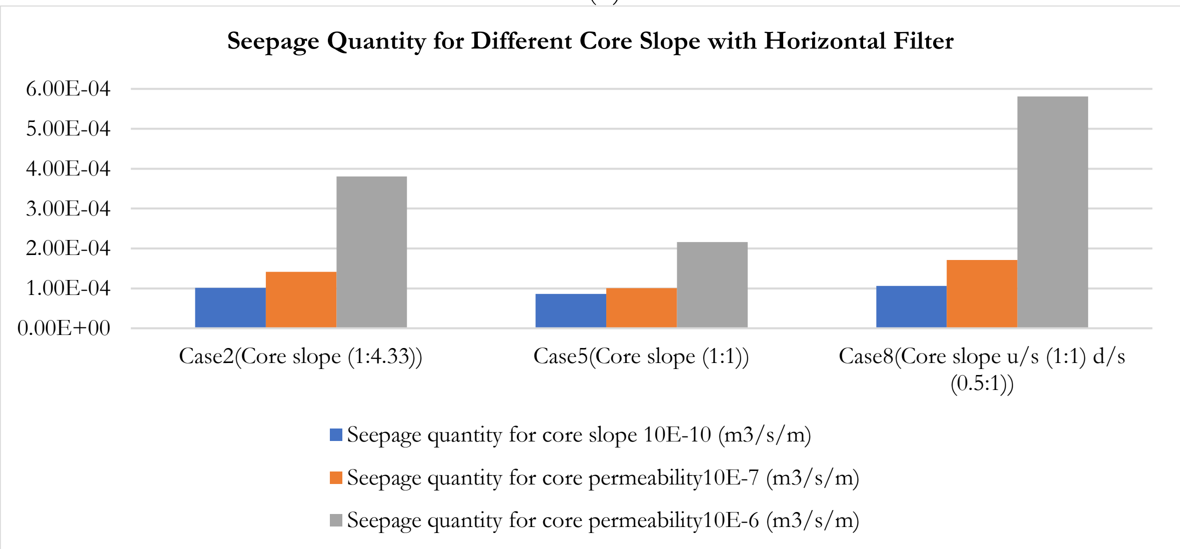
## 10.Effect of Changing the Core Permeability

Permeability is a measure of how easily water can pass through a material, so when it drops, seepage through soil or a structure also drops. A soil with low permeability has fewer or smaller pores, which makes it more difficult for water to flow through. Over time, less water can permeate the material as a result. Darcy's Law explains this relationship by demonstrating that seepage and permeability are exactly proportional.

Consequently, lowering permeability lowers the seepage rate. Permeability should be sufficient to release seepage flows and stop excessive pore water pressure from building up. Different analyses have been conducted for varying core permeability values, ranging from the maximum value ($10^{-6}$ m/s) to the minimum value ($10^{-10}$ m/s) for clay material[23]; additionally, different core slopes (1:4.33), (1:1), and inclined core (1:1) for upstream and (0.5:1) for downstream with toe rock have been made in order to examine the impact of altering the core permeability as shown in the Fig.7 Across all permeability levels, the Toe Rock filter's seepage values stay comparatively low and consistent. The seepage ranges from $2.865\times10^{-5}$ to $3.2903\times10^{-5}$ for permeability of $10^{-10}$, which is the lowest of all filter types. Seepage increases to a range of $7.5587\times10^{-5}$ to $1.0906\times10^{-4}$ when the permeability reaches $10^{-6}$, indicating a discernible but controlled increase. Seepage ranges from $3.5726\times10^{-5}$ to $5.3886\times10^{-5}$ for $10^{-7}$. The Toe Rock filter's effectiveness and dependability are demonstrated by its consistent behavior in all circumstances, particularly when it comes to reducing seepage in low-permeability settings. In comparison to the Toe Rock type, the horizontal filter exhibits higher seepage values, especially at higher permeability. Seepage can reach $3.8016\times10^{-4}$ at $k = 10^{-6}$, which is much higher than the toe rock.




(A)




(B)

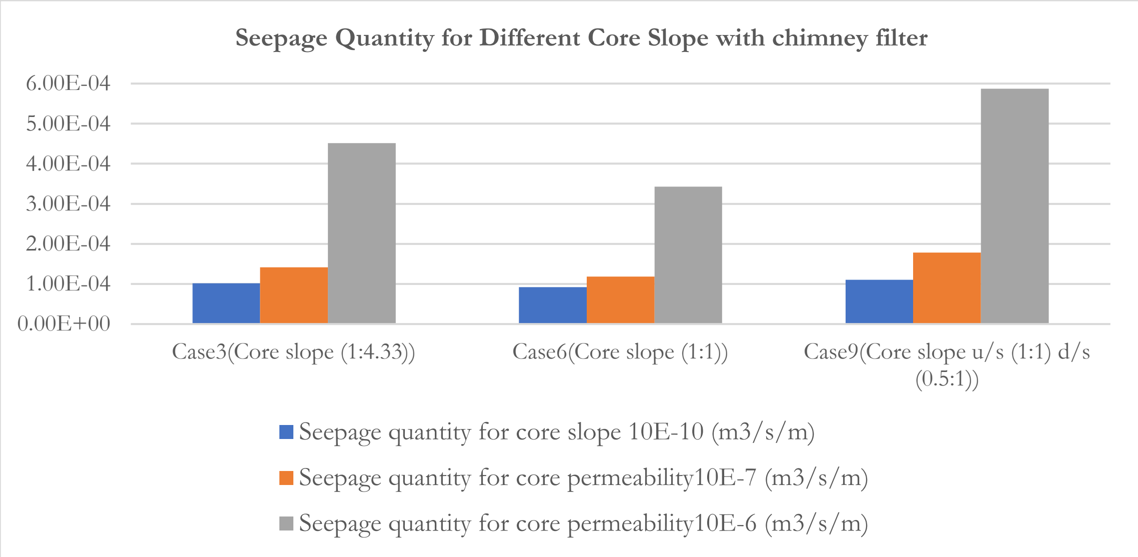



**Figure (7)**: seepage quantity for different permeability for three slopes of core (1:4.33), (1:1) and core slope u/s (1:1) d/s (1:0.5) A) with toe rock B) with horizontal filter C) with chimney filter

## 11. Conclusion

The sloping core of Horan Dam with core slope (1H:1V) with toe rock has the value of seepage 4.3587*$10^{-4}$ $m^3/s/m$, maximum pore water pressure 263.34142and hydraulic gradient 0.55. The result demonstrates that using a dam with a decreased slope of core (1:1) compared to the present slope of core (1:4.33) with a rock toe filter seems to be the most favorable. It has a relatively low seepage quantity of 4.3587*$10^{-4}$ $m^3/s/m$ compared to other cases, which mostly exhibit a higher seepage and lower hydraulic gradient of about 0.55. A lower hydraulic gradient is generally more beneficial for dam safety as it reduces the risk of piping and internal erosion, which are critical issues in dam stability. The results show using a chimney filter with a different core slope reduces maximum pore pressure distribution to about 191.52104 kPa compared with the case used another filter, which mostly exhibits a higher pore pressure of about 263.34142 kPa. Additionally, the seepage line's location varies, being under the downstream toe in Cases 1, 4, and 7; under the downstream horizontal filter in Cases 2, 5, and 8; and under the downstream transition filter in Cases 3, 6, and 9 controlled seepage paths, suggesting enhanced stability and effectiveness of the filter design in all these cases. Case 4 is likely the best option due to its balanced seepage characteristics, contributing to a more stable and efficient seepage control system.

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