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Performance Assessment of Shirin Earth Dam in Iraq Under Various Operational Conditions

Adnan Jayed Zedan[1]*, Marewan Ridha Faris [2], Ali Kareem Bdaiwi[1]

1 Civil Engineering Department, College of Engineering, Tikrit University, Tikrit, Iraq.
2 Civil Engineering Department, University of Kirkuk, Kirkuk, Iraq.

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ABSTRACT

Proper dam management should be ensured regularly to avoid breaches and failure. In this study, the finite element method was used to analyse the stability of the Shirin earthen dam under various conditions. The necessary laboratory tests for soils used in the construction of the dam were carried out in the laboratories of the College of the Engineering /University of Tikrit, and these data were employed in the GEO-STUDIO program to analyse the seepage and stability of the dam. The seepage was analysed at three levels of the water lake reservoir including the highest, middle and lowest water levels. In addition, factors such as the permeability of the shell layer, the presence and thickness of the dam's core layer, the placement of filters at the back of the dam and the exit gradient have been considered. The results have shown that by increasing the permeability of the shell layer, the exit gradient is decreased while the seepage through the dam body is increased. The presence of the dam's core layer has a significant effect on reducing the amount of seepage through the dam's body as the amount of seepage is reduced by (99%). Moreover, it was found that the minimum safety factor is 1.95 and it occurs after (4 days) of the rapid emptying of the reservoir, and this indicates that the upstream slope of the dams is safe during water emptying.

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[*] Corresponding Author: E-mail: jayedadn@tu.edu.iq , Civil Engineering Department, College of Engineering, Tikrit University, Tikrit, Iraq.

تقييم أداء سد شيرين الترابي في العراق في ظل ظروف تشغيلية مختلفة

عدنان جايد زيدان قسم الهندسة المدنية / كلية الهندسة / جامعة تكريت / العراق.
مريوان رضا فارس قسم الهندسة المدنية / كلية الهندسة / جامعة كركوك / العراق.
علي كريم بديوي قسم الهندسة المدنية / كلية الهندسة / جامعة تكريت / العراق.

الخلاصة

تعد السدود من أقدم الوسائل التي استخدمها الإنسان لترويض عنفوان الأنهار وبقية المجاري المائية الطبيعية، وقد بدأ الإنسان في إقامتها في الأساس إما بهدف درء وتجنب خطر هو متكرر الحدوث مثل الفيضانات أو السيول، أو بهدف إدارة الموارد المائية المتاحة وتنظيمها وتوفير احتياجاته من المياه الصالحة للشرب والزراعة، أو لتحقيق كلا الغرضين معا. لتجنب حدوث خروقات في السدود والتي تؤدي الى الفشل يجب ان تكون هناك ادارة سليمة للسد .في هذه الدراسة استخدمت طريقة العناصر المحددة لغرض تحليل استقرار سد شيرين الترابي تحت مختلف الظروف، وهو من السدود الترابية غير المتجانسة يبلغ طوله 410 متر وارتفاعه 18 متراً. أُجريت الفحوصات المختبرية اللازمة للترب المستخدمة في انشاء السد في مختبرات كلية الهندسة/ جامعة تكريت، كما أُستخدم البرنامج الحاسوبي (GEO-STUDIO)في عملية تحليل العوامل المدروسة عبر برامجه الفرعية (SEEP/W) و .(SLOPE/W) عُرِض تقييم لصلاحية البرنامج عبر عرض لدراسات سابقة تقارن بين النتائج المستحصلة من البرنامج الحاسوبي والبرامج الاخرى والطرائق العملية وتبين ان النتائج جيدة ومقبولة .تم تحليل التسرب بأخذ منسوب المياه في الخزان عند ثلاث ارتفاعات، أعلى مستوى (16.0متر) واوطأ مستوى(5.8متر) وعندما يكون مملوءاً للنصف (10.9متر). التحكم بكمية التسرب وتدرج المخرج تم دراستها عن طريق معرفة تأثير بعض العناصر مثل: نفاذية طبقة الغلاف، اهمية وجود طبقة لب السد وسمكها، اهمية وجود المرشحات عند مؤخر السد وتأثيرها على كمية التسرب وتدرج المخرج. النتائج بينت انه بزيادة نفاذية طبقة الغلاف يؤدي الى خفض لتدرج المخرج وزيادة للنفاذية داخل جسم السد. وجود طبقة لب السد لها تأثير كبير على تخفيض كمية التسرب خلال جسم السد، حيث بينت النتائج بأنها تقلل كمية التسرب بنسبة (99 %)، في حين وجود المرشحات في جسم السد له تأثير قليل على زيادة التسرب خلاله، ولكن تأثيرها كبير في خفض تدرج المخرج .البرنامج الفرعي الثاني (SLOPE/W) أُستخدم لتحليل استقراريه منحدر مقدم السد (Upstream) خلال تفريغ المياه من الخزان بأخذ اعلى مستوى في الخزان، تمت دراسة حالتان عند تفريغ الخزان هما التفريغ السريع والبطيء، وجد ان الحد الأدنى لعامل الأمان يساوي 1.95 ويحدث بعد (4 أيام) من التفريغ السريع للخزان وهذا يدل على ان منحدر مقدم السد مستقر عند انخفاض مستوى المياه.

الكلمات الدالة: السدود الترابية، عناصر محددة، تحليل التسرب، سد شيرين، ثباتيه المنحدر.

1. INTRODUCTION

Earthen or Rock dams arise mainly from gravel or rubble in addition to sand. This form of the dam has a lower construction cost than other types of dams, such as concrete dams, and it does not require the building of intricate foundations, as concrete dams do. As a result, it is more prone to cracking or crumbling than the first type.Earthen dams are subjected to failure due to many reasons, the most important of which are: floods, structural instability, seepage through the dam's body or foundation, and slope instability as a result of the rapid emptying of the reservoir. This research will concentrate on earthen dams since the analyzed case was an earthen dam, which is also the most common form of a dam in the world, and its stability is one of the key issues in dam engineering. The design and construction of the dam is a major challenge in the field of engineering, due to the inevitable difference in the condition of the foundation and the properties of the available building materials [1].A study was conducted until 1986 on large earth dams, in which it was found that the probability of annual failure of dams is estimated at (4.5×10^{-4}) dams per year (136 dams failed out of 300,400 earthen dams per year). This probability of failure was reduced to (4.1×10^{-4}) taking into account the causes of failure during the construction process. Up to 1986, Table 1 shows the failure of big dams [2].

Table 1:

Failure probability prior to 1986 [2]

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

The basic requirement for designing the earthen dam; is having a safe and stable structure with minimal construction and maintenance costs. Due to the nature of the building materials from which an earthen dam is built, such as clay, gravel, sand, and silt, earthen dams are more prone to problems such as seepage or erosion than other types of dams.

As a result, the research focused on the issues that can arise with earthen dams: A study was conducted by Shakir, 2011 [3] on the flow of large earth dams and the effect of core permeability, thickness, and location. The finite element method was used to solve the incompressible fluid flow problem. A wide range of dam side permeability to core permeability values was used. Two cases of the nucleus were studied: a vertical nucleus and a sloping nucleus downstream. By analyzing the actual design of the dam using the program (SEEP/W), which is one of the branches of the main program Geo-Studio by Fattah et al, 2014 [4], the amount of water seeping through and under Al-Adhim dam with water pressure distribution was estimated using the theory of flow through porous media in a finite element method using the theory of flow through porous media in a finite element method. The effect of numerous elements such as the permeability of the casing material, the presence of an impermeable core, its position, and thickness on the dam's seepage management has been studied in several analyses. Using the Geo-Studio computer program by Irzooki, 2016 [5], a study was undertaken to establish a new equation to calculate the quantity of seepage through homogeneous earth dams with a horizontal drainage system at the lower end of the stern slope of the dam. For this purpose, three different cases of the slope of the downstream side of the dam, three different cases of the slope of the front, three different lengths of the horizontal drainage system, sewage at three different depths, three different dimensions of the width of the top of the dam, as well as three different heights of the dam were used. For each experiment conducted the amount of seepage through the dam body was calculated. The results showed that the amount of seepage increases with the increase in the front and back inclination angles and the increase in the depth of the water in the front reservoir, as well as the increase in the length of the horizontal drainage system. A study was carried out. Three different downstream slopes of the dam, three different upstream slopes, three varying downstream heads, three different upstream heads, three different earth dam heights, and three different earth dam top widths were used in the SEEP/W program. For each run, the quantity of seepage has been determined [6]. Dimensional analysis was used with helping of the theoretical results to develop an empirical equation in order to determine the quantity of seepage through a homogenous earth dam without afilter resting on the impervious base. Also, Verify the SEEP/W results with an artificial neural network (ANN), and compare them with analytical methods. Results show that when comparing the suggested equation with an artificial neural network (ANN) with less than 3% error with SEEP/W results with less than 2% error, Dupuit's solution has more than 20% error and Casagrande's solution has more than 15% error. Abass et al, 2017 [7] studied seepage through Al Shehabi Dam, a homogeneous earthen dam, by calculating equations for water flow via earthen dams using the finite element method via the GEO-STUDIO computer program. Using the computer program, the infiltration path, infiltration value through and under the dam body, infiltration velocity, pore water pressure distribution, total charge, pressure charge, and exit gradient of the dam were found. The dam was studied according to its actual design by examining infiltration through and down the dam body at two different water levels: normal and maximum. Three cases of rapid water subsidence were also taken into consideration: the rapid emptying of the reservoir within 116 hours, 78 hours, and 58 hours. Zedan et al, 2018 [8] conducted a study to gain a clear understanding of the behavior of the Khasa-Chai Dam during the drawdown action, taking into account the dam's new construction. Two cases were studied here to determine the effect of drawdown on the stability of the KHASA-CHAI Dam upstream slope: a) The first case is the rapid drawdown by fast draw of the water from the reservoir when the dam is at maximum natural reservoir level (spillway top-level). b) The second case is the slow drawdown by slow drawing the water from the reservoir during a time sequence when the dam is at the maximum natural reservoir level. the In first and second cases the water is drawn from the reservoir from height (45.17 m) till the tower intake point which is (17.17 m) height from the dam toe. The time required for the reservoir to be drawn down was taken to be (20 days) according to the toe drain discharge and the reservoir storage quantity. The pore water pressure dissipation was measured for (60 days). The slow drawdown case was investigated by completely draining the reservoir and leaving it empty (40 days). The dissipation of pore water pressure was measured at (60 days).

2. EXPERIMENTAL PROGRAM

This part aims to investigate the soil characteristics used to build the dam, and then use these parameters in the GEO-STUDIO software's SEEP/W and Slope/W subprograms to model seepage through the dam and the effect of drawdown on slope stability. Sub-base dirt, which is a local soil available in huge amounts near the position, was used in the construction of the SHIRIN shell. The silty-clay soil used to build the core layer. The filters were made of natural sand and gravel. Table 2 shows the experimental works' results.

Table2:
Experimentation results

Type of Experiments		Shell layer	Core layer	Fine filters	Coarse filters
Sieve Analysis	Coefficient of Curvature Cc	2.91	.....	1.27	1.2
	Coefficient of Uniformity Cu	29.23	.....	15.0	1.6
Compaction	Max. Dry density (gm/cm^3)	19.66	18.8	18.9	19.6
	Optimum moisture Content (%)	6.75	15.0	8.45	.....
Permeability At 20°C (m/s)		5.36×10^{-6}	1×10^{-8}	4.53×10^{-3}	1.0×10^{-2}
Specific gravity at 20° C		2.68	2.72	2.56	2.7
Angle of internal friction (ϕ)		38	15.5	38	38
Cohesion force (c) kPa		0	31	0	0

3. SEEPAGE ANALYSIS

3.1 General

SEEP/W, a sub-program of the GEO-STUDIO master program that uses finite element methods to predict pore water pressure distribution and water flow inside porous media, is used to study steady-state seepage through the dam (soil and rock). This application is commonly used in civil and geotechnical engineering projects for analysis, design, and hydrogeological engineering. This is a generic seep analysis software that can handle both saturated and unsaturated flow states, allowing it to handle a wide range of real-world challenges, comparable to other seep software packages.

3.2 Case study: shirin earth dam

Shirin Earth Dam was established in the Iraqi governorate of Kirkuk. This dam is located in the Laylan district, 14 km from the center of Kirkuk and 6.5 km from the Laylan district center. Work began on it in 2007 and then completed on January 24, 2009. The dam consists of three main parts which are: the dam body, the lower outlet, and the watercourse. Fig 1 presents the cross-section of the dam's body. The body of the dam is an earthen structure with a mud core, 410 meters long and 18 meters in height. The thickness of the muddy core is 3 meters at the top and it is impermeable to water. This thickness increases towards the bottom with the slope of its sides to become 35 meters at the base (horizontal slope to vertical slope 1:1 in forward and backward). A covering layer of mixed gravel surrounds the core layer, with vertical filters between the gravel covering and the clay core, and finger filters at the back of the dam to control leaching. The ordinary and dead storage capacity of the lake is (1.65 and 0.33) million cubic meters, respectively. The most important purposes of the establishment of Shirin Dam were for storing and regulating water and feeding, in addition to using it for drinking and providing water for limited agricultural uses [9].

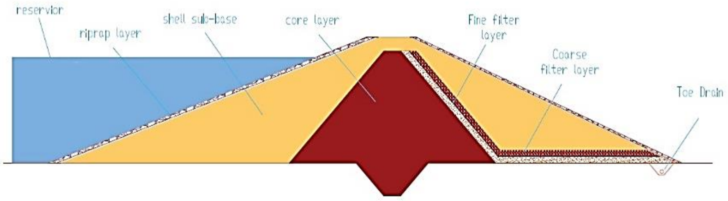

Fig. 1. The dam's body in cross-section

3.3 Seepage formulation

In this part, the steady state analysis of seepage was studied by representing the dam in the program using finite elements in a quadrilateral pattern containing eight nodes and for three cases depending on the water level in the reservoir. It is when the water level in the reservoir is at the highest (16.00 m) and the lowest height (5.80 m) and half filled with water (10.90 m). The first step to determine the geometric properties of the soil is to create a miniature model of the cross-section to be analyzed, the second step is to determine the soil areas in the cross-section. The next step in performing a seep analysis in SEEP/W is to set the terminal conditions. Setting these conditions into the model is an essential component of the solution and depends on the type of boundary conditions defined in the model. These conditions can only be if one of the two basic options, head or total flux, is available. The conditions for the upfront and backend limits in this step are set as follows:

1. The total head pressure represents the height of the water in the reservoir.
2. Possible surface seepage located on the backside face.
3. A toe drain point with a constant pressure equal to (zero).

The finite element network used in the analysis was shown at the number of elements (1839) and knots (1962) As shown in Fig 2, this estimate is shown from the number of finite elements by displaying them in the program and this number depends on the need for a more accurate estimate of the results in the analysis process. Fig 3 provides a general illustration of how the SEEP/W sub-computer works in the analysis process to obtain the results.

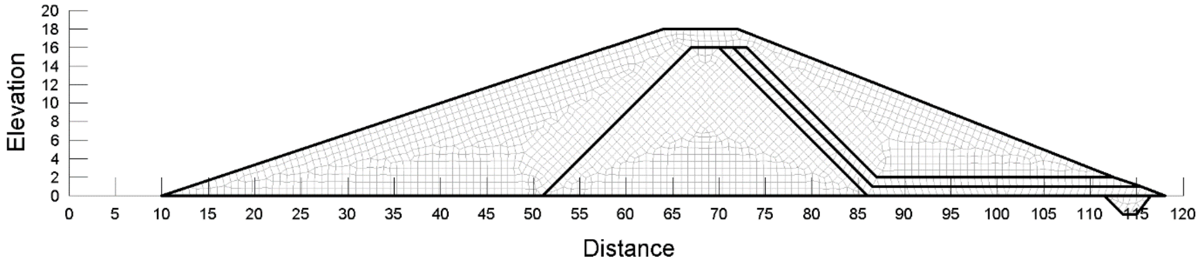

Fig. 2. The problem's finite element mesh

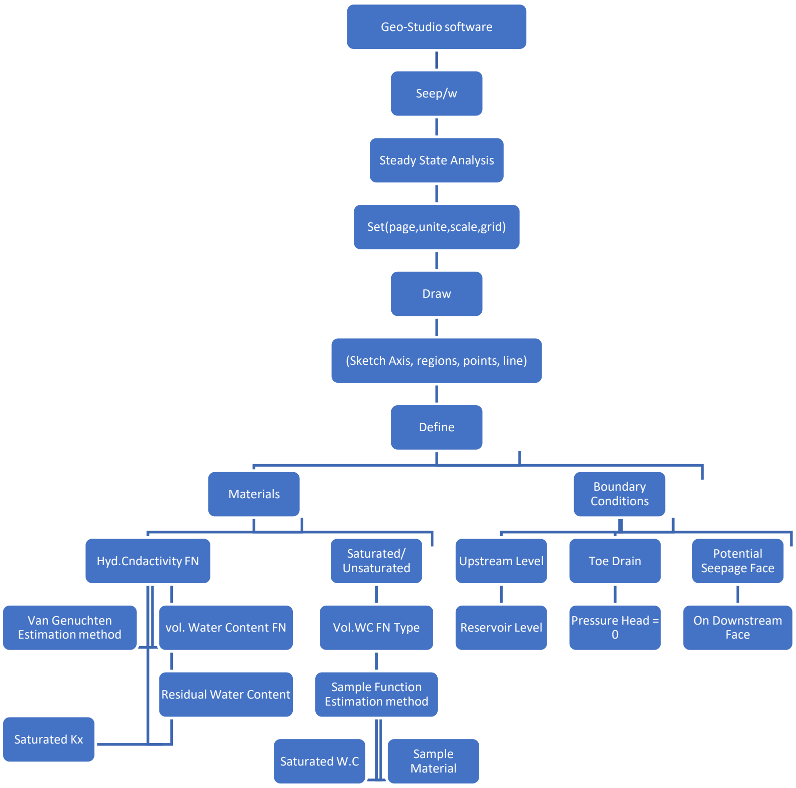

Fig. 3. the SEEP/W sub-computer works in the analysis process

The results of the analysis process are shown in Table 3, it can be noted that the rise of the water at the level of the core layer (the height of the water in the reservoir when flooding) leads to an increase in the exit gradient to double, as well as an increase in the amount of seepage to almost three times.

Table3:
Results from the basic analysis

Height of water (m)	**16.00**	**15.50**	**10.90**	**5.80**
Seepage (m^3/sec)	20.47×10^{-8}	7.50×10^{-8}	3.025×10^{-8}	0.897×10^{-8}
Exit gradient(x)	7.64×10^{-7}	3.21×10^{-7}	1.354×10^{-7}	0.411×10^{-7}
Exit gradient(y)	37.35×10^{-5}	13.73×10^{-5}	5.54×10^{-5}	1.644×10^{-5}
Maximum velocity(x)(m/s)	7.645×10^{-6}	3.203×10^{-6}	1.354×10^{-6}	0.411×10^{-6}
Maximum velocity(y)(m/s)	7.264×10^{-7}	3.158×10^{-7}	1.247×10^{-7}	0.378×10^{-7}

4. SEEPAGE CONTROL

4.1 Effect of changing the permeability of the shell

To illustrate the effects of these changes on the seepage line, seepage value, and exit gradient, three scenarios will be explored at this point by altering the permeability of the shell relative to the permeability of the core:

a) The permeability of the shell equals (100) the permeability of the core.

$$K_{shell} = 100\times1.0\times10^{-8} = 1.0\times10^{-6}\ m/s$$

b) The permeability of the shell equals (1,000) the permeability of the core.

$$K_{shell} = 1000\times1.0\times10^{-8} = 1.0\times10^{-5}\ m/s$$

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

$$K_{shell} = 10000\times1.0\times10^{-8} = 1.0\times10^{-4}\ m/s$$

The relationship between the amount of seepage and exit gradient and various changes in the (k_{shell}/k_{core}) at various reservoir levels is shown in Fig (4, 5).

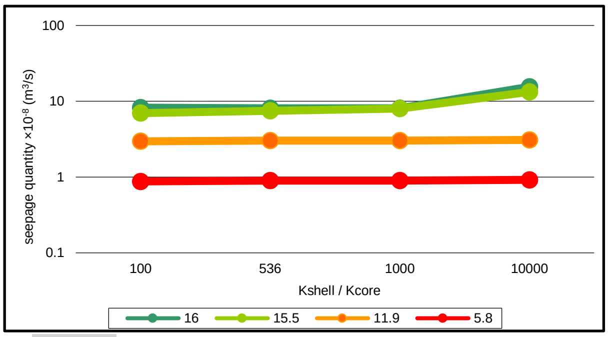

Fig. 4. The effect of changing (k_{shell}/k_{core}) on seepage quantity

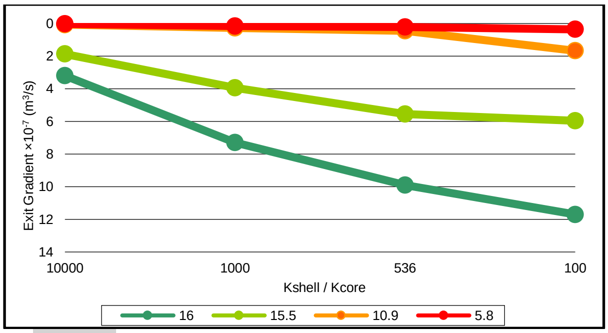

Fig. 5. The effect of changing (k_{shell}/k_{core}) on exit gradient

By comparing these numbers, it can be shown that the ideal cover layer to core layer permeability ratio is at (k_{shell}/k_{core} = 1,000), as this ratio offers a tolerable level of seepage and a decent exit gradient. The following statement summarizes the impact of modifying the (k_{shell}/k_{core}) ratio on the quantity of seepage and the exit gradient:

- As this proportion rises, the exit gradient will decrease.
- As this proportion rises, the amount of seepage will also rise.

4.2 Effect of the Core in the Dam body

In order to prevent water from going through the dam, this is the main component of the majority of earth-fill dams. Depending on the availability of materials and the difficulty of building, cores may be made of soil, steel, concrete, or wood. Here, the effects of two cases—core existence and thickness on seepage volume and exit gradient—are examined.

a) Studying the impact of core existence on the amount of seepage and exit gradient. The relationship between the amounts of seepage and exit gradients with different heads of water when the dam is with and without the core is shown in Figs (6, 7).

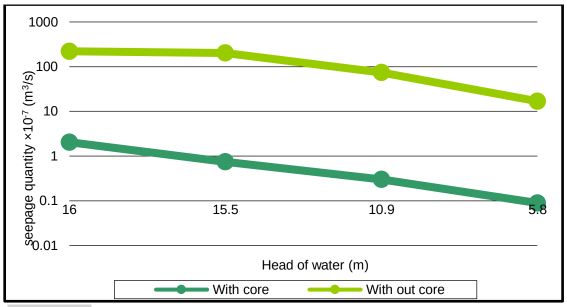

Fig. 6. Relationship between seepage quantity & head of water

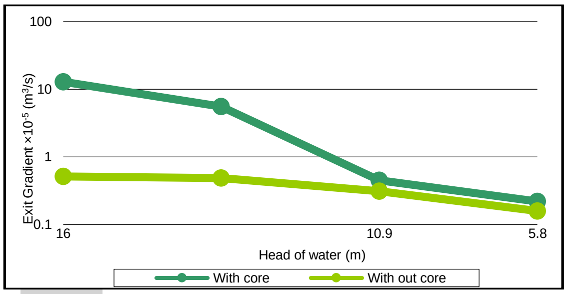

Fig. 7. Relationship between exit gradient & head of water

The findings indicated that removing the core layer from the dam body greatly increases the quantity of seepage. Additionally, the existence of a core layer has a significant impact on lengthening the seepage path, which lowers the exit gradient. Following is a succinct summary of how the core layer affected the quantity of seepage and the exit gradient:

- Reducing seepage by 99 percent.
- the gradient at the exit by 92 percent.

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

The thickness specified here is situated at zero level on the ground line. The core of the dam is 35 meters thick when it is at its lowest point. To maintain the core's symmetry in each of the three situations, the thickness of the core was reduced by 5 meters from each side (upstream & downstream). The relationship between the amount of seepage and exit gradient and various changes in the thickness of the core at various reservoir levels is shown in Figs (8, 9).

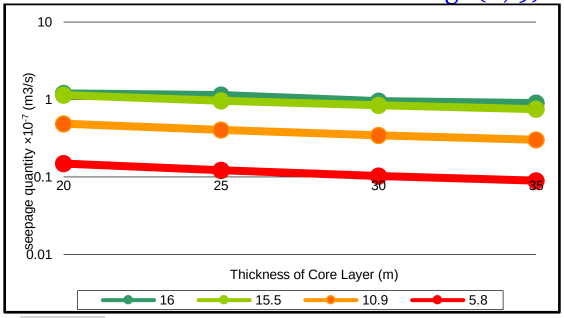

Fig. 8. Relationship between the quantity of seepage and core thickness

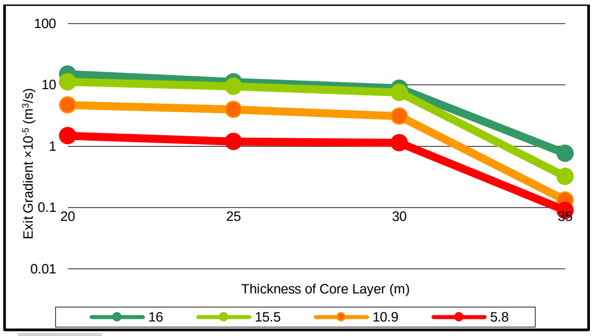

Fig. 9. Relationship between exit gradient and thickness of the core

The following sentence sums up how lowering core thickness affects the amount of seepage and exit gradient:

- Increasing seepage quantity by (21-88 %) for each decreasing the core thickness by 5m.
- Increasing exit gradient by (20-89 %) for each decreasing the core thickness by 5m.
- The current thickness of the core layer (35 meters, 1h: 1v) achieves the lowest exit gradient with an acceptable seepage rate.

4.3 The role of filters in the dam

Filters are used in most earthen dams, as they are made of coarse-grained soils and are placed inside or next to the dam body. Good filters may be made of granular materials with porous holes small enough to prevent soil movement when water seeps through the dam, Additionally, the filters must be porous enough to allow water to pass through with minimum resistance [12]. To have these functions the perfect filters should be [13]:

- Don't separate while handling, compaction, processing, etc.
- Possess the ability to resist chemical and physical reactions without turning into cement.
- Maintain gradation throughout handling, compaction, and processing.
- The particles should have the internal stability property to prevent separation from the filter as the seepage flow proceeds.
- The permeability ought to be sufficient to let the seepage flows go and stop the buildup of extra pore water pressure.
- to prevent erosion from the dam's shell caused by concentrated leaks, reverse erosion, etc.

The effect of all filters can be summed up by increasing the amount of seepage by a small percentage. On the other hand, the presence of these filters may significantly lessen the exit gradient [14]. This instance was studied to determine whether it was possible to dispense filters from the dam's body while also learning the significance of filters and their impact on the amount of seepage and exit gradient. The relationship between the amounts of seepage and the exit gradient with the removal of downstream filters during the change in reservoir levels is shown in Figs (10, 11).

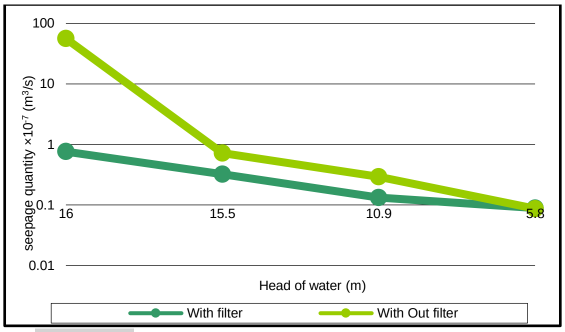

Fig. 10. Relationship between quantity of seepage and water head

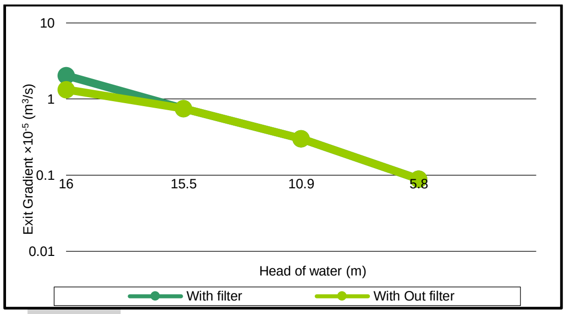

Fig. 11. Relationship between exit gradient and water head

From these results, it can be concluded that the presence of these filters on the downstream side has an effect on the amount of seepage and exit gradient. This important function of filters could be noted by preventing the movement of fine pulp soil particles as well as dissipating pore water pressure by drawing water and pushing it downstream. The effect of the presence of downstream side filters on the amount of seepage and exit gradient can be summarized as follows:

- Increasing the amount of seepage by 20% at different water levels in the reservoir.
- Decreasing the hydraulic gradient by (97%) at different water levels in the reservoir.

5. THE EFFECT OF EMPTYING THE DAM'S RESERVOIR ON ITS STABILITY

rapid drawdown of dam reservoir is known as one of the most dangerous conditions for slope stability. When the upstream water pressure disappears, it threats the stabilization of the upstream slope. The upstream crust cannot maintain stability under hydrodynamic pressure due to the rapid drawdown of water. The soil inside the dam body remains saturated and seepage begins in the opposite direction, which is towards the dam's chest. seepage and hydrodynamic pressures generate downward forces that affect this slope and create a critical condition for it [15]. The following are the precise mechanics of the emptying process: It is assumed that the reservoir has been filled with water at a high level for long enough for a steady rate of seepage to occur through the material of the dam body. This is the most dangerous situation for the backflow of water into the dam's reservoir because if the reservoir is swiftly emptied at this point, the direction of flow reverses, generating instability in the dam's chest slope.

5.1 Computer program

Evaluation of the impact of abrupt unloading on slope stability, dissipation of pore water pressures, and velocity lines were done using the SLOPE/W software that is linked to the SEEP/W program. SLOPE/W is able to handle saturated and unsaturated soil conditions in the stability study since it uses pore water pressures computed using the finite element method. The steps for using the SLOPE/W program are shown in Fig 12.

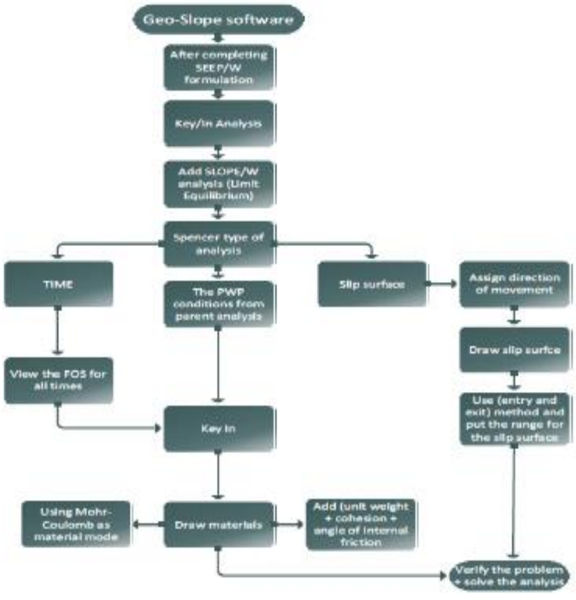

Fig. 12. The flow chart of the SLOPE/W program [8].

5.2 Slope stability during rapid drawdown conditions

This research focuses on completely emptying the reservoir of water when the water level in the dam is at the maximum storage level (top of the spillway), or 384.5 meters above sea level. Water is discharged from the reservoir at a height of (14.50 m) and then released to the lower part of the tower at a height of (5.80 m) above the toe drain. Fig 13 shows the quick steps for dealing with rapid drawdown. The time required to empty the reservoir (4 days) according to the amount of bottom outlet drain and the size of the reservoir. Through the analysis in the computer program, the pressure of pore water continues to dissipate from the dam body for up to (30 days). As the water velocity vectors flow from the reservoir towards the downstream face as shown in Fig 14a, the potential seepage face (failure face) existed on the downstream face prior to the start of drawdown. The upstream face will be the potential seepage face as the reservoir's water level begins to drop and the water velocity vectors begin to leave it (Fig 14b). Fig 15a depicts the safety factor for all time periods of rapid regression, Fig 15b the pore water pressure prior to the drawdown condition, and Fig 15c the dissipation of pore water pressure following (30 days) of drawdown.

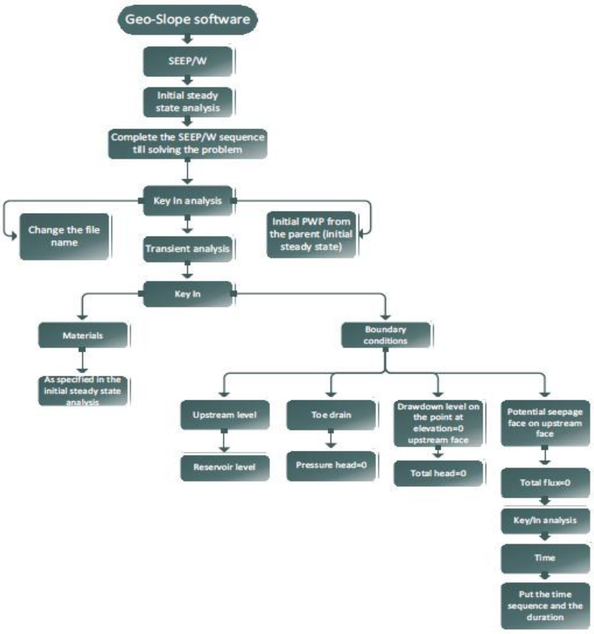

Fig. 13. The brief procedures for dealing with rapid drawdown conditions [8].

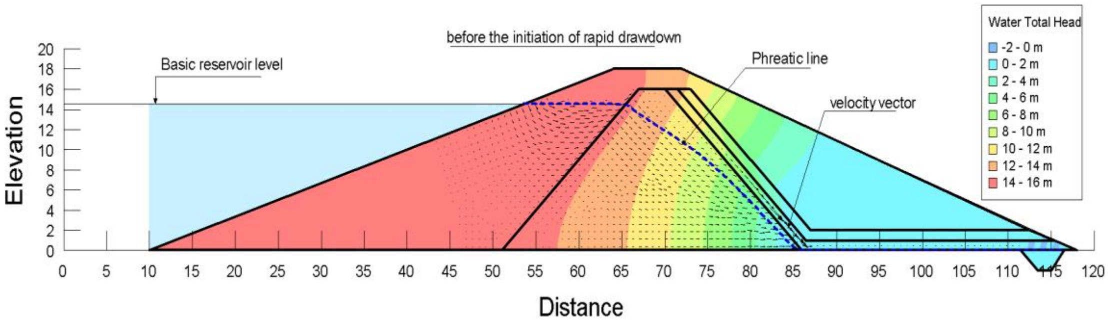

Fig. 14a. Phreatic line, velocity vectors, and total head prior to the start of the rapid drawdown

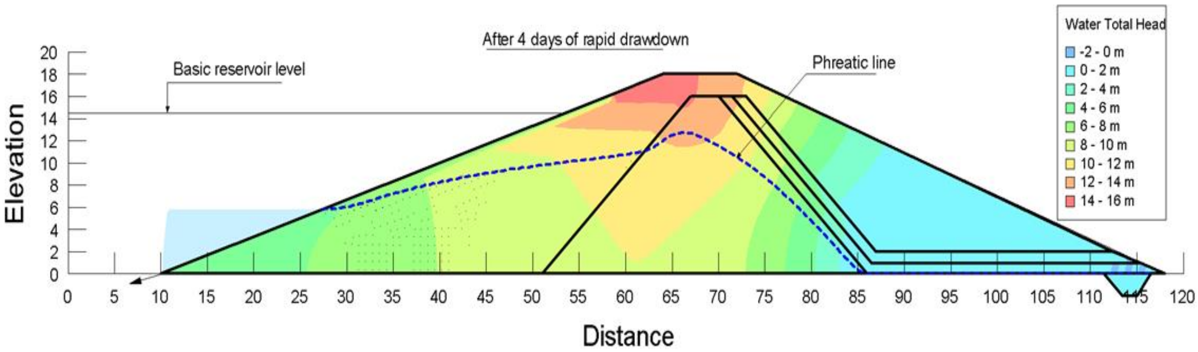

Fig. 14b. Phreatic line, velocity vectors, and total head after 4 days of rapid drawdown

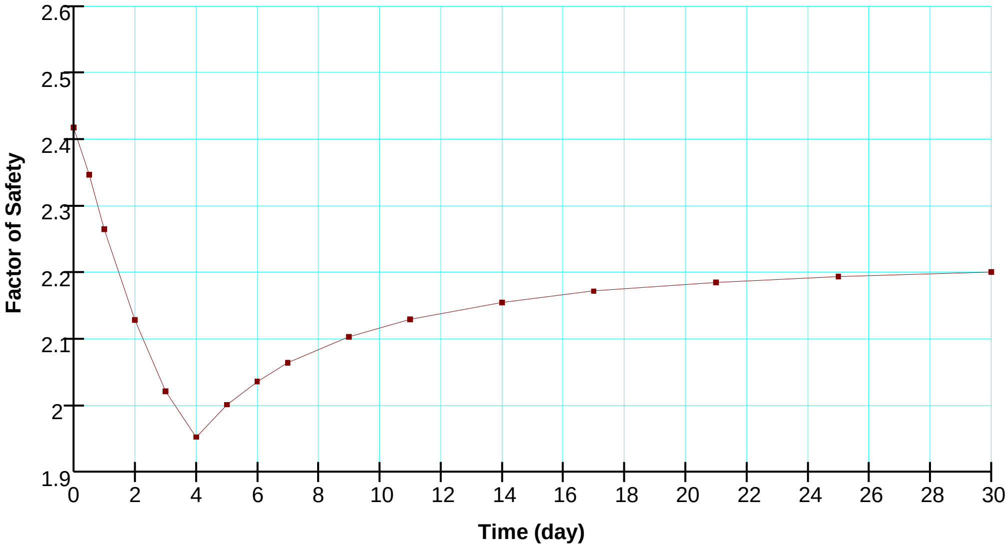

Fig. 15a. The safety factor over all time periods of rapid regression

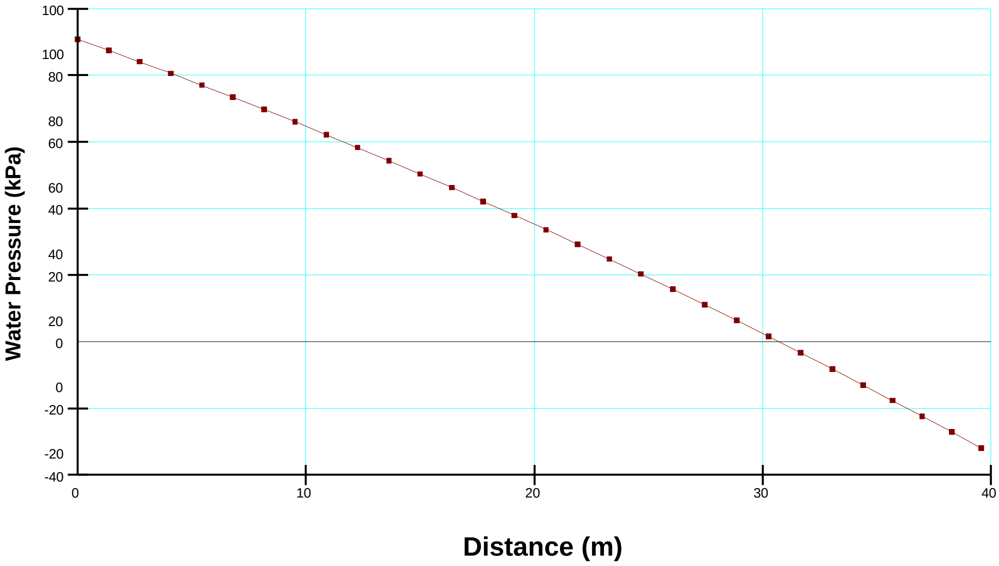

Fig. 15b. the pore water pressure before the rapid drawdown state

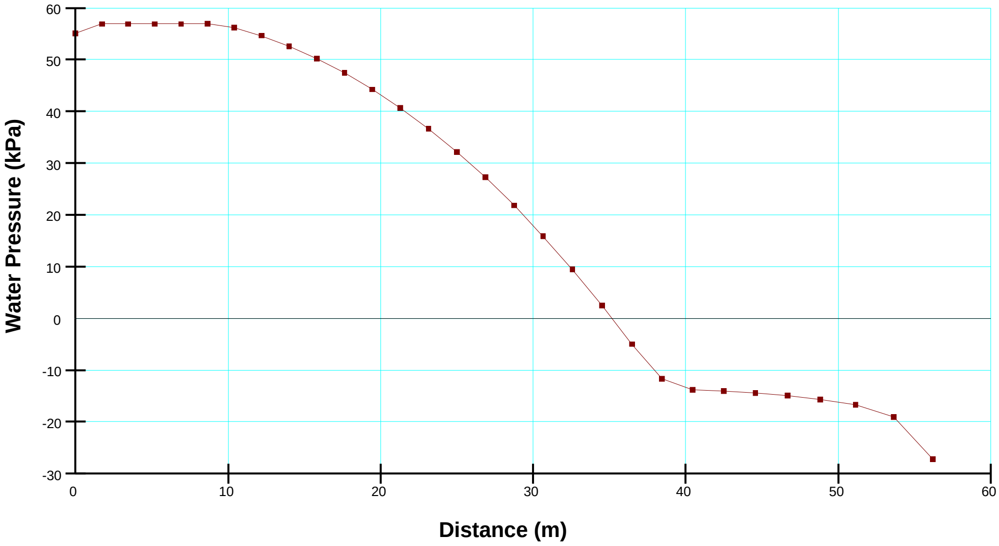

Fig. 15c. the dissipation of water pressure in the pores after (30 days) of degassing.

From the above, the following may be said about these forms:

- At all drawdown levels, the pore water pressure in the dam's body appears to remain rather constant. Because the phreatic line doesn't drop, the pore water pressure in the dam's body remains high even when the water is almost completely empty.
- As the water is slowly drained from the reservoir, the hydraulic slope at the filter progressively drops, increasing the safety factor against the occurrence of the phenomena known as soil boiling.
- When the reservoir's water level is first being emptied, it becomes less safe; but, as time goes on and the pore water pressure lowers, it becomes safer.
- The downstream slope will be in a safe condition when the water is drained from the reservoir within 1.954, which is the minimum safety factor during rapid emptying (4 days).

5.3 Slope stability during slow water emptying

This study focused on withdrawing the water completely from the reservoir when its height is at the normal storage level of the reservoir (spillway top level), which is at a level (384.5 m) above sea level. The water is withdrawn from the reservoir at a height of (14.50 m) to the entry point of the tower (the lower part) at a height of (5.80 m) above the level of the toe drain. The time required for slow emptying of the entire reservoir (15 days) was considered according to hydraulic conditions. The shortcut steps for dealing with slow drawdown are presented in Fig 16. Through the analysis in the computer program, the pressure of pore water continues to dissipate from the dam body for up to (30 days). The Phreatic line, velocity vectors after (0.5, 14, 30) days when the dam is drawdown slowly shown in Fig (17a, b, c). Slip surfaces and factors of safety after (0.5, 14, 30) days when the dam is drawdown slowly are shown in Figs (18a, b, c). The relationship between slip surface and safety factor over time and for different time steps is shown in Fig 19. The result of the safety factor during each time period after the slow regression condition is shown in Fig 20.

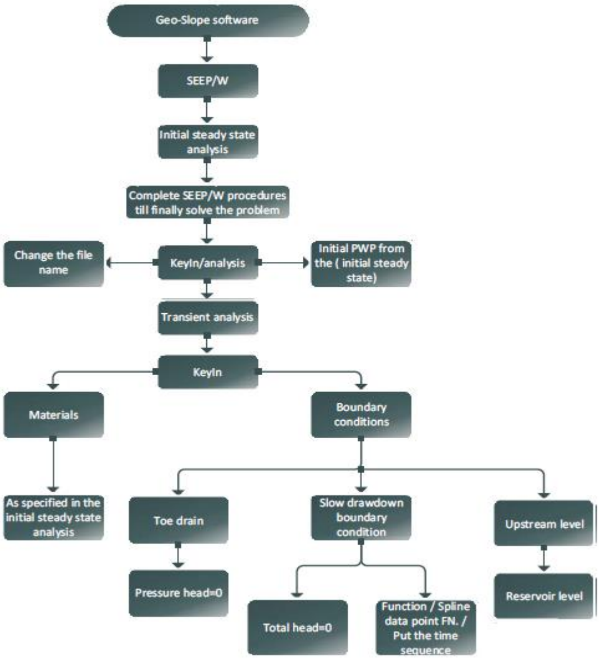

Fig. 16. The steps for slow drawdown [8].

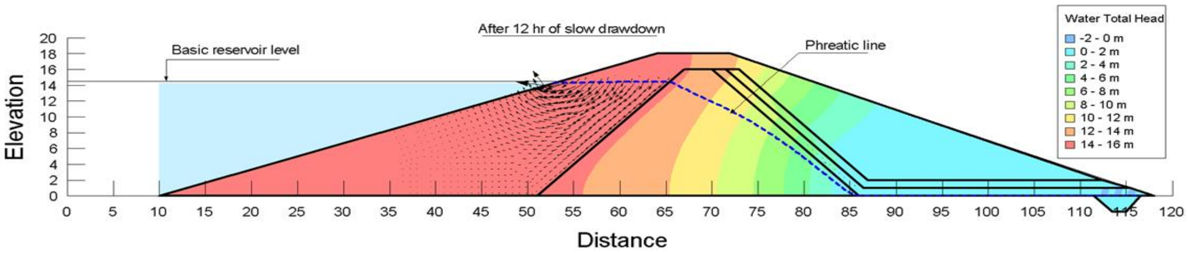

Fig. 17a. Phreatic line, velocity vectors, and total head after 12hr when the dam is drawdown slowly.

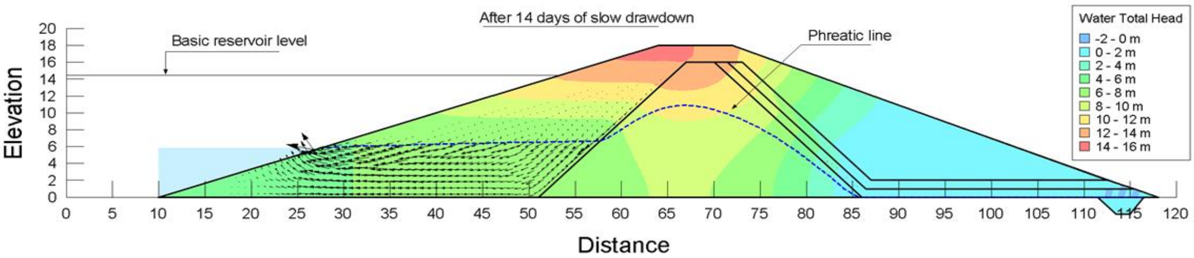

Fig. 17b. Phreatic line, velocity vectors, and total head after 14 days when the dam is drawdown slowly.

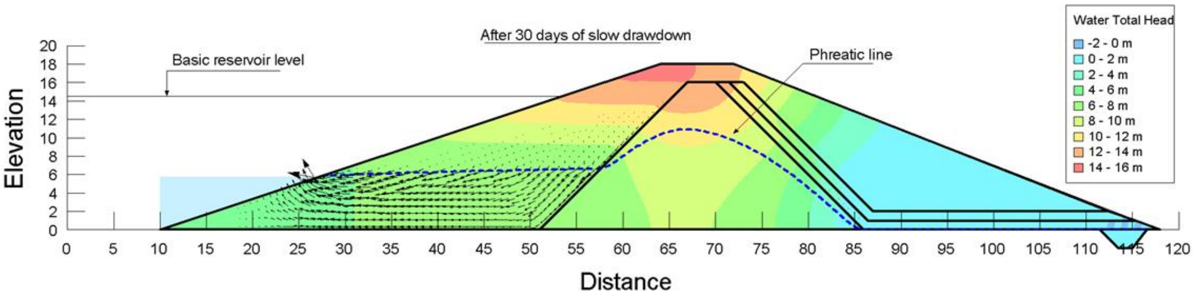

Fig. 17c. Phreatic line, velocity vectors, and total head after 30 days when the dam is drawdown slowly.

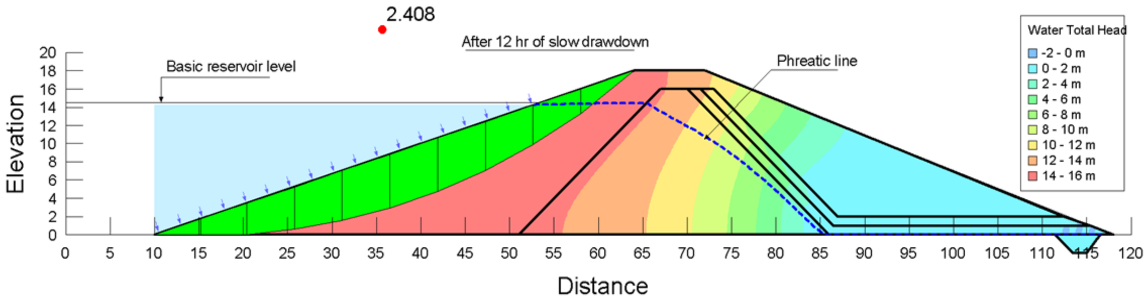

Fig. 18a. Slip surface, the factor of safety, phreatic line, and total head after 12 hours when the dam is drawdown slowly.

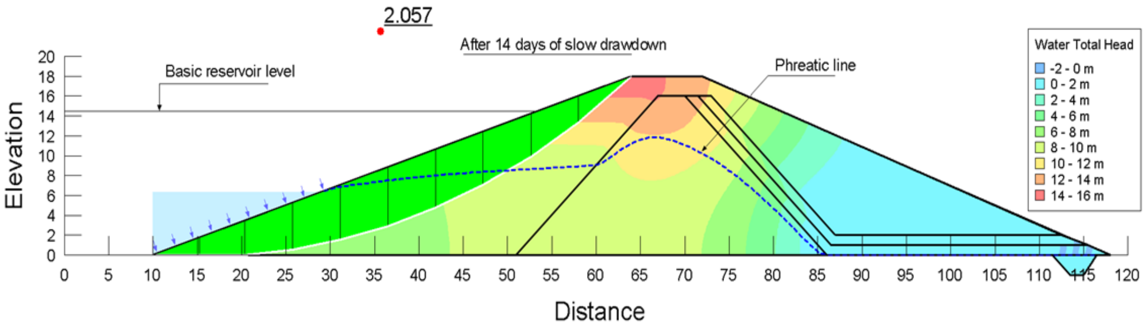

Fig. 18b. Slip surface, the factor of safety, phreatic line, and total head after 14 days when the dam is drawdown slowly.

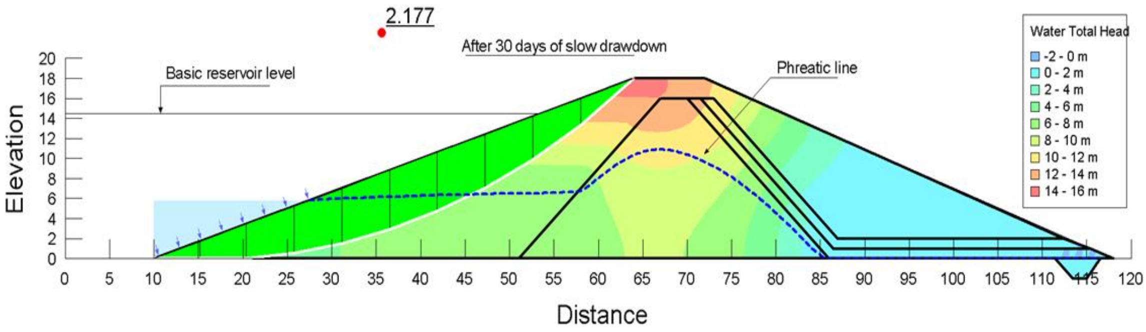

Fig. 18c. Slip surface, a factor of safety, phreatic line, and total head after 30 days when the dam is drawdown slowly.

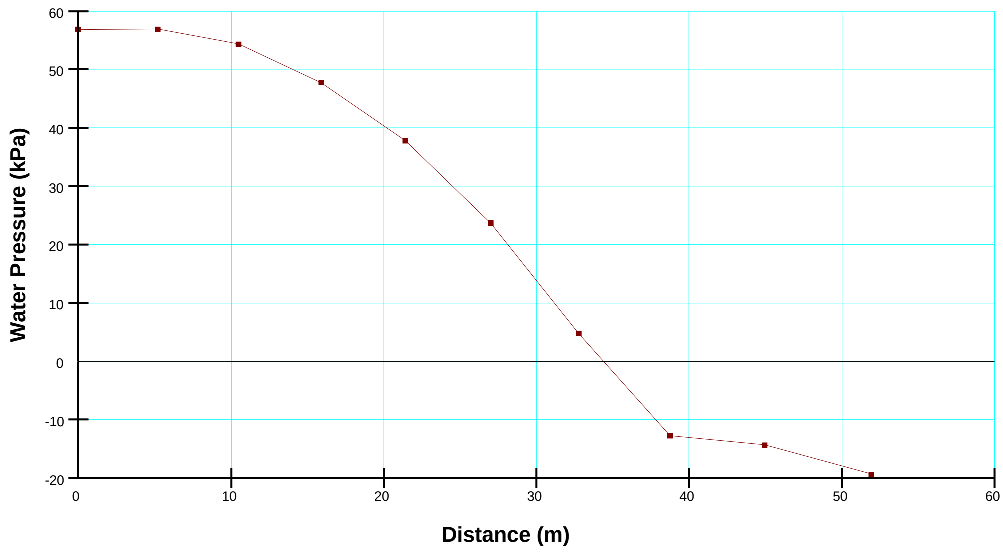

Fig. 19. Pore water pressure across the slip surface after 30 days.

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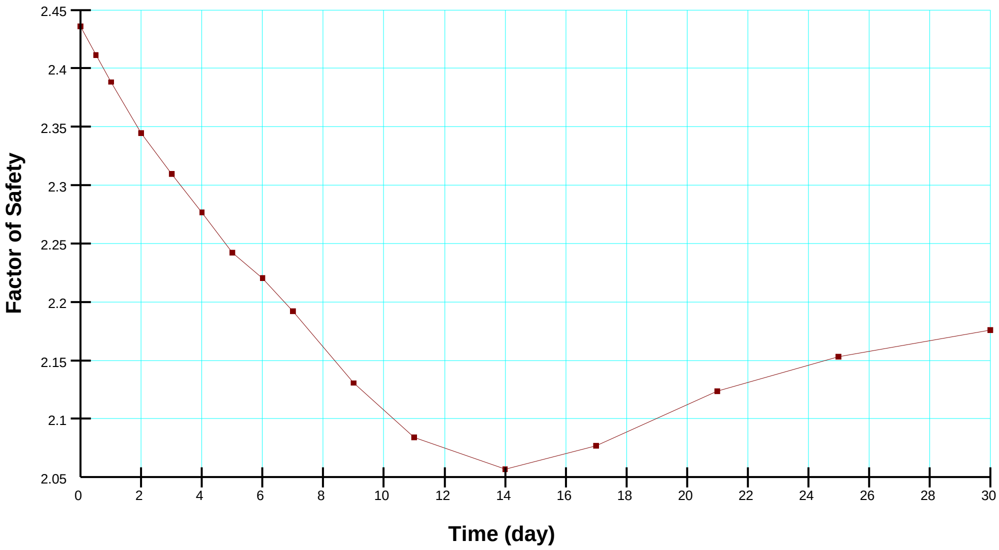

Fig. 20. Relationship between each upstream slip surface's time and the safety factor when the reservoir is slowly drawdown.

From the foregoing, the following can be said about these shapes in general:

- In the case of a rapid discharge, the seepage line is roughly in the same location.
- As the water level in the reservoir dropped over time, there was less seepage through the dam body.
- As the water level in the reservoir decreased to its lowest level, the safety factor gradually decreased until it began to rise as the pressure of the pore water in the dam body began to decrease.
- In this case, the minimum safety coefficient is (2.057), which indicates that the slope of the dam body is safe when it is emptied within (15 days).

6. CONCLUSIONS

First: By studying the seepage through the nonhomogeneous Shirin earthen dam, the following can be summarized:

1) The four cases studied for the water level in the reservoir (16.0 m, 15.5, 10.9, 5.8), represent the maximum (when flooded and natural), half-filled, and the lowest level, respectively. the results showed that the exit gradient is always less than (one) and these Indicate that the dam is safe against the occurrence of the boiling phenomenon (boiling).
2) The rise of the water at the level of the core layer (16.00 m) caused an increase in the amount of exit gradient of the dam to double that of the recommended water level (15.50 m), as well as an increase in the amount of seepage to almost three times.
3) The difference in the ratio of the permeability coefficient of the shell layer to the core layer (K_{shell}/K_{core}) has an effect on the amount of seepage and the exit gradient, increasing this ratio increases the amount of seepage and decreases the exit gradient.
4) It can be distinguished that the best ratio of permeability of the cover layer to the core layer is at (k_{shell}/k_{core}=1,000), as this ratio provides an acceptable amount of seepage and the exit gradation is good.
5) The dam core layer has an important effect on the seepage quantity and the exit gradient, its presence reduces the seepage amount by 99 (%). Also, the exit gradient is 92%.
6) Reducing the thickness of the core layer base by 5m increases the seepage amount and exit gradient by (22.3%) and (23%) respectively. Also, the current thickness of the core layer (35m, 1H:1V) achieves the lowest exit gradient with an acceptable seepage rate.
7) The presence of a layer of filters in the dam body has a slight effect on the amount of seepage, as it increases by (20%) when there are no filters. While this effect on the exit gradient decreases to be (97%).

Second: By studying the case of the rapid and slow emptying of the nonhomogeneous Shirin earthen dam, the following can be summarized:

1) The amount of seepage through the dam body decreases over time as the water in the reservoir decreases.
2) The safety factor decreases with the start of emptying i.e., when the water level drops rapidly from the reservoir. Then this factor increases with time as the pore water pressure dissipates.
3) The minimum safety factor is 1.95 and occurs after (4 days) of rapid emptying of the

reservoir, i.e., the ramp will be in a safe state at the rapid emptying condition.

4) The exit gradient at the downstream filter gradually decreases with the start of drawing water from the reservoir, which increases the safety factor against the phenomenon of boiling the soil.

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