Tikrit Journal of Engineering Sciences (2025); 32 (1): 1761
DOI: http://doi.org/10.25130/tjes.32.1.26

IRAQI Academic Scientific Journals

ISSN: 1813-162X (Print); 2312-7589 (Online)
Tikrit Journal of Engineering Sciences
available online at: http://www.tj-es.com

TJES Tikrit Journal of Engineering Sciences

Effect of Core Angle in Earth Dam on Seepage Characteristic (Numerical Model)

Asmaa Abdul Jabbar Jamel *, *Hiba Falah Hassan*
Civil Engineering Department, Engineering College, Tikrit University, Tikrit, Iraq.

Keywords:
SEEP/W; Seepage; Top seepage line; Angle of Core; Finite element.

Highlights:

- *Inclined central core decreasing seepage characteristic in earth dam.*
- *Statistical analysis by SPSS is effective in developing empirical equations for seepage.*
- *Finite element modeling by SEEP/W software is effective in examining seepage characteristics.*

ARTICLE INFO
Article history:

Received	04 Oct. 2023
Received in revised form	08 Jan. 2024
Accepted	12 Feb. 2024
Final Proofreading	30 Aug. 2024
Available online	25 Mar. 2025

Citation: Jamel AAJ, Hassan HF. **Effect of Core Angle in Earth Dam on Seepage Characteristic (Numerical Model)**. *Tikrit Journal of Engineering Sciences* 2025; **32**(1): 1761.
http://doi.org/10.25130/tjes.32.1.26

***Corresponding author:**
Asmaa Abdul Jabbar Jamel
Civil Engineering Department, Engineering College, Tikrit University, Tikrit, Iraq.

Abstract: Seepage through earth dams causes seepage forces, pore water pressures, and hydraulic gradients. These forces could create piping, sloughing, or sliding, which could fail an earth dam if not kept within the allowable ranges. Consequently, seepage analysis is critical in the design of any hydraulic construction. In this study, the finite element modeling method by SEEP/W software was used to examine seepage characteristics through earth dams with the central core at an angle of (α=90°,50°, and 30°) for different dam materials and geometries under steady-state conditions. The results indicated that the reduction of seepage through the earth dam body increased as the core slope decreased, while it increased with increasing the permeability ratio and the upstream head. The core slope angle of 30° was the most effective of those evaluated in decreasing seepage discharge, exit gradient, and top seepage line at the core's faces. Also, using the statistical analysis program SPSS to develop empirical equations, to estimate seepage through the earth dam with a central core and top seepage intersecting core slope. The correlation coefficient (R^2) was greater than 0.95 and 0.98 for the suggested seepage and top seepage equations line, respectively.

تأثير الزاوية المركزية في السدود على خصائص التسرب (نموذج عددي)

أسماء عبدالجبار جميل، هبه فلاح حسن
قسم الهندسة المدنية / كلية الهندسة / جامعة تكريت / تكريت – العراق.

الخلاصة
يتسبب التسرب عبر السد في قوى التسرب وضغوط مياه المسامي والتدرجات الهيدروليكية. فقد تؤدي إلى ظاهرة النحر وانزلاق السد، وكلاهما يمكن أن يؤدي إلى فشل السد. ان لم تكن ضمن الحدود المسموحة. وبالتالي، فإن دراسة التسرب مهم جدًا في تصميم السدود الترابية. في هذه الدراسة، استخدمت طريقة العناصر المحدودة بواسطة برنامج SEEP/W لتحليل خصائص التسرب عبر السدود الترابية ذات اللب المركزي بزاوية(90, 30,50=α) لمختلف مواد السد والابعاد الهندسية في حالة الجريان المستقر. اظهرت نتائج الدراسة أن نسبة الانخفاض في التسرب عبر جسم السد الأرضي يزداد مع انخفاض ميل اللب، بينما يزداد مع زيادة نسبة النفاذية، وارتفاع الماء عند مقدم السد. كما لوحظ ان زاوية اللب (30°) هي الأكثر فعالية في تقليل التسرب وتدرج الخروج وخط التسرب العلوي. كما تم استخدام التحليل الاحصائي بواسطة برنامج الحاسوبي SPSSلإيجاد معادلات وضعية، لتخمين كمية التسرب لسد ذي لب مركزي وارتفاع خط التسرب عند تقاطعه مع اللب. معامل التقارب كان أكبر من 0.95 و 0.98 للمعادلات المقترحة لكل من التسرب وخط التسرب الأعلى على التوالي.

الكلمات الدالة: SEEP/W ، التسرب، خط التسرب العلوي، زاوية القلب، عنصر محدود.

1.INTRODUCTION

Earth dams are widely used worldwide due to suitable materials' availability and flexibility. Dams are used for various purposes, including flood control, irrigation, and hydroelectric power generation. Fully homogenous embankment dams and inhomogeneous embankment dams (zoned and diaphragm) are examples of earth-fill dams. The wetted area height on the dam's downstream face is decreased using a core to prevent seepage through the dam and lower the phreatic level [1]. Many seepage issues and earth dam failures have been caused by insufficient seepage control methods or inadequate cleanup and preparation of the base and abutments [2]. Seepage through the dam imposes seepage forces, pore water pressures, and hydraulic gradients. These forces may result in piping and embankment sloughing or sliding if forces are not within permissible ranges, both of which can cause dam failure [3]. Many studies have focused on monitoring the effect of static loads on the dam body. Noori and Ismaeel [4] studied the Duhok zoned earth dam with a central clay core using a finite element SEEP2D. The results showed that the amount of seepage increased with the permeability ratio (K_x/K_y). Shakir [5] used SEEP/W analysis, for two cases of core: vertical core and inclined core toward the upstream side. The study showed that the quantity of seepage was reduced as the ratio of shell to core permeability increased. Doubling the core base thickness might reduce the quantity of seepage. While the inclination of the core toward the upstream side slightly increased the seepage quantity. Irzooki and Jamel [6] used the Hele-Shaw model to simulate the seepage flow through a homogenous earth dam with a horizontal filter. The results indicated that the unit discharged through the earth dam body increased as decreasing upstream and downstream slopes. Also, the results showed that the unit discharge through the earth dam body increased with increased hydraulic conductivity. Moayed et al. [7] studied homogeneous earth dams with an impermeable foundation and symmetrical in-zone section. ABAQUS found that the toe drain prevented erosion of the downstream toe and its efficiency as the dam water table in the reservoir increased. Talebi et al. [8] studied a cross-section of a Silver dam and found that the core slope substantially influenced the soil arching and the associated load transfer from the core to the shell materials. Therefore, reducing the side slopes of the core significantly reduced soil arching. Fattah et al. [9] studied an earthen dam for unsteady flow conditions with a sloping core for the Al-Adhaim dam. The result showed that the flow rate at the dam downstream decreased with time due to the rapid flow of water caused by emptying the reservoir in a short period. Irzooki [10] investigated a homogenous earth dam with a horizontal toe drain using SEEP/W. The findings proposed a new equation for calculating the amount of seepage. Zedan et al. [11] studied the Khasa-Chai dam using SEEP/W. The results showed that the exit gradient would decrease, and the quantity of seepage would increase as the permeability ratio (K_{shell}/K_{core}) increased. Abass and Najeeb [12] evaluated the Al-Shahabi dam in Wasit/Iraq using SEEP/W. The findings indicated that seepage through the earth dam increased with the dam reservoir's upstream head. Also, as the height of the upstream head increased, the exit gradient increased. Salem [13] experimentally and numerically studied the state seepage through an earth embankment with the internal core. The numerical analysis was verified using an experimental model, with a difference of 18%. Abdel-Kawy et al. [1] used computer models SEEP2D and SEEP/W to simulate seepage through earth dams with internal cores. It was discovered that the vertical and wedge-shaped cores successfully reduced the phreatic line level and seepage discharge at the downstream face of the core. The core slope slightly affected seepage and intersected the seepage line with the upstream core, especially when the hydraulic conductivity of the core (K_{core}/K_{shell}) was lower than 0.01. The present study aims to reduce the seepage effect in the earth dam using different incline central cores with constant cross-section area. The results of the SEEP/W software and computing general empirical equations were used to analyze the flow characteristics, i.e., seepage, exit gradient, and phreatic surface.

2.SEEP/W MODEL

SEEP/W is a finite element software product part of the international model GEO-SLOPE, the chief in geotechnical modeling products. It helps analyze groundwater infiltration and excessive pore water pressure in porous materials, such as soil and rock [14]. SEEP/W is formulated on the basis that the water flow through saturated and unsaturated soil follows Darcy Law's proposition, showing that flow through soil is laminar and can be used to describe water flow through soils in saturated and unsaturated conditions. The discharge velocity (v) is proportional to the hydraulic gradient (i). Darcy's law is thus Eq. (1) and (2):

$$\mathbf{Q = kiA} \tag{1}$$

$$\mathbf{q = kiy} \tag{2}$$

The Laplacian equation represents seepage flow through a homogeneous, isotropic media in steady-state conditions, as shown in Eq. (3) [15].

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2} = 0 \tag{3}$$

Also, for two–dimensional seepage, Eq. (4) can be expressed as:

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial H}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial H}{\partial y}\right) + Q = \frac{\partial \theta}{\partial t} \tag{4}$$

3.STUDY MODELS

3.1.Mesh Properties

The mesh convergence analysis used the numerical model with the highest element mesh, i.e., the element mesh edge length was 0.5. Figure 1 shows the comparison charts of seepage curves for the size distance of 3, 0.5, 1,0.5, 0.25, and 0.1 m. The mesh convergence analysis found that global element size with a minimum mesh size of 0.1 m and maximum mesh size of 3 m can give a stable model with very similar deflection with the finer mesh size. The lowest errors occurred when used at a global element size of 0.5 m. Table 1 describes the mesh convergence analysis for the problem. The present study utilized the elements of the quadrant and triangle shapes, with the number of elements reaching 18651 and the node number exceeding 19045, while the global size distance was around 0.5 m, as shown in Fig. 2.

3.2.Boundary Condition and Applied Load

In the present study, the constant total head (H) boundary condition was used to specify the steady state condition. While along the downstream face of the dam, a potential seepage face was also identified as a boundary condition through a zero-flux (Q = 0), which indicated that no additional flux could be added or removed at these nodes, Fig. 3. This boundary condition ensures that there would be no accumulation or ponding of water on the downstream face, in case the phreatic surface or any flow lines intersect with the slope Talukdar and Dey [15].

Table 1 Mesh Convergence Analysis.

Global element size	Nodes number	Element number	Discharge (m³/sec)
3	547	486	0.001315773
1.5	2033	1910	0.001318429
1	4453	4267	0.001320854
0.5	19045	18651	0.001353572
0.25	67064	66396	0.001353573
0.1	371257	370429	0.001353748

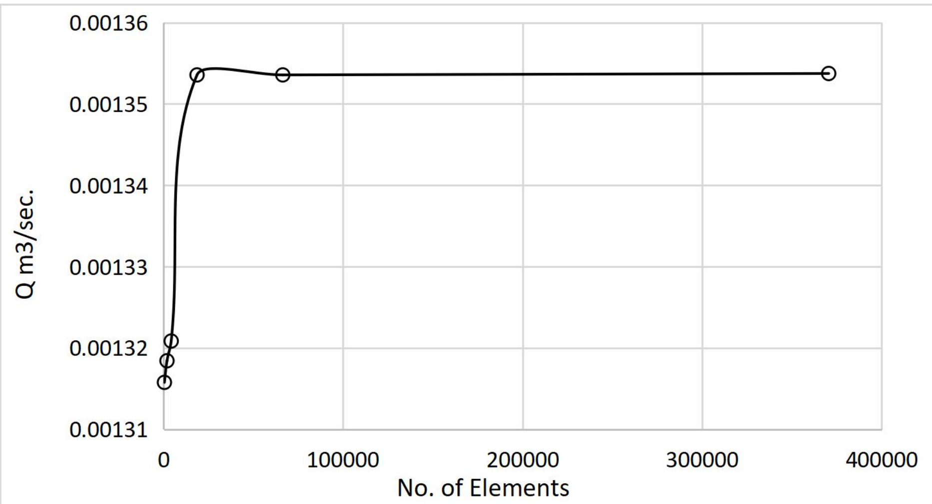

Fig. 1 Mesh Convergence Analysis (MCA).

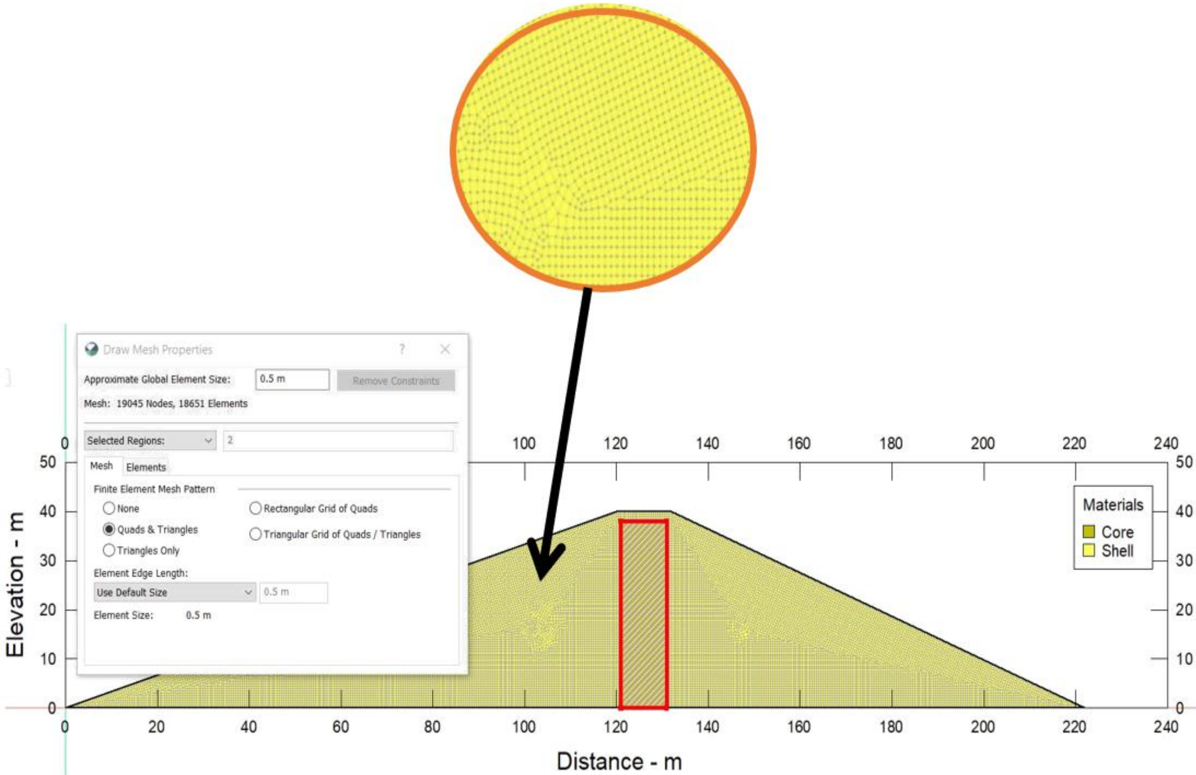

Fig.2 Mesh Approach for Earth Dam with Vertical Core (Current Study).

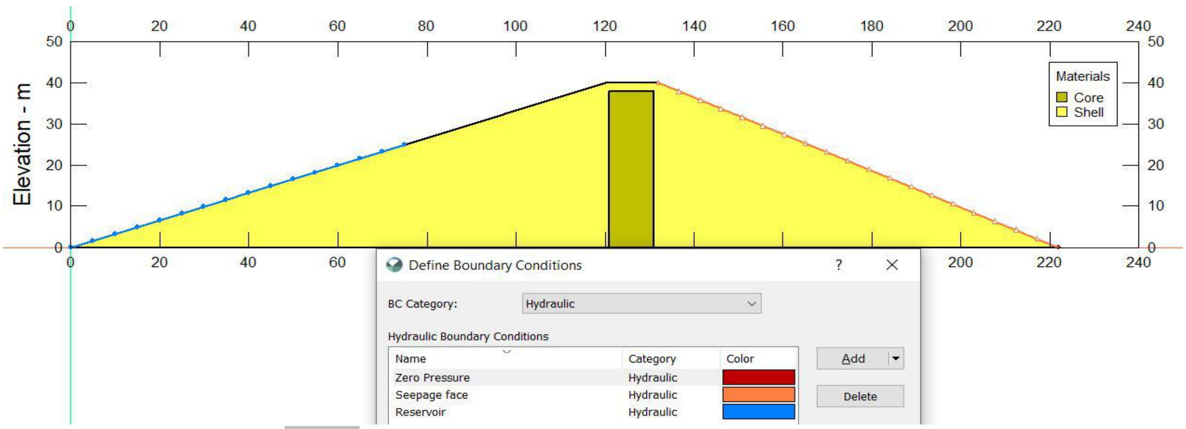

Fig. 3 Boundary Conditions SEEP/W (Current Study).

3.3. Numerical Simulation

Figure 4 shows the cross-section model for the present study. Using three incline cores (with a constant area) at $\alpha(90°, 50°,\ and\ 30°)$. For each core model, three groups of the upstream slope (U/S), upstream head (h_w), and permeability of the core (K_{core}) of the shell (K_{shell}) were applied, as shown in Fig. 5. As a result, 243 runs were submitted in SEEP/W software. For each run test, the quantity of seepage through the earth dam (q), exit gradient (i), and height of the phreatic surface at intersecting points with upstream and downstream core slopes (Y_1, Y_2) were determined.

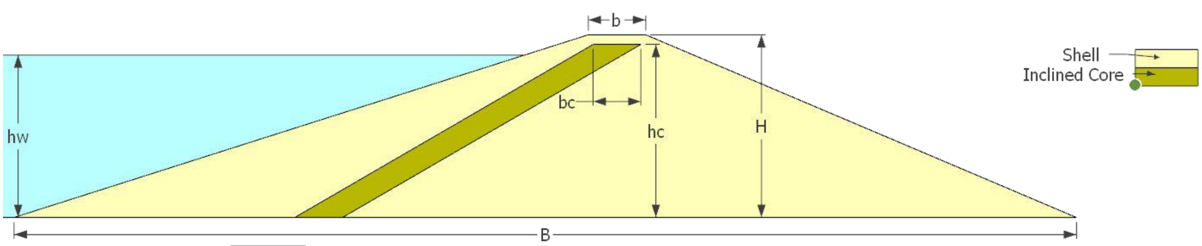

Fig. 4 Earth Dam Section (Present Study), α = 90°,50°, and 30°.

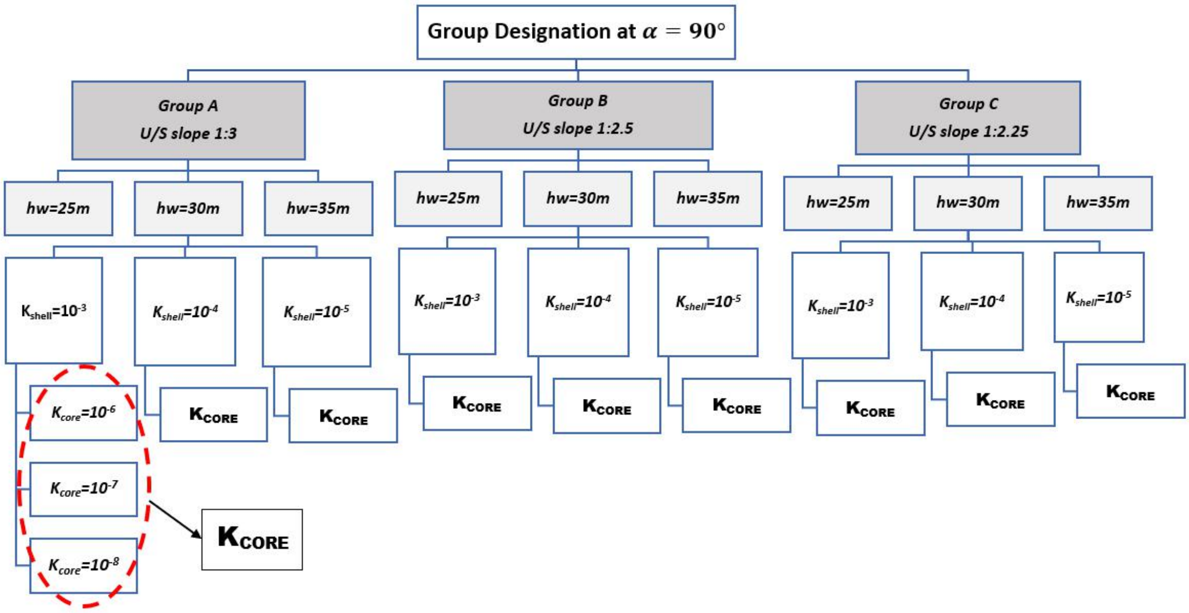

Fig. 5 Schematic of Groups of Model Tests for Each Angle (α), where K_{shell} and K_{core} in (m/sec); No. of Tests (81).

4.RESULTS AND DISCUSSION

The dam body was investigated by obtaining the effect of all variables of seepage characteristics, examining the slope stability for upstream and downstream to be at a safe state in all cases.

4.1.Reduction in Seepage Quantity

Figures 6 and 7 represent the relationship between the normalized quantity of seepage reduction (Q_r) with permeability ratio (K_{shell}/k_{core}) at (semi-log) scale for three head ratios (H/h_{w1} = 40m/25m), (H/h_{w2} = 40m/30m), (H/h_{w3} = 40m/35m), and upstream and downstream slopes (V: H) 1:3, and 1:2.25. Figure 6 shows the relationship between discharge reduction (Q_r), defined as the ratio of the difference between ($q/k_{shell}\,h_c$) for the case of ($\alpha = 90°$) with ($\alpha = 50°$) for five ratios (k_{shell}/k_{core}), i.e., 10, 10^2, 10^3, 10^4, and 10^5). As the ratio of (k_{shell}/k_{core}) increased, the reduction (Q_r) increased, which agrees with (Shakir [5] and Abdel-Kawy et al. [1]). Discharge reduction (Q_r) reached its maximum value, i.e., 13.47, 5.85, and 2.32 % in the case of H/h_{w1}, H/h_{w2}, and H/h_{w3}) respectively, for (k_{shell}/k_{core}) = (10^4). While at (k_{shell}/k_{core}) $\geq 10^4$, the reduction Q_r seemed to be a linear constant value. It was noticed that increasing the upstream head decreased Q_r. Therefore, the inclined core with ($\alpha = 50°$) significantly affected the reduction of seepage quantity through the earth dam, reaching 13.6%. Figure 7 shows the relationship between the discharge reduction (Q_r) for ($\alpha = 90°$) and ($\alpha = 30°$). The results showed that as the ratio of k_{shell}/k_{core} increased, Q_r increased. Its maximum value reached 24.15, 14.95, and 7.95 % for H/h_{w1}, H/h_{w2}, and H/h_{w3}, respectively, for (k_{shell}/k_{core}) less than 10^4. For (k_{shell}/k_{core}) $\geq 10^4$, Q_r seemed to be a linear constant value. It was noticed that increasing the upstream head decreased Q_r. Therefore, the inclined core with ($\alpha = 30°$) significantly affected the reduction of seepage quantity through the earth dam, reaching 24.39%. The difference in the behavior of the angle between (50° and 30°) is that the discharge reduction at $\alpha = 30^\circ$ was higher than at $\alpha = 50^\circ$ by 24.39%. The present study developed an empirical equation that can be used to estimate the amount of steady-state seepage through the earth dam with a core of different slopes. A statistical analysis by SPSS was conducted using the resulting data of the SEEP/W program for different cases mentioned previously. Equation (5) was created using approximately two-thirds of these data, while Table 2 shows a validation of non-linear regression models, which shows good agreement:

$$\boldsymbol{Q = 3.38 * 10^{-8} h_w^{1.29} B^{2.54} K_{core}^{0.009} K_{shell}^{0.923} (U/S)^{-1.112} \alpha^{0.097}} \qquad \textbf{(5)}$$

Figure 8 shows the relationship between the remaining one-third of the results of the unit discharge through the homogenous earth dam with core estimated from the SEEP/W program and those computed from Eq. (5) using the same characteristics and geometry boundary conditions. It can be seen that the program and equation results agree very well within a value of less than 5%.

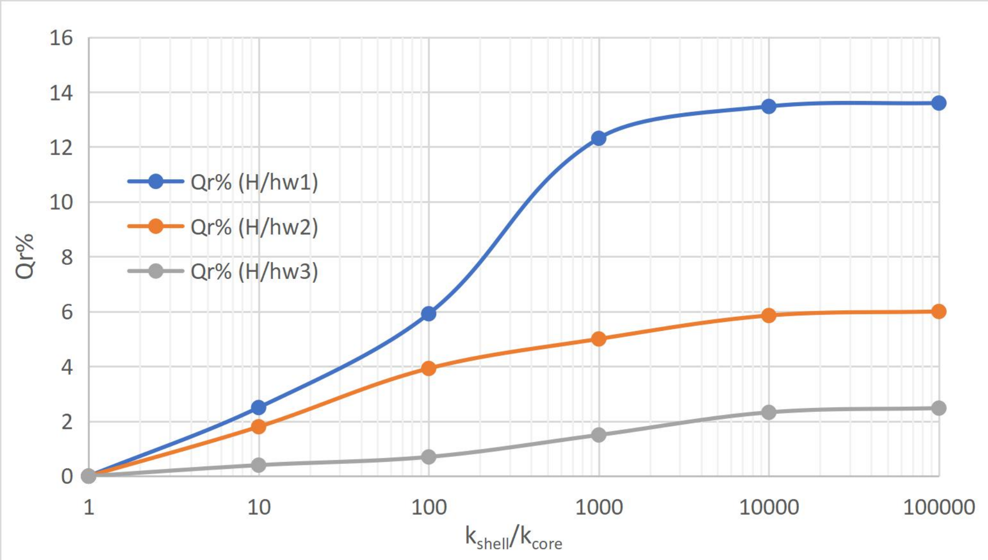

Fig. 6 Effect of the Seepage Reduction (Q_r %) with (K_{shell}/K_{core}), at U/S 1:3, $\alpha = 50°$.

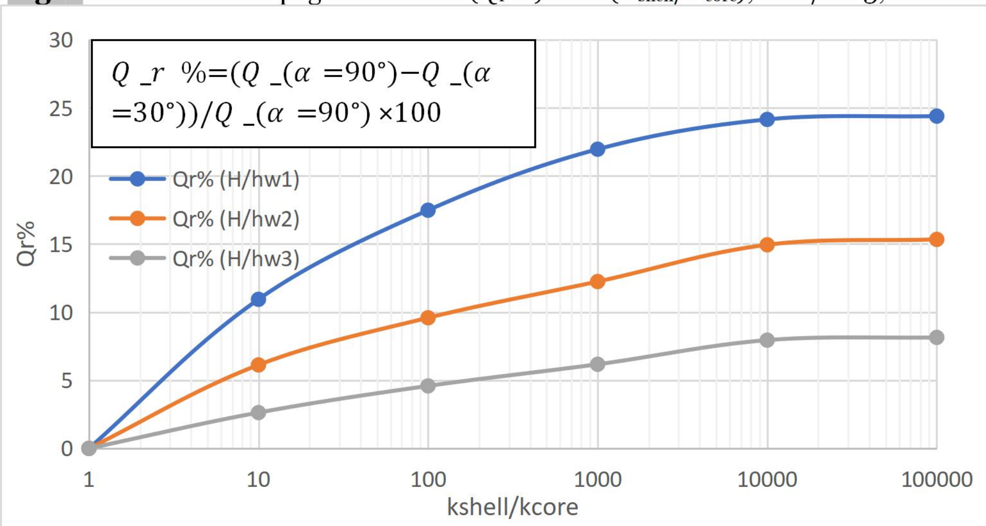

Fig. 7 Effect of the Seepage Reduction (Q_r%) with (K_{shell}/K_{core}), at U/S 1:3, $\alpha = 30°$.

Table 2 Validation of Non-Linear Regression Discharge Model.

Model	R²% (Coefficient of Correlation)	MAPE% (Mean Absolute Error)	AA% (Average Accuracy)
Q Static (Eq.5)	0.957	6.37	93.63

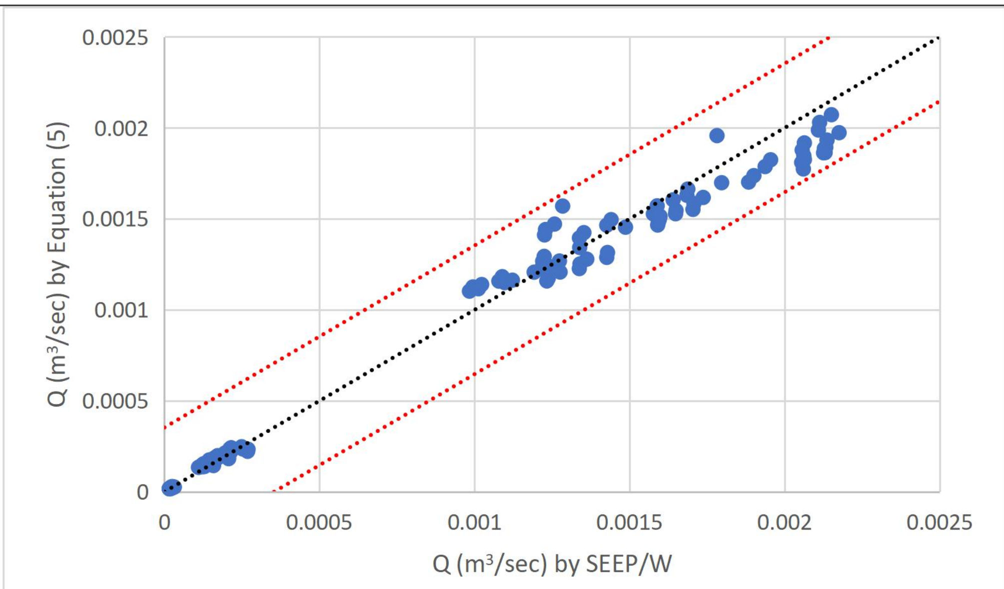

Fig. 8 Relationship Seepage Quantity Computed by Eq. (5) and Estimated by SEEP/W.

4.2.Exit Gradient Behavior

Upward seepage at the toe of the earth dam caused local soil instability, leading to erosion. A process of gradual erosion and undermining of the dam may begin. This type of failure, piping, has been a common cause of the total failure of earth dams. The initiation of piping starts when the exit hydraulic gradient of upward flow is close to the critical hydraulic gradient. The factor of safety against piping is defined as $\left[F.S = \frac{i_{crtical}}{i_{exit}}\right]$ [2]. Figure 9 represents the relationship between exit gradient (i_e) with permeability ratio (k_{shell}/k_{core}) (semi-log) scale for three angles of core ($30^{\circ}, 50^{\circ}$, and 90°) with upstream and downstream slopes of (V: H) 1:3, 1:2.25, respectively. As the ratio (k_{shell} / k_{core}) increased, the exit gradient decreased, which agrees with Fattah et al. [9], and Zedan et al. [11]). Also, as the permeability ratio (k_{shell}/k_{core}) increased from (0.001 to 0.01), the rate of decrease was an average of 0.025% for ($\alpha = 90°$ *and* $50°$) and 0.005% for ($\alpha = 30°$). As a result, the influence of permeability on lowering exit gradient values at an angle less than ($\alpha = 30°$) was minimal. Additionally, as the slope of the core increased, the values of the exit gradient increased. The increase in exit gradient values caused by decreasing the slope from 90° to 50° had a slight effect, about 0.008%. However, decreasing the slope from 90° to 30° increased the exit gradient by 13.27%. Therefore, as a result, ($\alpha = 30°$) increased in the exit gradient greater than its value at the slope of ($\alpha = 50°$) by 13.27%. Figure 10 shows the relationship between (k_{shell}/k_{core}), with a factor of safety against piping for ($\alpha = 50^{\circ}$). The safety factor against piping increased by increasing the permeability coefficient, particularly by reducing the core's permeability. For each case of H/h_{w1}, H/h_{w2}, and H/h_{w3}, respectively. Increasing the permeability from (0.001 to 0.01) noticeably increased the factor of safety against piping by (0.045, 0.022, and 0.027) % for (H/h_{w1}, H/h_{w2}, and H/h_{w3}), respectively. For a permeability value greater than 0.01, a factor of safety against piping by increasing 0.02%. It can also be noted that the lowest factor of safety was about 3.37, higher than the minimum value of 3 [2]. Therefore, in all cases for the present study, the dam was safe against piping.

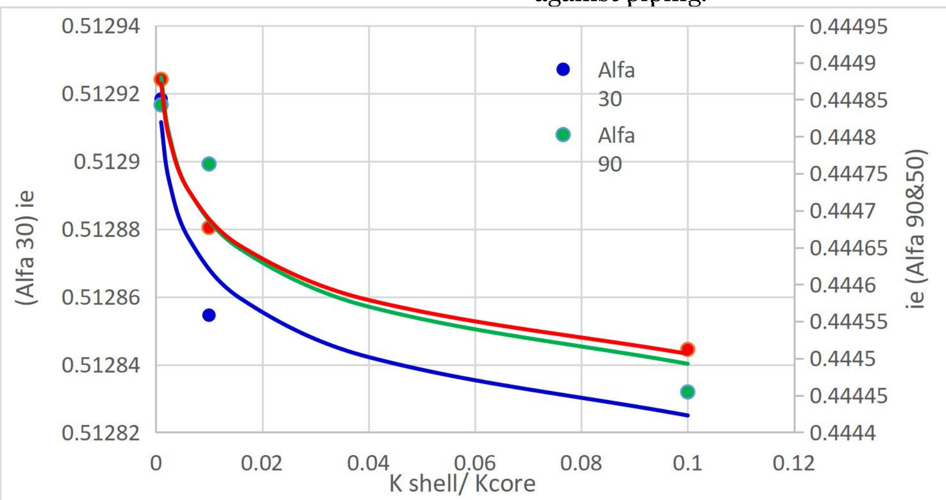

Fig. 9 Relationship between Exit Gradient to k_{shell}/k_{core} of k_{shell} (10^{-6}), $h_{w=}25$, U/S 1:3, D/S 1: 2.25.

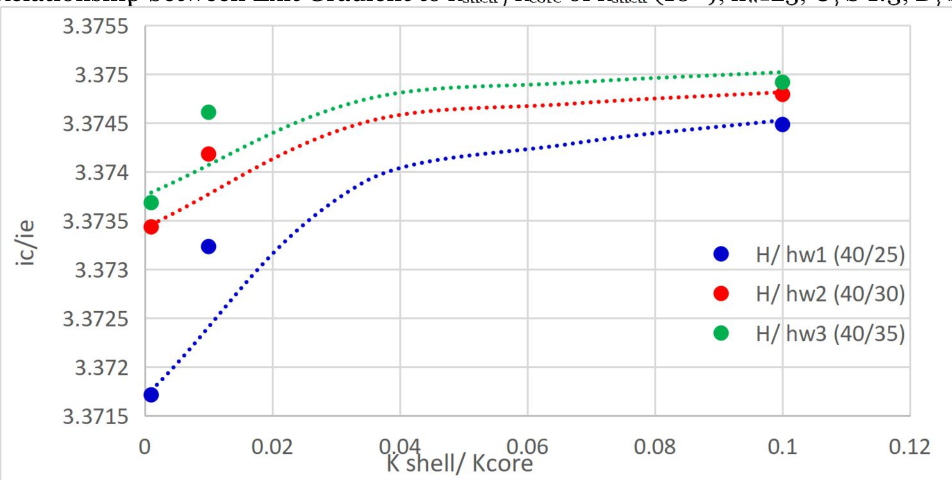

Fig. 10 Relationship between k_{shell}/k_{core} with a Factor of Safety Against Piping at U/S 1:3, D/S 1: 2.25, $\alpha = 50°$.

4.3.Top Seepage Line (Y_1 and Y_2)

The central core would lower the top seepage line inside the body of the body, as a result lowering the dangers of seepage. Figure 11 shows the relationship between the top seepage line elevation intersecting the core upstream and downstream Y_1 and Y_2, respectively. It is noted that increasing the slope upstream slightly affected the values of Y_1 and Y_2. Also, increasing upstream heads (h_{w1}, h_{w2}, and h_{w3}) affect the values of Y_1 and Y_2. The high upstream head values resulted in the maximum values in Y_1 and Y_2. Also, increasing the permeability of the core and shell insignificantly impact on Y_1 and Y_2. Figure 12 shows the relationship between the reduction $\%\Delta Y$ with ($\alpha = 90^{\circ}, 50^{\circ}$, and 30°). The figure shows that the reduction of $\Delta Y\%$ increased whenever the angle of the core decreased. The reduction percentage ΔY% at α= 90° and α=50° was about 55.84 % and 56.86 %, respectively. While the maximum ratio of the reduction %ΔY was 60.015% at ($\alpha = 30°$). A statistical program SPSS used to develop equations for computing the Y1 and Y2 through the earth dam with the central core is expressed in Eq. (6) and (7):

$$\boldsymbol{Y_1 = 0.93 * h_w{}^{1.054} * (K_{shell}/K_{core})^{0.000164} * U/S^{-0.01389}\alpha^{-0.03135}} \quad \mathbf{(6)}$$

$$\boldsymbol{Y_2 = 0.158 * h_w{}^{3.823} * (K_{shell}/K_{core})^{-0.002} * U/S^{-0.074}\alpha^{-0.012}Y_1{}^{-2.512}} \quad \mathbf{(7)}$$

Figure 13 shows the relation between the remaining one-third of the results of Y_1 and Y_2 were estimated from the SEEP/W program, and those computed from Eq. (6) and (7) using the same characteristics and geometry boundary conditions. From this figure, a very good agreement between the results of the program SEEP/W and equations can be seen. Additionally, Table 3 shows the non-linear equations validation.

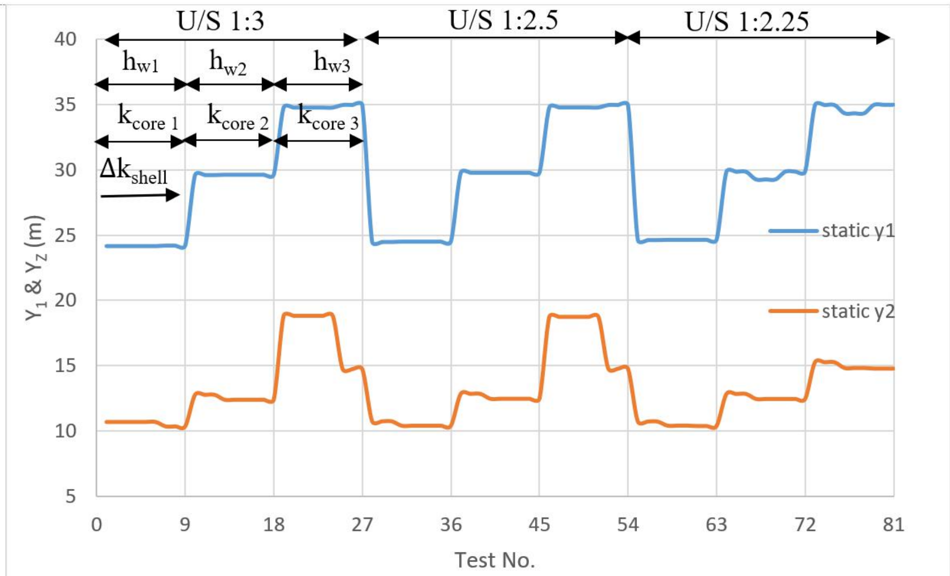

Fig. 11 Comparison between Y_1 and Y_2 for (81 Runs) D/S 1: 2.25, $\alpha = 50°$.

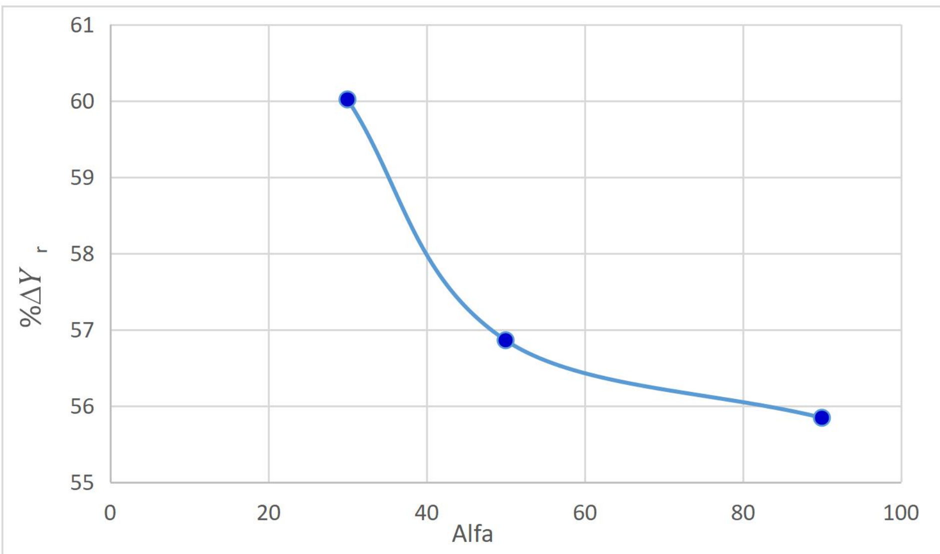

Fig. 12 Reduction of $\%\Delta Yr$ with Core Slope (α), h_w=30m.

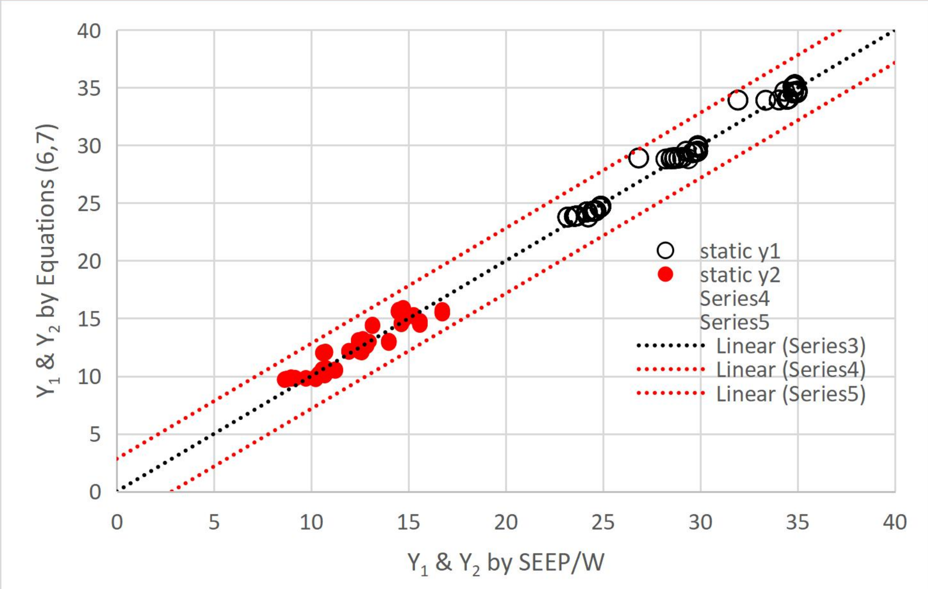

Fig. 13 Relationship between Y_1 and Y_2, Computed by Eq. (6) and (7) Estimated by SEEP/W.

Table 3 Validation of Non-Linear Regression Models.

Model	R²% (Coefficient of Correlation)	MAPE% (Mean Absolute Error)	AA% (Average Accuracy)
Y_1 (Eq. 6)	0.982	7.85	92.15
Y_2 (Eq. 7)	0.992	6.22	93.78

5.CONCLUSIONS

The present is concerned with studying the seepage flow across the earth dam with a central core using (SEEP/W). The following points summarize the conclusion of the present study:

- The reduction of seepage through earth dams with core increased at various rates, with a decrease in the height of upstream water, decreasing core slope, and the permeability ratio.
- The angle of core (α) was the most affecting geometrical variable on the seepage discharge, where inclined core with (α=50° and α=30°) significantly affected the reduction of seepage quantity through the earth dam, reaching 13.6% and 24.39%, respectively.
- The factor of safety against piping increased with the coefficient of permeability.
- The factor of safety against piping increased with the upstream head, recording the lowest safety factor of about 3.37 at α 30°.
- Increasing the permeability of the core and shell insignificantly impacted y_1 and y_2; therefore, it may be neglected.
- The seepage discharge, exit gradient, and y_1 and y_2 were all clearly impacted by decreasing the core slope. As for the core slope $\alpha = 30°$, the exit gradient increased by 24.39%, the reduction discharge ratio decreased by about 24.39%, and the reduction in Δ y increased by 60.015%.
- The present study proposes the empirical equations for different core angles with high validation in coefficient of correlation more than 0. 95,0.98, and 0.99 for (seepage, Y1, and Y2), respectively.

NOMENCLATURE

α	Core Slope.
Δy	Reduction of Top Seepage Line.
b	Top Width of Dam (L).
bc	Top Width of Core (L).
D/S	Downstream Dam Slope.
H	Height of Dam (L).
hc	Height of Core (L).
h_w	Upstream Head (L).
ic	Critical Exit Gradient.
ie	Exit Gradient.
K_{core}	Hydraulic Conductivity of Core (L/T).
K_{shell}	Hydraulic Conductivity of Shell (L/T).
q	Seepage Discharge Per Unit Width (L^3/T/M).
Q	Seepage Discharge (L^3/T).
R^2	Coefficient of Determination.
U/S	Upstream Dam Slope.
Y_1	Phreatic Level at the Core Upstream Face (L).
Y_2	Phreatic Level at the Core Downstream Face (L).
Qr	Reduction of Seepage.

REFERENCES

[1] Abdel-Kawy A, Aboulatta N, El-Molla D. **Effects of Core Characteristics on Seepage Through Earth Dams**. *Water Practice and Technology* 2021; **16**(4):1248–1264.

[2] Manual Engineer. **Earth and Rock-Fill Dams-General Design and Construction Considerations.** US Army 1994.

[3] Omofunmi O, Kolo J, Oladipo A, Diabana P, Ojo A. **A Review on Effects and Control of Seepage through Earth-Fill Dam**. *Current Journal of Applied Science and Technology* 2017; **22**(5): 1–11.

[4] Noori B, Ismaeel K. **Evaluation of Valuation of Seepage and Stability of Duhok Dam**. *Al-Rafidain Engineering Journal* 2011; **19**(1):42–58.

[5] Shakir R. **Effect of an Impervious Core Constructed into a Large Earth Dam on the Quantity of Seepage**. *Thi-Qar University Journal of Engineering Science* 2011; **2**(2): 1-17.

[6] Irzooki, R, Jamel A. **Experimental Study of Characteristics of Top Seepage Line through Homogenous Earth Dam Using Hele-Shaw Model**. *International Review of Civil Engineering* 2012; **20**(10): 1-8.

[7] Moayed R, Rashidian V, Izadi E. **Evaluation of Phreatic Line in Homogenous Earth Dams with Different Drainage Systems**. *2nd Annual USSD Conference on Innovative Dam and Levee Design and Construction for Sustainable Water Management Civ 2012*; Iran.

[8] Talebi M, Vahedifard F, Meehan C. **Effect of Geomechanical and Geometrical Factors on Soil Arching in Zoned Embankment Dams**. In: *Geo-Congress: Stability and Performance of Slopes and Embankments III* 2013; 1056-1065.

[9] Fattah M, Omran, H, Hassan M. **Behavior of an Earth Dam During Rapid Drawdown of Water in Reservoir - Case Study**. *International Journal of Advanced Research* 2015; **3**(10): 110–122.

[10] Irzooki, R. **Computation of Seepage through Homogenous Earth Dams with Horizontal Toe Drain**. *Engineering and Technology Journal* 2016; **34**(3):430–440.

[11] Zedan, A, Faris M, Abdulsattar A. **Seepage Analysis through an Earth Dam (KHASA-CHAI Dam) as a Case Study**. *Engineering and Technology Journal* 2017; **35**(2A): 172–181.

[12] Abbas A, Najeeb A. **Analysis of Seepage through Embankment Dams as Case Study (Al-Shahabi Dam) in Iraq.** *International Journal of Sciences: Basic and Applied Research (IJSBAR) International Journal of Sciences: Basic and Applied Research* 2018; **40**(2): 7–17.

[13] Salem M. **Analysis of Seepage through Earth Dams with Internal Core.** *International Journal of Engineering Research* 2019; **8**(08): 768–777.

[14] GEO-SLOPE International . **Seepage Modeling with SEEP/W Calgary**.1st ed.; Canada: 2015.

[15] Talukdar P, Dey A. **Finite Element Analysis for Identifying Locations of Cracking and Hydraulic Fracturing in Homogeneous Earthen Dams**. *International Journal of Geo-Engineering* 2021; **12**(10): 1-26.