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Research paper

Experimental work: the effect of using agricultural pond insulators in the core of earthen dams on water flow and dissolved solids content

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Abstract: Gypsies soils are frequently found in semiarid and arid environments where rainfall does not sufficiently let the gypsum to leach from the soil cover. The efficiency of dams that impound water is reduced by a number of factors, including the breakdown of gypsum salts that lead to caverns, an increase in soil material permeability, an increase in flow rate caused by expanding fissures, and an excessive settlement rate. This work aims to understand the behavior of earth dams containing gypsum salts in their structure and the effect of isolation on their permeability and the amount of salts in the water flowing from them. To determine the amount of seepage through the dam body and the location of the phreatic line, a model was developed using actual samples from one of the backfill dams. Then, in addition to gypsum salts, we constructed an additional model for the same samples. We identified the phreatic line's position, velocity, change in flow and total dissolved solid. Then, using Geo Studio software, we simulated the two models. The results showed that the flow increased with the addition of gypsum salts and the formation of the phreatic line began after a period of time estimated at 16 hours in the first model and appeared in the second model after 12 hours, which is the sample containing gypsum salts. However, the insulator prevented leakage through the dam body by 89% in the third model.

Keywords: dams, environmental, geo studio, insulators, phreatic line, salty sand

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1. Introduction

Water storage in dams has a long history, dating back to ancient times, making dams one of the oldest manmade structures. Today, dams serve various crucial purposes including storing water for human consumption, food production, electricity generation, industrial activities, and flood mitigation [1, 2]. Embankment dams or fill-type dams, constructed primarily from earth and rock materials, precede the history of concrete dams. Evidence suggests that the construction of earth dam's dates back approximately 3,000 years, found notably in the ancient cultures of the Eastern regions. Hence, it is readily acknowledged that the global trend has shifted towards the construction of embankment dams, replacing concrete dams [3]. The foundation requirements for dams differ significantly between concrete dams and embankment dams. Concrete dams necessitate a foundation of hard and sound rock, whereas embankment dams can be built on alluvial deposits and permeable foundations, often without the need for rigorous conditions [4]. They are versatile structures that can be built in a wide range of environments and are often chosen for their cost-effectiveness and adaptability to different geological conditions [5]. One of its most prominent strengths lies in the availability of materials with which to build the dam's body near the chosen construction site [6]. The design of the dam, addressing various hydraulic concerns, relies on factors such as the dam type, construction materials, and foundation conditions. These include issues like seepage through the dam body, under-seepage in the foundations, and uplift pressure on the dam base. During the operation of a dam, hydraulic challenges may arise, posing risks to its safety [7]. Examples of such hazardous problems, requiring careful analysis and practical solutions, include seepage issues, scouring, cavitation from high-velocity flow, and blockages caused by sediments and debris in outlet facilities or gates of structures like spillways [8]. Studies indicate that 39 cases of failure of embankment dams are due to seepage that occurs through the dam body. Seepage occurs in all embankment dams, and excessive seepage affects many of them. Water in the reservoir may provide certain risks to the safety of the dam as it looks for the least resistance routes through the dam's base and body. If excessive seepage is not adequately managed and controlled, it could result in dam failure [9, 10]. If significant amounts of seepage flow are let to continue unchecked, the seepage force may dissolve tiny soil particles and wash them out, leading to internal erosion process pipe failure in the dam or creating uplift issues. Hence, seepage may be regarded as one of the most frequent safety risks for embankment dams, and several collapses of these dams have been noted in registries of dam failures. The fundamental issue that designers face [10, 11].

2. Experimental methods

2.1. Experimental setup and site description

Refer to Fig. 1. show the project area on Google earth image. The study was conducted on real samples of one of the earthen dams located in Jordan in the Azraq Basin, and gypsum salts were added to these samples to simulate the effect of saline soil on the earthen dams. This is a dam

One of the most important components of Jordan's water infrastructure for the nation's water management system. Located east of Amman, close to the town of Azraq, this dam fulfills several vital purposes. Its primary function is that of a reservoir, holding water for use in domestic consumption, industry, and agriculture [12]. Furthermore, the dam helps control the flow of water in the area, reducing the likelihood of flooding during times of high precipitation. Furthermore, the Azraq Dam makes a substantial contribution to groundwater recharge, which is crucial given Jordan's dry environment and limited groundwater supplies. By collecting and holding onto water, the dam helps aquifers refill, supporting regional ecosystems and offering essential resources to nearby communities. Study area in Fig. 1 is located (N: 314325.9°, E: 362730.9°).

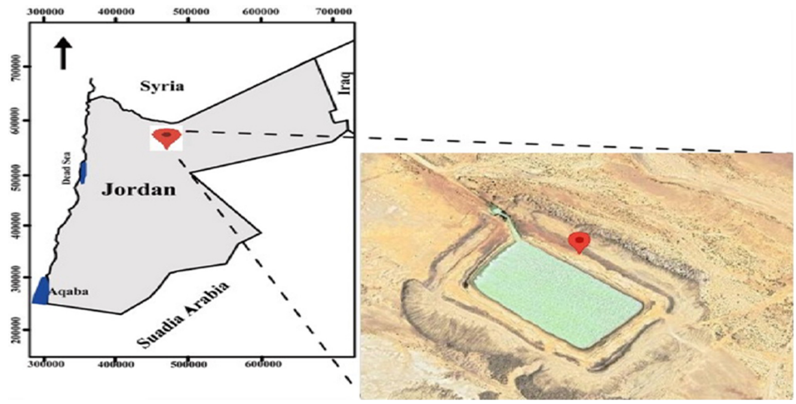

Fig. 1. Project area location

Refer to Fig. 2. This project aims to study the effect of the phreatic line location in the bodies of earth dams that contain gypsum salts in their components. Real samples were taken from the dam body, a percentage of gypsum salts were added to it, and then the effect of seepage through the dam body was studied. The specific objectives of this project can be summarized as follows: Accessing the amount of seepage that occurs through the dam body for real dam samples, dam samples after adding gypsum salts. The technical constraints of the design are summarized as follows: Dam height (25 cm), Dam width (84 cm), Crest width (9 cm), Dam thickness (15 cm), Dam slope (1.5H: 1 V), Constant head (water level: 20 cm). Scale 1:1000.

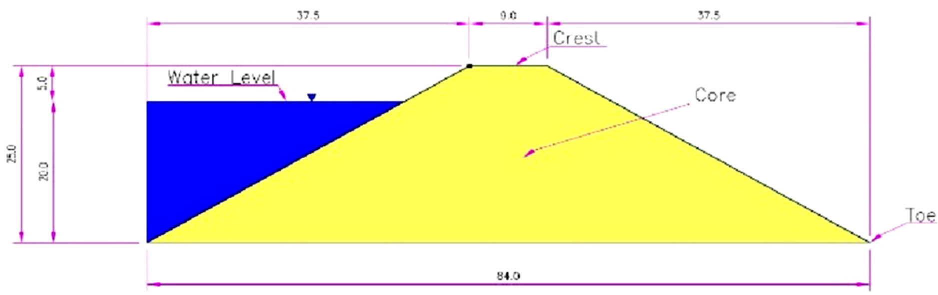

Fig. 2. Dimensions of the dam model

Refer to (Fig. 3). Gypsum salt soluble salts are present in various amounts in natural soils and aggregates over most of the world, but mainly in the Middle East. When present in large amounts in the soil, soluble salts like gypsum ($CaSO_4 \cdot 2H_2O$) can be harmful to subgrade soils, buildings, and earth structures. It is primarily composed of 32.6% calcium oxide (CaO), 46.5% sulfur trioxide (SO_3), and 20.9% mixed water (H_2O) [13]. Bassanite ($CaSO_4 \cdot \frac{1}{2}H_2O$) is the product of gypsum dehydration, which occurs when the first $1\frac{1}{2}$ molecules of (H_2O) in gypsum are lost relatively consistently between 0°C and around 65°C, possibly with only minor structural modifications. The last ($\frac{1}{2}H_2O$) molecule in bassanite (hemihydrate) is still held rather firmly at roughly 70°C, but at about 95°C it is lost and the structure transforms to that of anhydrite ($CaSO_4$) [14]. Pure gypsum consists of hydrated calcium sulfate: $CaSO_4 \cdot 2H_20$. Labs frequently use sulfur assays and convert the results to gypsum. Consequently, percent S times 5.38 is percent gypsum, and percent Gypsum times 0.186 equals percent sulfur. Since calcium can also be found in the form of lime, or $CaCO_3$, it is invalid to determine the purity of gypsum by looking only at its calcium concentration. It is important to distinguish between the fixed water the $2H_2O$ in the gypsum It is important to distinguish between the fixed water the $2H_2O$ in the gypsum molecule – and the moisture content of gypsum. The temperature ranges for driving off fixed water is 45°C to 128°C. Plaster of Paris, $CaSO_4 \cdot \frac{1}{2}H_2O$, is created when this occurs. Alternatively, gypsum can be heated to 40°C to eliminate all moisture. After removing the moisture, every assay is performed [15]. These are dry gypsum.as shown (Table 1).

Bring a soil sample from the actual study site. Conduct sieve analysis of the soil sample. Obtain pure gypsum salts to mix with soil samples. Conduct a constant head permeability test of the soil sample. Dividing the front end of the device in order to build the dam body with

Fig. 3. Gypsum salt

Table 1. Pure gypsum consists

Component name	Component ratio (%)
calcium in pure gypsum	23.3%
sulfur in pure gypsum	18.6%
oxygen (in sulfate) in pure gypsum	37.2%
fixed water in pure gypsum	20.9%

equal dimensions and similar slopes. Fill the water inlet to reserve an equal amount of water behind the dam and wait until the soil becomes saturated and the dam body begins to build leakage channels through it. When we see water in the outlet area, we begin taking samples to determine the amount of leakage over a certain period of time.

2.2. Soil characteristics and dam model construction

Refer to Fig. 4 and 5 and Table 2 and 3. The process of dividing a sample of aggregate into fractions of the same size in order to determine the grading or size distribution. Sieve analysis was conducting following the ASTM C136 Standard. Sieve analysis based on shaking the aggregates sample through a set of sieves that have progressively smaller openings. Equipment: Balance of (0.1 g) sensitivity, set of sieves (#4, #8, #16, #30, #50, #80, #100, #140, #200), Cleaning brush and Sieve shaker. We record the weight of the dry soil sample we used 1245.5 g for the sample without gypsum and we used (3000 g) for sample with gypsum (259.5 g gypsum: 2740.5 g soil).

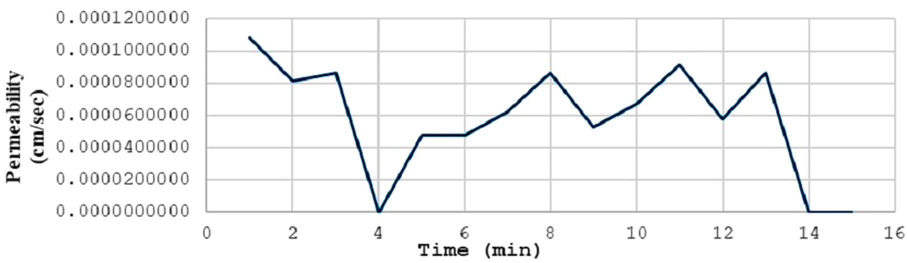

Fig. 4. Constant head permeability test of the soil sample

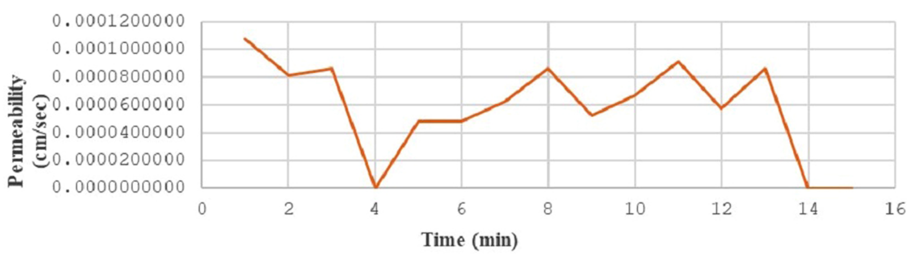

Fig. 5. Constant head permeability test with gypsum

Table 2. Sieve analysis test of soil sample without gypsum

Total weight of sample (gm)							
Sieve size		Weight of empty sieve (gm)	Weight of sieve & agg. (gm)	Weight of retained agg. (gm)	Retained (%)	Cumulative retained (%)	Cumulative passing (%)
in	mm						
4	4.75	1126.50	1225.50	99.00	7.95	7.95	92.05
8	2.36	1072.50	1160.50	88.00	7.07	15.01	84.99
16	1.18	943.00	1041.50	98.50	7.91	22.92	77.08
30	0.60	933.00	1067.00	134.00	10.76	33.68	66.32
50	0.36	820.50	950.50	130.00	10.44	44.12	55.88
80	0.18	854.50	951.50	97.00	7.79	51.91	48.09
100	0.15	762.50	804.00	41.50	3.33	55.24	44.76
140	0.11	841.50	897.00	55.50	4.46	59.69	40.31
200	0.08	836.50	1033.50	197.00	15.82	75.51	24.49
Pan		827.00	1126.50	299.50	24.05	99.56	0.44
Total				1240.00	99.56	465.60	

Table 3. Sieve analysis test of soil sample with gypsum

Total weight of sample (gm)							
Sieve size		Weight of empty sieve (gm)	Weight of sieve & agg. (gm)	Weight of retained agg. (gm)	Retained (%)	Cumulative retained (%)	Cumulative passing (%)
in	mm						
4	4.75	1126.00	1879.00	753.00	25.10	25.10	74.90
8	2.36	1073.00	1364.00	291.00	9.70	34.80	65.20
16	1.18	944.00	1272.00	328.00	10.93	45.73	54.27
30	0.60	934.50	1263.00	328.50	10.95	56.68	43.32
50	0.36	821.00	1115.00	294.00	9.80	66.48	33.52
80	0.18	852.50	1023.00	170.50	5.68	72.17	27.83
100	0.15	760.50	832.00	71.50	2.38	74.55	25.45
140	0.11	841.50	948.50	107.00	3.57	78.12	21.88
200	0.08	836.00	1101.50	265.50	8.85	86.97	13.03
Pan		826.50	1211.00	384.50	12.82	99.78	0.22
Total				2993.50	99.78	640.38	

Refer to Fig. 6. We begin by gradually placing the soil sample in the form of layers and compacting each layer to the next to extract the air from between the pores of the soil until the model is completed with the required dimensions.

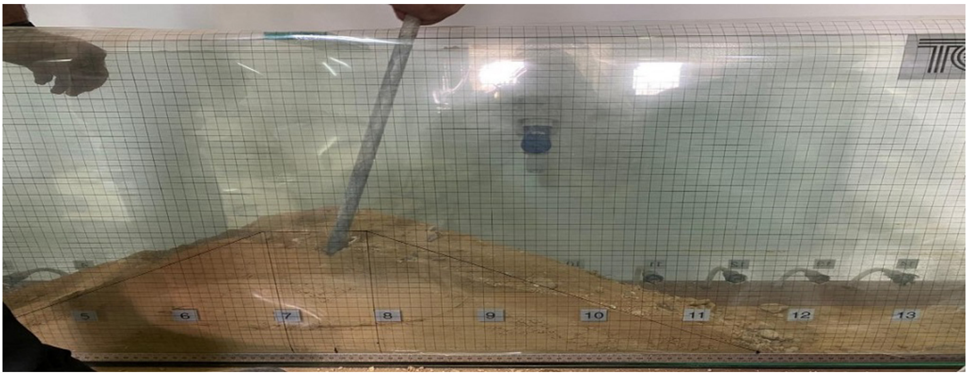

Fig. 6. Placing the soil sample in the form of layers and compacting each layer

Refer to Fig. 7. After ensuring that the dam body does not contain any voids and that the lateral inclinations are equal, we begin pumping water to a constant level and maintain this level throughout the period of operation of the model.

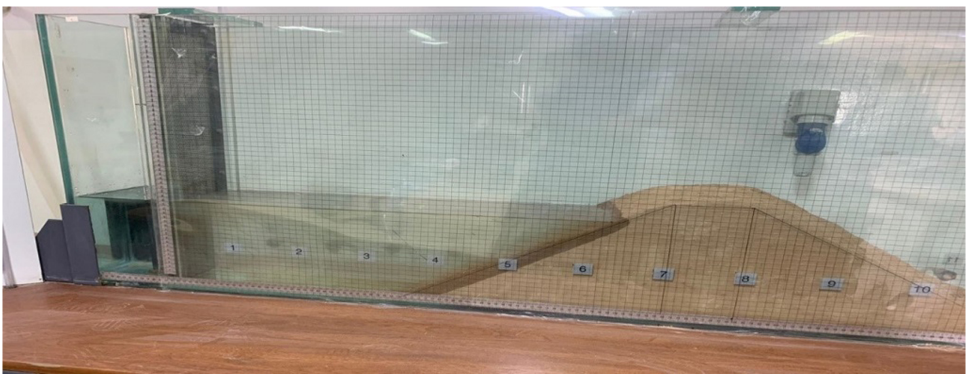

Fig. 7. Pumping water to a constant level

Wait on the model until leakage channels begin to form through the dam body and the water moves to the other side of the model. The waiting time varies depending on the type of soil and its porosity, and it is not required that the soil has reached the point of saturation.

3. Results and discussion

3.1. Flow velocity results

Refer to Fig. 8. The sieve analysis identified the soil as fine sandy soil. Over six days, the experiment lasted 5.667 hours, during which 34 samples were collected at 10-minute intervals, with each sample taken over 10 seconds. Key parameters, including total dissolved solids, pH, electrical conductivity, and flow quantities, were recorded. The data revealed discharge variations influenced by factors such as temperature, precipitation, or human activities. For instance, on 14/1/2024, discharge ranged from 733.00 ml/10 sec to 1.00 ml/10 sec within an hour. Flow rate comparisons showed that in the initial sample without gypsum, flow rates ranged from 0.22 to 6.9 cm/s, while gypsum-added samples ranged from 0.01 to 7.33 cm/s. Gypsum salts contributed to increased flow and channel formation. Discharge before gypsum addition ranged from 733.00 ml/10 sec to 1.00 ml/10 sec and shifted to 640.00 ml/10 sec to 95.00 ml/10 sec after gypsum addition. These variations underscore the impact of gypsum on flow dynamics. The experiment highlights gypsum's role in altering flow characteristics and its potential implications for soil and water management.

Fig. 8. Insulator in the core of the earthen dam model

Refer to Fig. 9. The graph indicates that the existence of the insulator in the heart of the earthen dam worked to eliminate the flow rate through the dam body of 93.7, and the presence of flow in some areas is due to water leakage under the insulator and its accumulation.

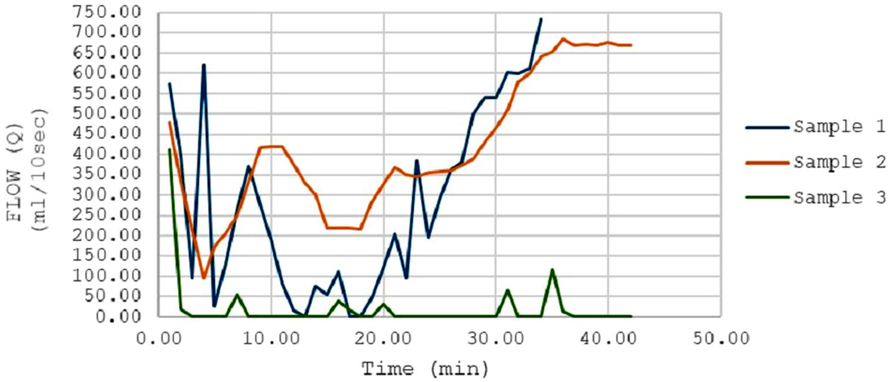

Fig. 9. Flow comparison between 3 Models

3.2. Total dissolved solids (TDS) & electric conductivity (EC) results

Refer to Table 4. The following tests were performed and recorded for the inlet water.

Table 4. Inlet water specification

Parameter	Amount
TDS	0.518
EC	1.036

As shown Fig. 10. In Model 1, total dissolved solids (TDS) ranged from 6.06 to 2010 mg/L, while electrical conductivity varied between 12.11 and 4020 µs/cm. In Model 2, TDS ranged from 10.00 to 10175.00 mg/L, reaching a maximum of 16310.00 mg/L, and electrical conduc-

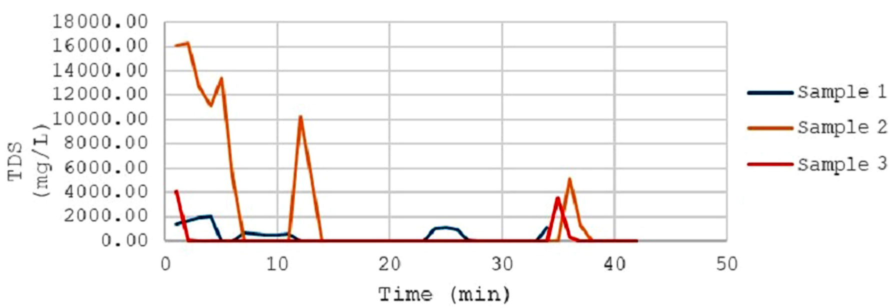

Fig. 10. TDS results for three model

tivity increased significantly from 2550 to 32620 µs/cm due to gypsum addition. The rise in TDS and conductivity in Model 2 reflects higher ion concentrations, likely from gypsum salts and organic matter.

As shown Fig. 11. TDS levels, comprising organic materials, minerals, and salts, influence water quality and usability. High TDS levels indicate potential contamination, affecting applications such as irrigation or consumption. Similarly, electrical conductivity measures the water's ability to conduct electricity, directly correlated to dissolved ion concentrations. Elevated conductivity, as seen in the gypsum sample, suggests increased ion presence, potentially impacting water quality. Hydrogen ion concentration (pH) varied between 7.77 and 8.29 in the gypsum sample and 8.11 to 9.16 in the first sample. The pH drop in the gypsum sample is attributed to the salts present, which influence acidity. Overall, the increased ion concentrations and conductivity in Model 2 demonstrate gypsum's significant impact on water properties and potential contamination risks.

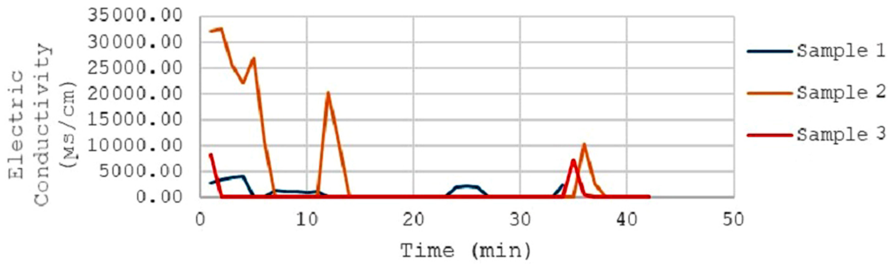

Fig. 11. EC results for three model

3.3. Sample simulation using (GEO) studio software

Refer to Fig. 12. In the initial sample without gypsum, the flow started at (0.008×10^{-6} m^3/sec), pressure was 20 kPa, and speed was (0.5×10^{-5} m/sec). In the second reading, pressure dropped to 17.5 kPa, and flow increased to (1.3128×10^{-6} m^3/sec), while speed remained constant. In the third reading, pressure continued to drop to 15 kPa, and flow

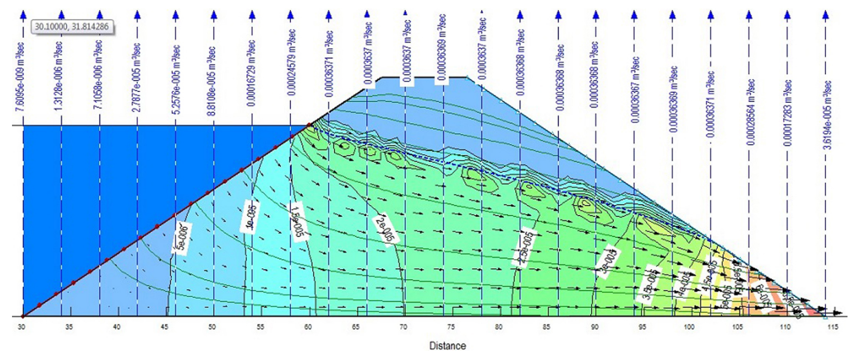

Fig. 12. Pressure head & flow in geo studio

increased to (7.1058×10^{-6} m^3/sec), with speed unchanged. The fourth reading showed further flow increase to (27.87×10^{-6} m^3/sec) and pressure reduced to 12 kPa. Flow steadily increased with each reading, while pressure continued to decrease. In the fifth reading, the flow remained constant at (88.108×10^{-6} m^3/sec), but pressure dropped to 7 kPa. As the pressure continued to drop in subsequent readings, flow and speed increased, with the flow reaching (245.79×10^{-6} m^3/sec) and speed rising to (2×10^{-5} m/sec) in the ninth reading. The flow continued to increase while pressure dropped throughout the measurements. Overall, the flow progressively increased until it stabilized, while pressure decreased from the top to the bottom of the phreatic line.

Refer to Fig. 13. Due to the type of soil used in its construction, the water velocity through the dam body is at normal levels. However, as the main leakage channel through the dam body begins to form, it starts to increase, giving a noticeable increase in values and reaching high levels at the end of the sedimentation channel. When water starts to flow from the collection area to the back of the dam, a leakage channel is formed through the dam body.

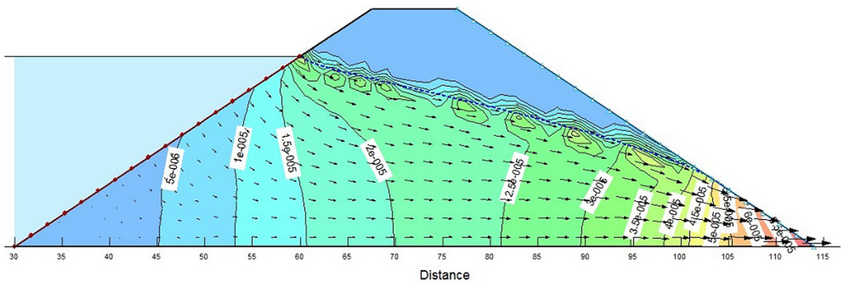

Fig. 13. Velocity through the dam

Refer to Fig. 14 and 15. Previous comparisons showed that the coordinates of the infusion line are close practically and theoretically for this type of soil. However, we failed in practice to obtain all the coordinates for the end of the channel formation, due to the rapid disappearance of the injected ink.

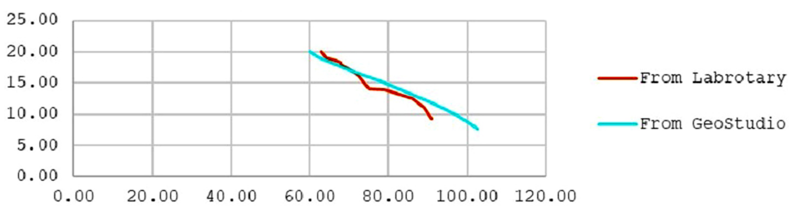

Fig. 14. Phreatic line results laboratory & geo studio in model 1

Refer to Fig. 16. In practice, the channel formed at an x-coordinate of 63 cm and y-coordinate of 20 cm, while in Geo Studio, it formed at an x-coordinate of 60 cm, with the same y-coordinate. Differences of 2 cm in the x-coordinate and 0.1 cm in the y-coordinate were observed at the second point. At the third point, the y-coordinate differed by 0.2 cm, with the x-coordinate at 18 cm. Endpoints of the phreatic line could not be compared due to unreadable

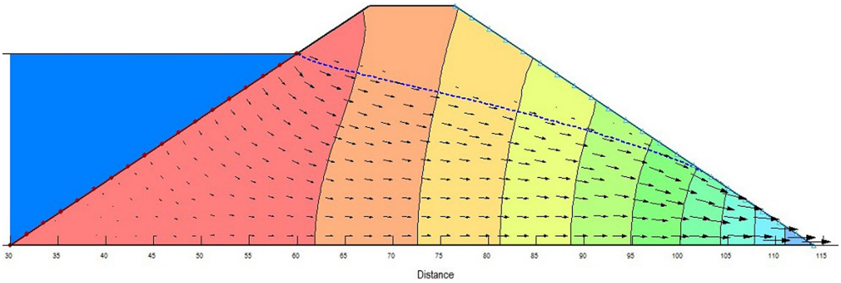

Fig. 15. Phreatic line geo studio results in model 1

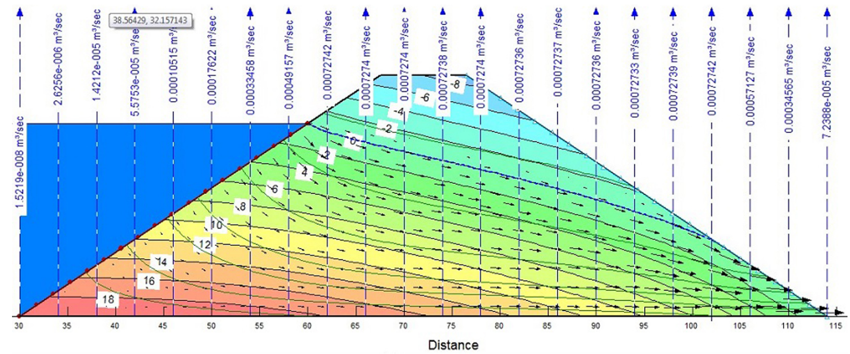

Fig. 16. Pressure head & flow in geo studio

coordinates, but variations in x- and y-values remained minimal. Gypsum Sample Simulation for a Dam: Flow values were measured every 4 cm, with minimum and maximum flows of (0.015×10^{-6} m^3/sec) and (727.42×10^{-6} m^3/sec). Flow values in the gypsum sample were higher compared to those in the sample without gypsum.

Refer to Fig. 17. Maximum velocity (12.0×10^{-5} m/sec), Minimum velocity (2.0×10^{-5} m/sec). At the maximum value of the flow, the velocity (4.0×10^{-5} m/sec). At the minimum value of the flow, the velocity (2.0×10^{-5} m/sec).

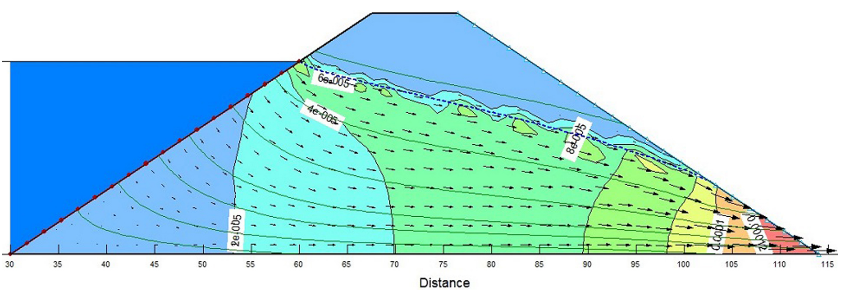

Fig. 17. Velocity through the dam

Refer to Fig. 18 and 19. The phreatic line in saline soils, such as those containing gypsum, is influenced by salt types, soil composition, groundwater flow, and climate. Soluble salts in saline soils typically reduce infiltration due to pore blockage or altered soil structure [16]. Reduced infiltration in saline soils can lead to decreased groundwater recharge, resulting in a shallower phreatic line. In some cases, salt accumulation makes the soil denser and less permeable, causing water to build up above the impermeable layer, which may elevate the water table or phreatic line [17]. Salts in soil can influence capillary action, potentially raising the phreatic line, especially in areas with high evaporation rates. In regions with restricted groundwater flow or high salt concentrations, these effects are more pronounced, causing localized rises in the phreatic line compared to areas with lower salt content.

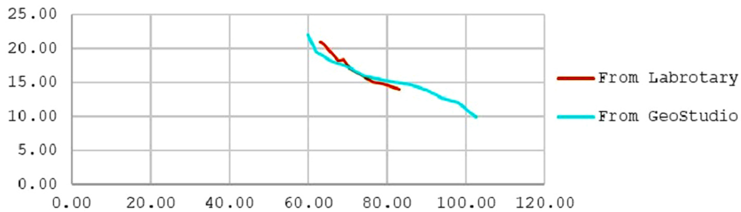

Fig. 18. Phreatic line geo studio results and geo studio in model 2

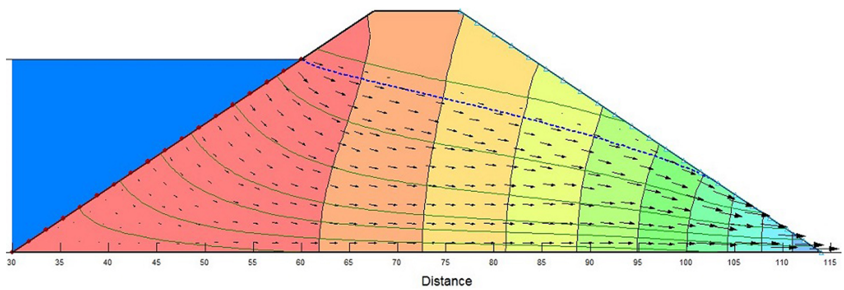

Fig. 19. Phreatic line results laboratory in model 2

A phreatic line was formed at a height of (22 cm), and the coordinates in the y-axis and x-axis were collected along the phreatic line in the table shown above. The flow value at the starting point is (0.015×10^{-6} m^3/sec), the velocity is (2.0×10^{-5} m/sec), and the pressure value is (20 kPa). The flow value at the end point is (72.388×10^{-6} m^3/sec), the velocity is (12.0×10^{-5} m/sec), and the pressure value is (1 kPa). We notice that from the Velocity values shown in the table that in the beginning there was stability in the velocity value at the first 6 flux and its value was (2.0×10^{-5} m/sec). After that, there was an increase in the value of the velocity, and the increase continued until it reached a value of (6.0×10^{-5} m/sec). The flow remained constant until 6 flux, after which it continued to increase, reaching a maximum value (12.0×10^{-5} m/sec). Techniques such as cutoff walls, drainage channels, or impermeable barriers can be used to manage the phreatic line sustainably, helping preserve dam integrity, reduce the risk of erosion, and protect downstream habitats .[18]. Uncontrolled phreatic lines have the potential to cause dam instability and failure, which would have disastrous effects on the ecosystem, such as habitat destruction and floods. Engineers can lessen the chance of dam failure by keeping the phreatic line within safe parameters by constructing the dam with sustainability in mind [19, 20].

4. Conclusions

Because the materials used to construct the dam body come from the same designated area, earthen dams are widely employed and have a significant impact on water collection. An obstacle arises when certain types of salts are present in the materials. In this study, actual earth dam body samples were used to examine leakage through the dam. The leakage and the impact of the gypsum salts on the leakage line, speed, pressure, and flow through the samples were then examined. In the model with the salts, it was discovered that the sedimentation line shifts, and there is also an increase in leakage. and the same model's speed. Geo Studio software was used to recreate these real-world trials, and it was discovered that the outcomes agreed with the location of the deposition line.

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