Comparison of Seepage Trough Zoned Earth dam Using Improved Light-Textured Soils

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ABSTRACT

Seepage through earth dams is one of the most popular causes for earth dam collapse due to internal granule movement and seepage transfer. In earthen dams, the core plays a vital function in decreasing seepage through the dam body and lowering the phreatic line. In this research, an alternative soil to the clay soil used in the dam core has been proposed by conducting multiple experiments to test the permeability of silty and sandy soil with different additives materials. Then the selected sandy soil model was used to represent the dam experimentally, employing a permeability device to measure the amount of water that seeps through the dam's body and to represent the seepage line. A numerical model was adopted using Geo-Studio software in the branch (SEEP/W) to simulate the experimental model, examined soils with different percentages of additives, and compared the numerical and experimental results to predict the innovation model of soil. It was found that the sandy type (C) soil model has a permeability very close to that of clay soil when using 10% cement kiln dust (CKD) and 5% cement as additives. Furthermore, soil type (C) was calibrated with the core soil of HIMREEN Earth dam, which is clay soil, as well as with the core soil of HADITHA Earth dam, which is composed of dolomite. The comparison between the results of the hypothetical simulated cases and the real cases were revealed a high agreement between the two cases according to the resulted of identical phreatic (seepage) lines and the calculated amount of seepages water from these cases.
Keywords: Light-textured soils, core, Geo-Studio, zoned earth dam.

مقارنة التسرب عبر سد ترابي طبقي باستخدام تربة محسنة ذات نسجة خفيفة

الخلاصة

يعد التسرب عبر سدود الأرض أحد الأسباب الأكثر شيوعًا لانهيار سد الأرض بسبب حركة الحبيبات الداخلية ونقل التسرب. في السدود الترابية ، يلعب اللب دورًا حيويًا في تقليل التسرب وخفض خط التعرق عن طريق تقليل التسرب عبر جسم السد. في هذا البحث تم اقتراح تربة بديلة للتربة الطينية المستخدمة في قلب السد من خلال إجراء تجارب متعددة لاختبار نفاذية التربة الغرينية والتربة الرملية

باسـتخدام مــواد مضــافة مختلفـة. ثــم تــم اسـتخدام نمــوذج التربــة الرمليـة المختــار لتمثيـل السـد تجريبيـاً بواسـطة جهـاز نفاذيـة لقيـاس كميـة الميـاه التـي تتسـرب عبـر جسـم السـد ولتمثيـل خـط التسـرب. تـم اعتمـاد نمـوذج رقمـي باسـتخدام برنـامج GeoStudio بفرعـه SEEP/W لمحاكـاة النمـوذج التجريبـي ، وفحـص التربـة بنسـب مختلفـة مـن المـواد المضـافة ، ومقارنـة النتـائج العدديـة والتجريبيـة للتنبـؤ بنمـوذج الابتكـار للتربـة. وجـد أن نمـوذج التربـة الرمليـة مـن النـوع (C) لـه نفاذيـة قريبـة جـدًا مـن التربـة الطينيـة ، باسـتخدام 10٪ غبــار قمــائن الأســمنت (CKD) و 5٪ أســمنت كمضــافات. عــلاوة علــى ذلـك ، تمـت معـايرة نـوع التربـة (C) كتربـة أساسـية لـسد حمـرين مـن لـب التربـة الطينيـة وكتربـة أساسـية لـسد حديثـة مـن لـب مـن الـدولوميت. وأظهـرت المقارنـة بـين نتـائج الحـالات الافتراضـية المحاكيـة والحـالات الواقعيـة توافقـاً عاليـاً بـين الحـالتين وفقـاً لنتيجـة خطـوط (تسـرب) متطابقـة والكميـة المحسـوبة لميـاه التسـرب مـن هـاتين الحـالتين.

الكلمات الرئيسية: التربة ذات النسيج الخفيف ، اللب ، Geo-Studio ، سد ترابي طبقي .

1. INTRODUCTION

Earthfall dams are mainly the most frequent form of dams because a natural, accessible material can be used in the construction of such dams. In addition, earthfall dams are usually more suitable than other dams in terms of location or topography of the land and can also be built on weak foundations (**Chugh et al., 2011**).

Earthfall dams are basic compacted constructions; depending on body weight, they can endure twisting and sliding (**Jansen, et al., 1988**). Earth dams are characterized as "homogeneous" or designated as "inclined or central impermeable center" called Zoned earthen dams, zoned earth dams contain an impermeable interior portion known as a core which provides water-resistance to shells on both sides of the core and provides. Zoning is carried out in order to provide security in terms of sufficient strength, seepage control, and cracking and to make use of the cheapest combinations of materials available.

When impermeable zones or drainages are added to earth dams, the drainage is regulated, and the amount of water is minimized (**Singh**, **et al., 1995**). Excessive moisture through the earth dam could cause piping or internal erosion, resulting in a breakdown.

(**Shahien et al., 2015**) studied the seepage and stability analyses while executing Mandali dam using the finite element Geo Studio software. Mandali Dam has a central core, and the dam's total length is about 1316 m. The dam's maximum height is about 14m. In the analysis, three practical cases are considered; steady-state leakage condition, end of construction before filling the reservoir, and rapid drop of the reservoir. The analysis of results confirms the integrity of the Mandali Dam against seepage and stability of the slopes under all operating situations. (**Nia et al., 2015**) studied phenomenon of leakage in a two-dimensional manner in the body and foundation of Meydanak Dam using numerically simulated (SEEP/W software). Numerical simulation was carried out according to different conditions and semi-saturated soil modeling. A comparison was made with the data from the experimental models to validate the numerical model's results. The results of the comparison show that there is a variance of approximately 3.9%, which is reasonable and acceptable. (**Jamel A, 2016**) analyzed seepage in the homogeneous earth dam without an outlet for the drainage downstream by using the Geo-Studio program. The results revealed that the proposed equation (ANN) was with an error less than (3%) and results of SEEP/W was less than (2%) error, Casagrande solution having above the fifteen percentage error and Dupuit's solution having more than 20 percent error. (**Irzooki,2016**) studied the analysis of leakage through a homogeneous earth dam by the Geo-Studio program by representing three different cases for upstream and downstream slopes, dam height, drainage

length, freeboard height, and top width. The results show that the amount of seepage is proportional to the increase in slope at the U/S and D/S, the height of the water in the U/S, and the drainage length, and inversely with the top width and the height of the freeboard. **(Zedan et al., 2018)** studied the leakage analysis and the stability of slopes in a Khasa Chia dam -Iraq, using the Geo-Studio finite element program in its seep/w branch, where the program was run depending on the field results of the dam. The operation was carried out depending on the half-full state and the flood state. The results obtained show the importance of the presence of a core in the dam to reduce leakage and increase the dam's stability. **(Ali, 2018)**, studied the seepage analysis under hydraulic structures, such as concrete dams supported by sheet pile, by using Geo-Studio software. Three cases were run in the program for the variables that govern such cases; the permeability of the soil, head, the length of the sheet pile, the space between one sheet and another, and the angle of inclination of the sheet pile. The program results are used to represent the network of neurons to find out which variables affect the seepage more. The results showed that the effect of the highest has the permeability of 76%, then the head (H) 8%, the distance between the pile 5.5%, the length U/S and D/S pile 5%,4% respectively and the inclined angle upstream and downstream of the pile is 1%, 0.5%. **(Salem et al., 2019)** explored seepage traveling through the body of an earth dam with and without an interior core experimental and numerical state. Using the Geo-Slope (2012) program, numerous models have been examined using SEEP/W and SLOPE/W. The effects of core permeability, core width, core base thickness, core penetration on seepage, pressure head, exit gradient, and upstream and downstream slope stability were investigated. It is concluded that increasing downstream slope stability, decreasing core permeability, increasing core thickness, base core thickness, and core penetration, decreasing upstream slope stability, decreasing the amount of seepage and exit gradient, and increasing downstream slope stability results in a significant decrease in the seepage line. **(Jassam and Abdulrazzaq, 2019)** investigated the relationship between the amount seepage through dam body and the rise of water in upstream the case of homogeneous dams. They pointed out a non-linear relation in the case of the saturated soil. The relationship was linear in the case of heterogeneous dams, and the amount of seepage increases with the increase in water height upstream of the dam. **(Jehan, 2020)** studied the behavior of seepage during a homogeneous earthen dam with clay core was using different engineering conditions. The study was carried out using Slide v6 program. In this study, three different dam heights, three different upstream blanket lengths with four different blanket thicknesses and four distinct cutoff depth were employed and the findings revealed that the pace of the drainage declined with the upstream blanket length, cutoff depth, and blanket thickness increased. In addition, the influence of the upstream blanket length is higher than the cutoff depth. During this, the rate of filtering was enhanced with lower top breadth of the dam. **(Rafid and Uday, 2020)** studied the seepage analysis in hydraulic installations directly exposed to water through two different methods, which are Khosla theory and the finite element method by Geo-Studio program. The comparison between the results of the two methods was close, with some slight differences due to neglecting some soil properties by the Khosla method**. (Mohammed and Ibtisam,2020)** studied the seepage analysis and slope stability through Haditha Dam using the finite Elements Geo-Studio program. The results showed that the core components of dolomite, asphaltic concrete, and curtain were very important to reduce seepage through the dam. **(Bredy and Jandora, 2020)** evaluated the safety factor in the Karolinka dam's body and foundation. Also, they studied the effects of dam height on the dam's stability. The study was done by using the finite element method in Plaxis 3-dimension software. The obtained numerical results show a good agreement with the observed data.

The current research aims to study alternative improved light-textured soils to be used in constructing earth dams' cores by using suitable additives. Moreover, to define the best percentages of additive materials that reduce the permeability of these soil types. Finally, using Geo-Studio software to simulate the conducted laboratory tests and compare the numerical model results with these tests to study different conditions to achieve the minimum amount of seepage water through these earth dams.

2. Methodology
2.1. Laboratory work
Several laboratory experiments were conducted to support soil represented by sandy gravel soil and for two types of selected soils (alluvial soil and sandy soil) that will be used as an alternative to the clay soil in the dam's core to choose the best one in terms of permeability. For the best-selected soil, improve its permeability by using two types of additive and choosing the best additive that achieves the least permeability. Then use the laboratory data to run the numerical model represented by the Geo-Studio program.

2.2. Cement kiln dust (CKD)

The cement manufacturing process (all types of cement) has produced a large amount of waste and by-products. Cement kiln dust, or CKD, was produced due to the manufacturing procedures. This collection of materials would have been highly beneficial if it had been used in cement making as a recycling method. Still, it would have been considered waste and a pollutant in terms of industry and climate. For example, in new facilities, in addition to about 1 ton of cement product, approximately CKD 41 kilos can be produced. Annual cement production is believed to be billions of tons, with CKD estimating 2.5 to 4.0 billion tons globally. Cement production in Iraq is around 8 million tons per year, and because most cement mills are outdated, and the CKD recycling method is not employed, the CKD by-product is higher than normal **(Khaliefa 2014).**

2.3. Silica fume

According to the ACI Committee(1967), very fine, non-crystalline silica is created as a by-product of manufacturing elemental silicon or silicon alloys in electric arc furnaces. The amorphous silicon dioxide component of the silica fume that condenses from furnace gases is very high. It consists of very small spherical particles with an average diameter of 0.1 m to 0.2 m. The manufacturing of silicon and ferrosilicon alloys produces silica fume as a by-product. Because of its high silica concentration and specific surface area, this material is classified as pozzolanic and is 10 to 20 times finer than fly ash. Silica fume was simply thrown into the atmosphere until the mid-1970s. The usage of silica fume in diverse applications was justified by environmental concerns that required the collecting and landfilling of silica fume.

2.4. Laboratory tests

A physical model of a zoned earth dam was built in the hydraulic laboratory of the University of Kufa. The models were constructed in a glass transmittance meter 180 cm long, 21 cm wide, and 60 cm high, as shown in **Fig. 1**. The tests were performed with a constant water level of 0.3 m upstream. To obtain fully saturated soil with a constant perfusion rate, the dam model's tank was filled with water to the required level and kept at that level for 24 hours. The use of dark colors with water has been adopted to consider the continuity of water density to notice the

phreatic line. The soil sample in the shell of the embankment is sandy gravel soil, the core of the embankment is the improved soil with additives in different proportions. The shell is formed with a lateral slope (2H: 1V) and the core with a slope (1:1). The volumetric approach was used to measure the perfusion rate across the dam models, which involves calculating the amount of water drained from the model. As a result, the leakage rate was determined by dividing the amount of water drained by the leakage time. The dimensions of a typical cross-section of a zoned earth dam are shown in **Table 1**.

Table 1 Dimensions details of a typical cross-section of a zoned earth dam.

parameters	value
Height of dam	9 m
Width of crest	5 m
Free board	1.5 m
Shell material	Sandy gravel
Side slope U/S and D/S for Shell(H:V)	2:1
Core material	Sandy soil
Side slope U/S&D/S for Core(H:V)	1:1
Core type	Central
Core crest width	3 m
Height of core	8.5 m
Height of dam	9 m

A scale of 1/25 was used to reflect the dimensions of a typical high earth dam in the laboratory in order to accommodate the dimensions available for the device in the laboratory. The dam's dimensions after utilizing the scale are displayed in **Table 2** and **Fig.2.**

Table 2. Dimensions of the scaled zoned earth dam model.

Parameter	Value
Height of dam	0.36 m
Width of crest	0.2 m
Free board	0.06 m
Side slope U/S and D/S for Shell(H:V)	2:1
Side slope U/S and D/S for Core(H:V)	1:1
Core type	central
Core crest width	0.12 m
Height of core	0.34 m

Figure1. Permeability device in hydraulic laboratory, university of Kufa.
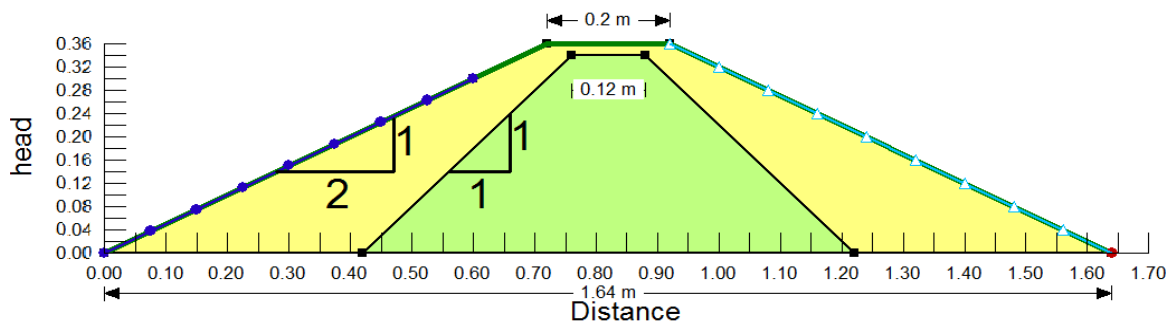

Figure 2. Typical cross-section of a zoned earth dam with a scale of 1:25.

3. NUMERICAL SIMULATION

Geo-studio -SEEP/W software was used to model and simulate the specialized core earth dam, which used the finite element method. The partial differential equation of Darcy law for flow water through a porous media was used to forecast the phreatic seepage through body earth dam and to estimate the seepage flow rate in the Geo-studio (SEEP/W) software. The water content, volumetric water content(VWC), and residual water content(RWC) in the dam shells are some of the most essential metrics that play a part in the Geo-studio (SEEP/W) software. In terms of the dam's core, the value of hydraulic conductivity plays an essential role shown in the **Figs**. **(3, 4, and 5)**.
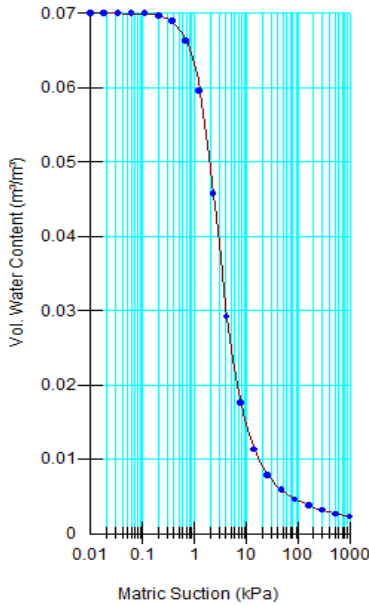
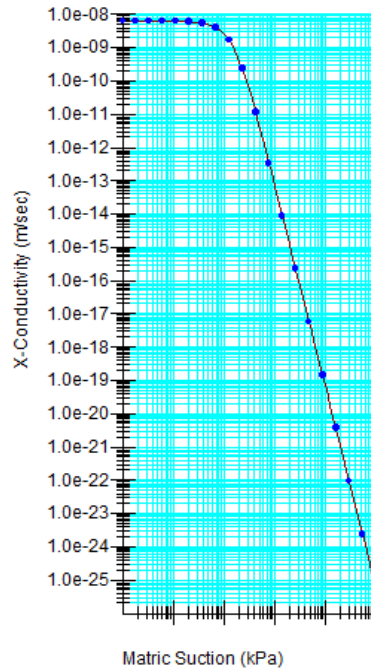**Figure 3.** The volumetric wate content for the soil used.

Figure 4. The hydraulic conductivity for soil used in the shell of earthdam model.
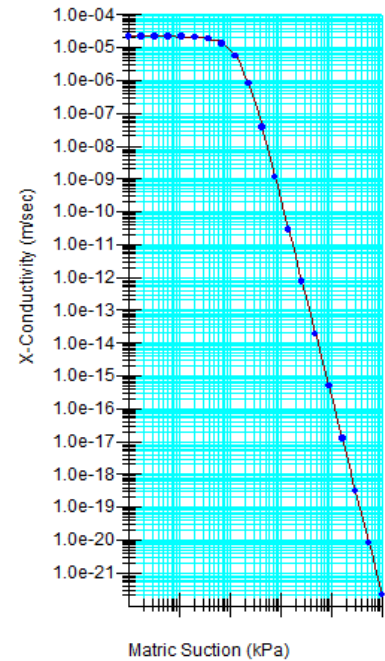

Figure 5. The hydraulic conductivity for soil used in the core of earth dam model.

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4. RESULTS and DISCUSSION

The following articles present results from the laboratory experiments and numerical simulations for different cases.

4.1. Selection type of soil and additives material

To find out the best type of soil particles and additives, a number of laboratory tests were conducted, such as sieve analysis and permeability tests. The first type of soil (alluvial soil). A sample of alluvial soil was used and was dried and analyzed to separate impurities. Permeability tests were performed, no additive was used with this type of soil. The permeability (k) of this soil type was ($4.81 * 10^{-5}$ m/sec). The water collected in the permeability test through 5 minutes was 1900 ml.

The permeability test was re-tested for the second type of soil (Sandy soil). No additive was used with this type of soil. The result of its permeability (k) was ($1.46 * 10^{-6}$ m/sec).The water collected in the permeability test through 10 minutes was 130 ml.

To check the best type of additive material, silica fume was added 5% to the second type of selected soil. The result of permeability test (k) directly some addition was ($1.575 * 10^{-6}$ m/sec) and The water collected in permeability test through 5 minutes was 125 ml, but the coefficient of permeability (k) after 48 hours of added silica was ($1.51 * 10^{-6}$ m/sec) and The water collected in the permeability test through 10 minutes was 120 ml.

When using cement kiln dust as an additive to sandy soil with 5%, the coefficient of permeability was($1.51 * 10^{-6}$ m/sec) and The water collected in permeability test through 10 minutes was 120 ml directly after additive, But the coefficient of permeability after 48 hours of added CKD material was ($7.59 * 10^{-7}$ m/sec) and The water collected in the permeability test through 10 minutes was 60 ml.

4.2. The selection of soil gradation

To find the best gradation for the selected sandy soil, a permeability test was used to find it, with a duration of 10 minutes and with different percentages of the additive, as shown in **Table 3** below.

Table 3. Summary of permeability tests with different soil and additive material.

Permeability	Soil type	Particle size (mm)	Additives material	Saturated condition	er collected n (10 min), (ml)	fficient of eability (k), m/sec)
1	Sand A	0.6-0.075	NON	SATURATED	130	$1.64 * 10^{-6}$
2	Sand A	0.6-0.075	CEMENT KILN DUST 5%	NON- SATURATED	120	$1.51 * 10^{-6}$
3	Sand A	0.6-0.075	CEMENT KILN DUST 5%	SATURATED(48h)	60	$7.59 * 10^{-7}$
4	Sand A	0.6-0.075	CEMENT KILN DUST 10%	SATURATED(48h)	25	$3.16 * 10^{-7}$
5	Sand A	0.6-0.075	CEMENT KILN DUST 15%	SATURATED(48h)	17.5	$2.15 * 10^{-7}$
6	Sand B	0.3-0.075	NON	SATURATED	130	$1.64 * 10^{-6}$
7	Sand B	0.3-0.075	CEMENT KILN DUST 5%	SATURATED(48h)	25	$3.16 * 10^{-7}$
8	Sand B	0.3-0.075	CEMENT KILN DUST 10%	SATURATED(48h)	15	$1.89 * 10^{-7}$
9	Sand B	0.3-0.075	MENT KILN DUST 10% AND CEMENT 3%	SATURATED(48h)	10	$1.26 * 10^{-7}$
10	Sand B	0.3-0.075	MENT KILN DUST 10% AND CEMENT 5%	SATURATED(48h)	2.5	$3.18 * 10^{-8}$
11	Sand C	0.15-0.075	NON	SATURATED	130	$1.64 * 10^{-6}$
12	Sand C	0.15-0.075	MENT KILN DUST 10% AND CEMENT 3%	SATURATED(48h)	1	$1.26 * 10^{-8}$
13	Sand C	0.15-0.075	MENT KILN DUST 10% AND CEMENT 5%	SATURATED(48h)	0.5	$6.3 * 10^{-9}$

4.3. Validation of the numerical model

To verify the numerical model, which used Geo-Studio software to simulate seepage through an upgraded core earth dam, a model with the same dimensions and characteristics was used. The results of the numerical are displayed in **Fig.6**. **Table 4** shows the amount of seepage in the experimental and numerical models for Sand (C), as well as the amount of seepage for Sand (A and B) (numerically) and the value of each soil. The comparison of the phreatic line for experimental and computational models is depicted in **Fig 7**.
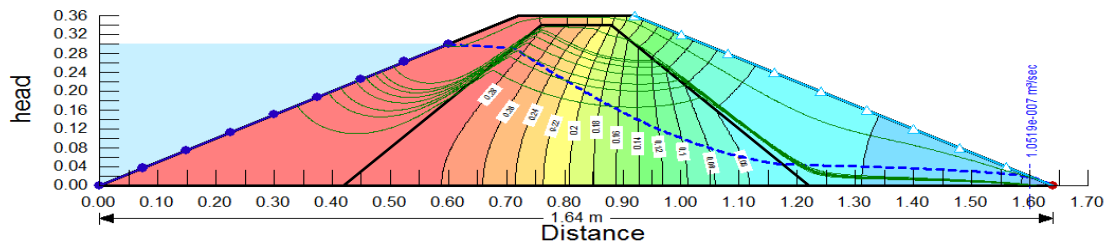
Figure 6. The amount of seepage and the phreatic line for sand class C.

Table 4. Summary of the hydraulic conductivity (k) and amount of seepage for sand soil types (A, B, and C).

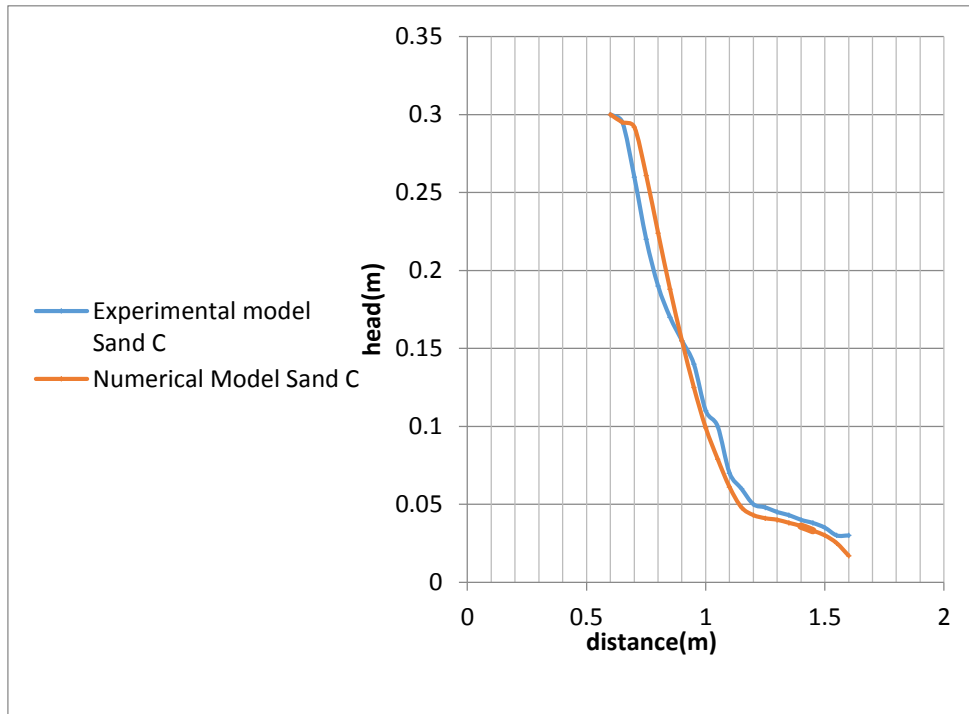| Type o	Hydraul conductivit standard soil	Hydraulic condu for Improved soi	Percentag improvemen Hydraulic cond (%)	seepage amou standard s $(m^3/sec$	seepage amou Improved s (numericall $(m^3/sec$	seepage amou Experimental r $(m^3/sec$
Sanc	$1.64x10$	$2.15x10^-$	86.8	2.0722×10	1.4059×10	
Sanc	$1.64x10$	$3.18x10^-$	98	2.0722×10	1.0989×10	
Sanc	$1.64x10$	$6.3x10^{-9}$	99.6	2.0722×10	1.0511×10	1.0708×10

Figure 7. Comparison between the phreatic line for experimental and numerical models.

4.4. Virtual tests of Improved Soil

To test and check the possibility of the improved soil to be used as an alternative to the soil used in the earth dams core, it was virtually used instead of soil used in the core of Haditha Dam, which is composed of dolomite, and instead of the core soil of Himreen Dam, which is made of pure clay. The results of the analysis are shown in the table below.

Table 5. Comparison of the hydraulic conductivity and the amount of seepage of the improved soil (sand C) with the dolomite and clay soils.

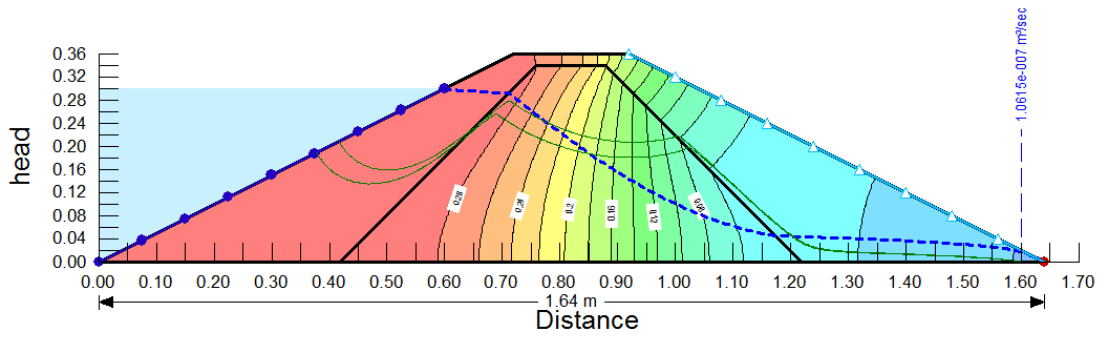| Type of soil	Hydraulic conductivity (m/s)	Amount of seepage (m^3/sec)
Sand C	$6.3\ x10^{-9}$	$1.0511\ x\ 10^{-7}$
Dolomite	$1.15x10^{-8}$	$1.0615\ x\ 10^{-7}$
Clay	$2.31x10^{-9}$	$1.0488\ x\ 10^{-7}$

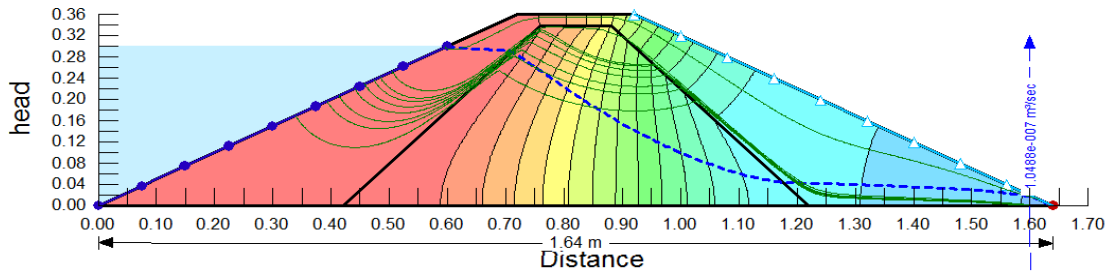**Figure 8.** The phreatic seepage line for the dolomite core (Haditha dam).

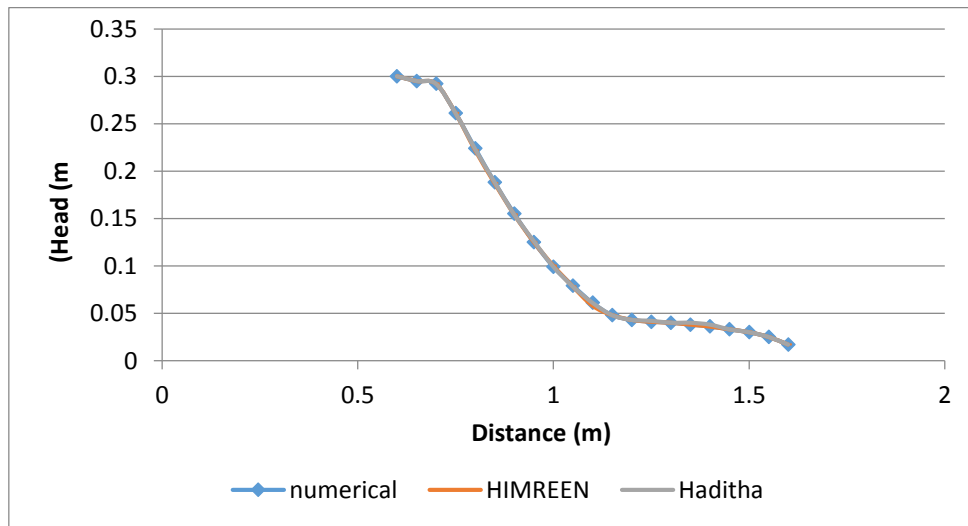**Figure 9.** The phreatic seepage line for clay core (Himreen dam).

Figure 10. Comparison between the phreatic lines of improved core soil, dolomite, and clay core .

5. CONCLUSIONS

In the current research, laboratory tests and numerical modeling concerned with analyzing the best type of light-textured soils were implemented as alternative soil, as well as defining the best gradation of improved soil particles and the best percentages of additives to assure a minimum amount of seepage water through the dam and the lowest level of the phreatic line. So, the most important obtained results can be deduced as follows:

1. Laboratory results showed that improved sandy soil is suitable for use as an alternative to standard soil used in the construction of the core of earth dams, as the permeability of the improved sandy soil has become much closer to clay soil which was usually used in the core of earth dams.

2. Laboratory results revealed that the use of cement kiln dust is more suitable than using silica fume in improving the permeability and reducing the amount of water passing through the soil, as the permeability coefficient was reduced by 53.7% and 8% when using CKD and silica fume respectively, for the same soil type.

3. It was found that the best type of soil to utilize in the core of a zoned earth dam was discovered through laboratory studies to be 'Sand C' with an additional ratio of 10% of CKD and 5% of cement. As a result, it has the lowest hydraulic conductivity (k), which is equal to 6.3×10^{-9} (m/s).

4. By the comparison between results of the experimental tests and numerical simulation by using Geo-Studio, it was found that the seepage rate was compatible by 97%, as well as good agreement obtained between the phreatic lines produced from the two approaches.

5. As a validation proof, the numerical simulation of the virtual replacement of the clay soil in the core of the Himreen dam and the dolomites soil that forms the core of a Haditha dam by the improved light-textured soil revealed closer seepage flow rates compared with the use of clay and dolomite soils used in these earth dams. And the phreatic lines in both cases were identical.

6. REFERENCES

- Abdul Jabbar Jamel, A., 2016. Analysis and estimation of seepage through homogenous earth dam without filter. Diyala Journal of Engineering Sciences, 9(2), 38-49.
- Alboresha, R., and Hatem, U., 2021. Anbar Journal Of Engineering Science © Emperical and Numerical Solution Of Seepage Problems Underneath Hydraulic Structures. 9, 1–9.
- Bredy, S., and Jandora, J., 2020. Effect of Dam Height on The Stability of Earth Dam (Case Study: Karolinka Dam). Journal of Engineering, 26(3), 117–126.
- Chugh A., 2011, "Embankment Dams General Design Standards", In chapter 1, the U.S. Department of the Interior Bureau of Reclamation.
- Irzooki, R. H., 2016. Computation of seepage through homogenous earth dams with horizontal toe drain. Engineering and Technology Journal, 34(3 part), 430-440.
- Jansen, R. B., 1988. Advanced dam engineering for design, construction, and rehabilitation. Springer Science and Business Media.
- Jassam, M. G., and Abdulrazzaq, S. S., 2019. Theoretical Analysis of Seepage through Homogeneous and Non-homogeneous Saturated-Unsaturated Soil. Journal of Engineering, 25(5), 52-67.

- Kirra, M. S., Shahien, M., Elshemy, M., and Zeidan, B. A., 2015. Seepage and slope stability analysis of Mandali earth dam, Iraq: A case study. In International Conference on Advances in Structural and Geotechnical Engineering (ICASGE'15).[6–9 April 2015 Hurghada, Egypt].

- Malik, M. K., and Karim, I. R., 2020. Seepage and Slope Stability Analysis of Haditha Dam using Geo-Studio Software. IOP Conference Series: Materials Science and Engineering, 928(2).

- Nia, Ruhollah P., Ali S., and Hossein Sedghi, 2015. Investigating and Analyzing Leakage Phenomenon in the Earth Dam by Using SEEP / W Numerical Model Case Study: Down Meydank Dam. Jurnal UMP Social Sciences and Technology Management. 3(3): 1–5.

- Saleh, L. A., 2018. Studying the seepage phenomena under a concrete dam using SEEP/W and Artificial Neural Network models. In IOP Conference Series: Materials Science and Engineering (Vol. 433, No. 1, p. 012029). IOP Publishing.

- Salem, M. N., Eldeeb, H. M., and Nofal, S. A., 2019. Analysis of Seepage through Earth Dams with Internal Core. Int. J. Eng. Res, 8, 768-77.

- Singh, B., and Varshney, R. S., 1995. Engineering for embankment dams. A. A. Balkema. 745, 745.

- Sulaymon, A. H., Faisal, A. A., and Khaliefa, Q. M., 2015. Cement kiln dust (CKD)-filter sand permeable reactive barrier for the removal of Cu (II) and Zn (II) from simulated acidic groundwater. Journal of hazardous materials, 297, 160-172.

- Suleimany, J. M. S., 2020. Seepage through earthen dams under different dam geometries and conditions. Zanco Journal of Pure and Applied Sciences, 32(2).

- Zedan, A. J., Faris, M. R., and Abdulsattar, A. A., 2018. Slope Stability of an Earth Dam during Drawdown Conditions (KHASA-CHAI Dam) as a Case Study. International Journal of Engineering and Technology, 7(4.37), 17-21.