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Seepage Simulation of the Proposed Makhool Dam in North Iraq

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Abstract

This study aims to simulate water seepage and identify areas of weakness in the foundations through the right and left sides of the proposed Makhool dam in northern Iraq, using the finite element method by advanced computer software (SEEP/ W, 2012). The earth fill dam is 3670 m long on the Tigris River. Many attempts were made to ascertain the program results on the supposed earth dam and compare the results with those of other analytical methods to verify the program. The results are comparable, showing that the program is suitable for use in the seepage analysis at the proposed Makhool dam. According to the seepage analysis, the quantity of seepage through the left side of Makhool is acceptable within permissible limits; however, the right side has a lot more than the left side because of the presence of cracks, fractures, and cavitations in the stratigraphic sequence of Fatha formation at great depths in the gypsum beds under the diaphragm. The results indicate the need to lower the diaphragm about 6 m extra in the foundation's zone to a level of 49 m.a.s.l until reaching the low permeability clay bed within the foundations' zone. This action will reduce the amount of seepage and flow velocity and avoid using more grouting during the dam life. The design limits of the piezometric head (total head) were also determined, which are supposed to be read by the monitoring devices when operating the dam at the maximum level of the reservoir and the normal operating levels.

Keywords: Makhool, dam, seepage, simulation, SEEP/W2012.

محاكاة التسرب لسد مكحول المقترح في شمال العراق

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الخلاصة

تهدف هذه الدراسة إلى محاكاة تسرب المياه وتحديد مناطق الضعف في نطاق الأسس من خلال الجانبين الأيمن والأيسر لسد مكحول المقترح في شمال العراق، باستخدام طريقة العناصر المحددة بواسطة برنامج حاسوبي متقدم (SEEP/W, 2012). يبلغ طول سد مكحول الاملائي الترابي 3670م على نهر دجلة. اجريت محاولات عديدة للتأكد من نتائج البرنامج على سد ترابي افتراضي ومقارنة نتائجه مع نتائج طرق تحليلية أخرى من أجل التحقق من البرنامج, وكانت النتائج مقاربة جداً، مما يدل على أن البرنامج ملائم للاستخدام في تحليل التسرب

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في سد مكحول المقترح. أعتماداً على نتائج تحليل التسرب، فإن كمية التسرب من خلال الجانب الايسر لسد مكحول مقبولة ضمن الحدود المسموح بها، اما كمية التسرب من خلال الجانب الايمن فهي أكثر بكثير من الجانب الأيسر بسبب وجود الشقوق، الكسور والتكهفات في التتابع الطباقي لتكوين الفتحة على أعماق كبيرة في طبقات الجبس تحت الحجاب الحاجز diaphragm. تشير هذه النتائج إلى الحاجة إلى انزال الحجاب الحاجز diaphragm حوالي 6 امتار اضافية في نطاق الأسس إلى منسوب 49 م فوق مستوى سطح البحر الى حين الوصول إلى طبقة الطين ذات النفاذية المنخفضة الموجودة داخل نطاق الأسس، حيثُ سيؤدي هذا الإجراء إلى تقليل كمية التسرب وسرعة الجريان وتجنب استخدام المزيد من اعمال التحشية طيل فترة عمر السد. كما تم تحديد الحدود التصميمية للضغوط المائية (total head) ، والتي من المفترض أن تقرأها أجهزة المراقبة piezometers عند تشغيل السد عند المنسوب الأعظمي للخزان ومناسيب التشغيل العادية.

1. Introduction

The study of seepage through and under the dam body is considered one of the important analyses during the dam design, especially when there are rock layers that contain lenses of soluble rocks such as limestone and gypsum, as in the scope of the proposed Makhool dam foundations. It is necessary to calculate the losses from the reservoir, estimate the pore-water pressure distribution and determine the phreatic line used in the dam stability analysis against shear failure and hydraulic gradient study that gives an idea of the weathering and erosion [1]. The finite element method was used as a numerical solution in different studies using computer programs.

(Noori and Ismaeel, 2011) [2] examined the seepage of the Duhok dam by using a (SEEP/2D) computer program. The quantity of seepage through the dam, the pore water pressure distribution, the total head measurements and the effect of anisotropy of the core materials (the ratio of the permeability in the horizontal direction to that in the vertical direction (Kx/Ky)) were examined.

The seepage through and under the Hub earth dam in Pakistan was simulated using (SEEP/W) program [3], for three different scenarios: maximum, minimum and normal pool level.

(Abdulsattar et al., 2017) [4] analyzed the seepage properties of the KHASA-CHAI dam using the finite element (SEEP/W) program. Attempts were made to verify the program's results by taking two cases for the study that were previously solved using the flow net method. It was found that the results obtained from the program are close to the previous results, indicating the integrity of the program (SEEP/W) for analyzing the KHASA-CHAI dam.

The water seepage through the Haditha earth-fill dam on the Euphrates River in the west of Iraq was assessed [5]. For this purpose, the finite element method (SEEP/W, 2012) program was used. The program results were compared to the field readings of the seepage amount and dam water level from1989 to 2017.

The current study aims to simulate and analyze the expected seepage properties through the body(clay core) and foundation of the Makhool dam using the (SEEP/W, 2012). Also, this study aims to determine the design limits of the water pressure (Total Head), which is supposed to be read by the monitoring devices when the dam is operating.

2. Location and geology

3. The Makhool dam is constructed on the Tigris River at a distance of about 16 km north of Fatha Bridge and 30 km northeast of Baiji city within Salah al-Din Governorate. The length of the dam axis is 3670 m and extends from the fold of mount Makhool in the west through the floodplains to end with the eastern heights forming the Khanukah fold [6]. The coordinates of the dam location are determined by the UTM WGS84 projection along the axis between point A at (355906.32)E and (3891666.87) N point B at (359818.05) E and (3893609.75) N, as shown in Figure 1, [7].

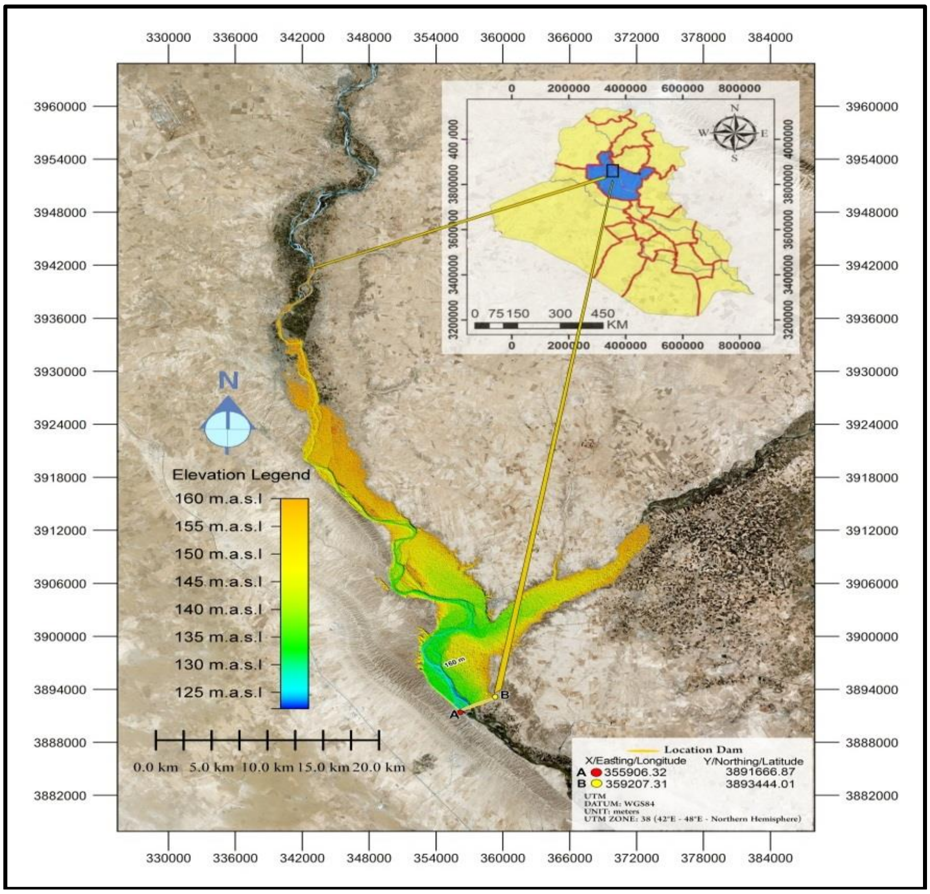

Figure 1: Location of the Makhool Dam on the Tigris River [7].

The dam is located in a geologically complex area. Two folds (Anticline) are noted in the south of the area, which is the Makhool fold parallel to the western side of the Tigris River, and the Khanukah fold parallel to the Makhool fold on the same bank of the river, while it is noted that there is a (Syncline) parallel to the eastern bank of the river [6].

The zone of the dam foundations consists of a sequence of several geological formations that include stratifications of sedimentary rocks, and these rocks are different in physical and chemical properties, as well as the method of their deposition, their subsurface vertical and horizontal extension, and spatial distribution of their outcrops. Among the geological formations exposed in the site and zone of the dam foundations are the Fatha, Injana formation and Quaternary sediments (modern and alluvial sediments) (Figures 2 and 3).

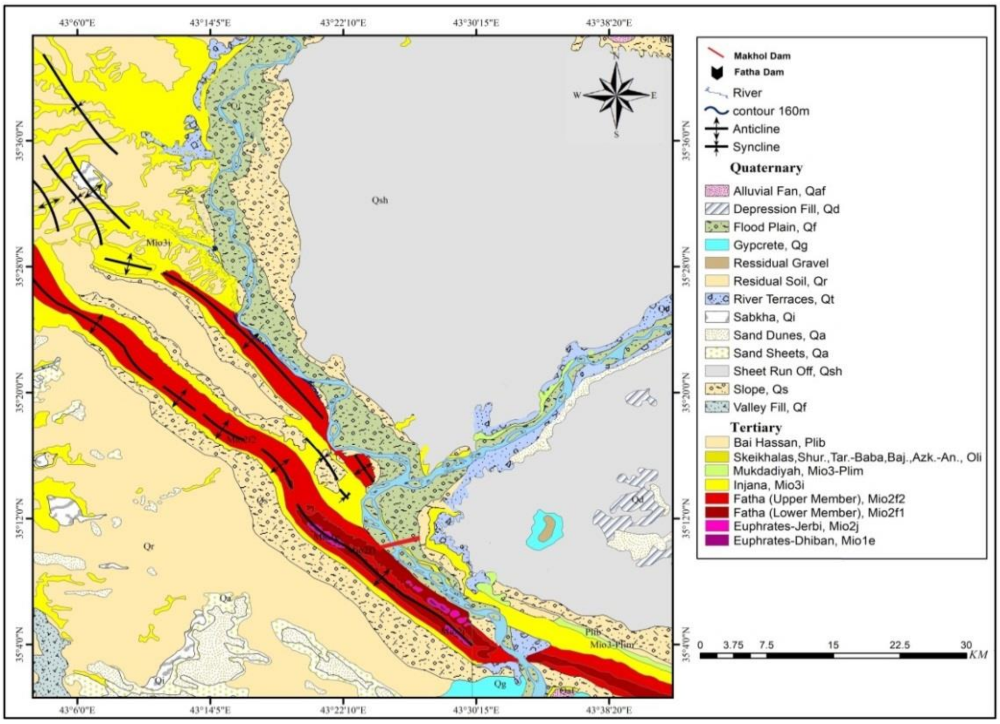

Figure 2: Geological map of the study area [7].

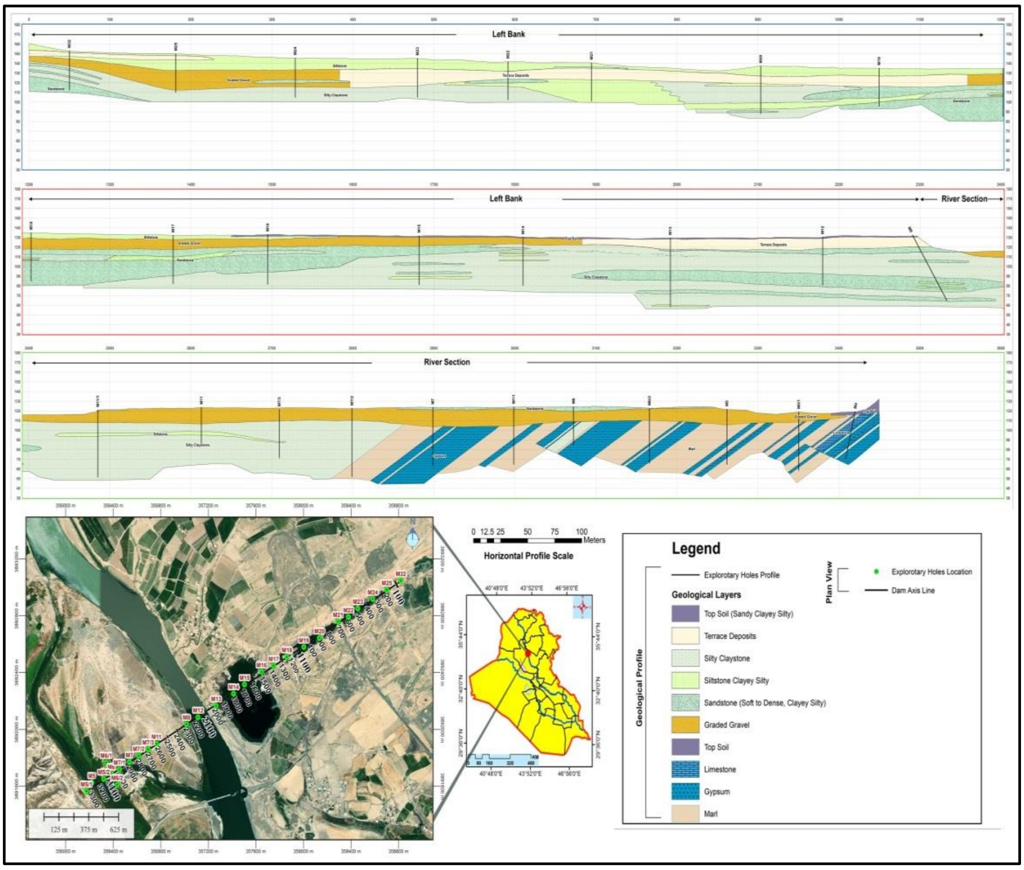

Figure 3: Longitudinal geological section of Makhool Dam foundations [8]

4. **Hydraulic conductivity of the dam foundations**

5. The permeability of the different rock components of the foundation zone of the Makhool dam proposed by the Ministry of Irrigation - General Authority for Irrigation and Reclamation

Projects [6], in 1997 and 2001 was determined by conducting field and laboratory permeability tests in the test wells shown in Figure 3. The permeability coefficients for different sediments were obtained as in Table 1. The seepage simulation process depends mainly on the coefficient of hydraulic conductivity (K) of the soil and rocks in the zone of the dam foundations.

Table 1: hydraulic conductivity of the deposits of the foundations zone of the Makhool dam[6].

Deposits type	Hydraulic conductivity (K)cm/sec
Clay soil	$6.9*10^{-5} – 3.33*10^{-4}$
Slope deposits	$9.24*10^{-5} –1.04*10^{-4}$
River deposits	$1.04*10^{-3}$ – open flow
River terraces	$8.13*10^{-5} – 2.1*10^{-4}$
Gravel	$8.5*10^{-4}$ –open flow
Fissured clay rocks and marl	$3.12*10^{-5} – 6.4*10^{-5}$
Sand rocks	$234*10^{-5} – 2665*10^{-4}$
Marle	$0– 4004*10^{-5}$
Mud rocks	$0– 416*10^{-6}$
Gypsum and cracked dolomites	$65*10^{-5} – 2015*10^{-4}$
Gypsum block	$156*10^{-5} – 104*10^{-4}$
Cracked limestone rocks	$104*10^{-4}$ – open flow

6. Program (SEEP/w, 2012)

It is a sub-program of the Geo-Studio computer program, an analytical model that can mathematically represent the physical processes of water movement and the distribution of pore water pressure within the porous media (soil and rocks). An effective tool for complex numerical analyzes as it led to the understanding of physical processes, as well as enabled the understanding of saturated and unsaturated flow modelling as shown in Figure 4. this program has wide applications in analysis and design of civil, geotechnical and hydrogeological engineering projects [1].

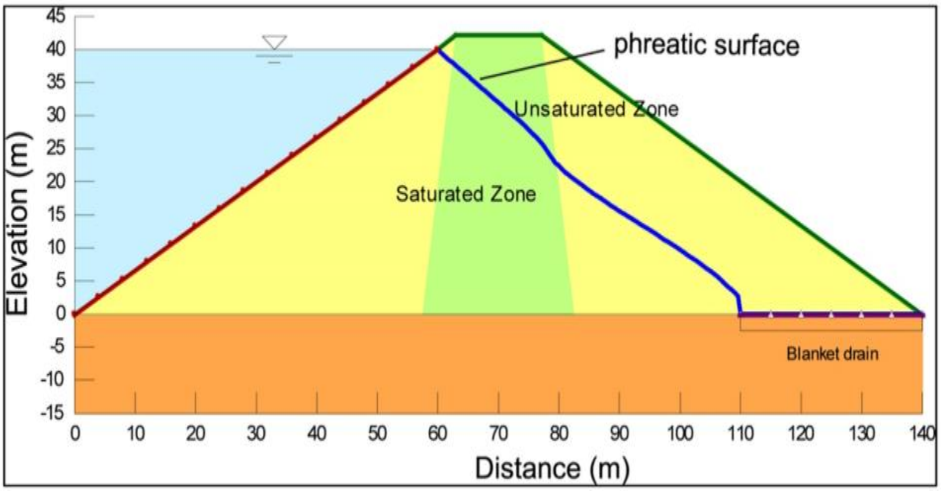

Figure 4: Illustrative model of seepage through embankment dam.

The basic idea of water flow through the saturated and unsaturated beds in (SEEP/w 2012) follows Darcy's law:

$$q = Kiy \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. (1)$$

q = discharge quantity per unit width (m^3/sec per unit length).

K= Coefficient of Permeability, its unit is the same as velocity (m/sec).

i = dh/ds Hydraulic Gradient (without units).
y = Flow depth (m).
And the differential equation for the flow during the program (SEEP/w 2012) is:

$$\frac{\partial}{\partial x}\left(kx\frac{\partial H}{\partial x}\right)+\frac{\partial}{\partial y}\left(ky\frac{\partial H}{\partial y}\right)+Q=\frac{\partial w}{\partial t} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..(2)$$

H = Total Head.
kx =The permeability toward x axis.
ky =The permeability toward y axis.
Q = Discharge quantity.
w= Water content.
t = Time.

This equation represents the difference of the internal and external drainage during a certain period equal to the volume change as a result of changing the water content, a condition that represents the sum of the amount of change in the flow towards the X and Y axis, in addition to the external drainage and equal to the amount of change in the water content during the time (t). In the case of constant flow, the amount of basic discharge in and out is the same over time. Therefore the right-hand side of the equation is equal to zero [1]. So the equation becomes as follows:

$$\frac{\partial}{\partial x}\left(kx\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left(ky\frac{\partial u}{\partial y}\right)+Q=0 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..(3)$$

The most important inputs that need to be provided to the program SEEP/w 2012 for seepage analysis are hydraulic conductivity (K) and water content (wc), as shown in Figure 5

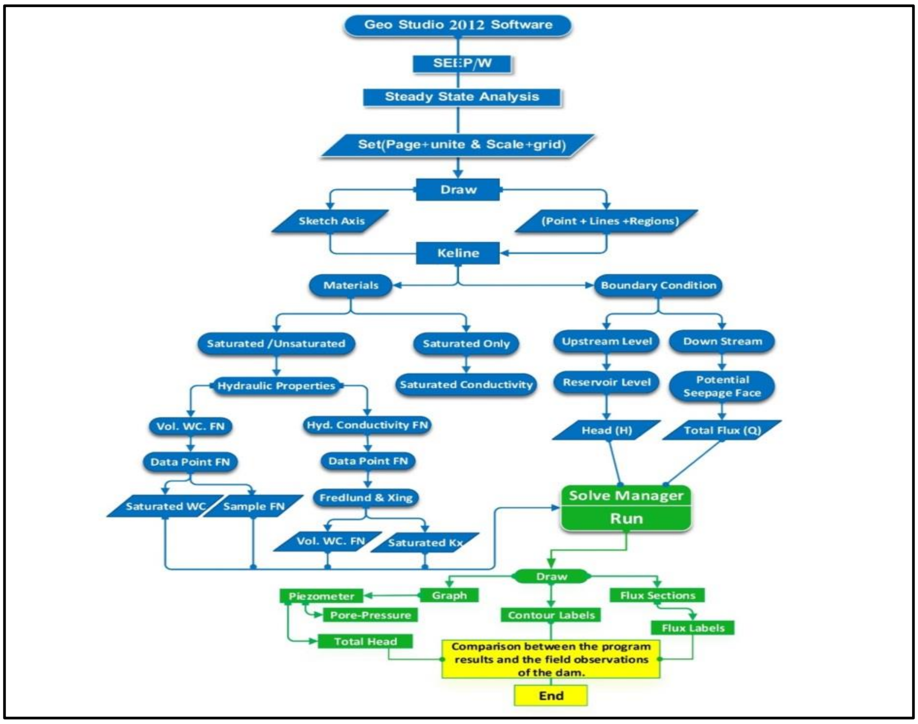

Figure 5: The working mechanism of the (SEEP/w 2012) program for seepage analysis.

7. Seepage through the dam body and foundation

The seepage is controlled at the Makhool dam with a clay core. This core is composed of clay material with low hydraulic conductivity ($10^{-7} – 10^{-10}$) m/sec [9]. Cross sections of the Makhool dam were obtained, where these sections are represented by several stations along the axis of the dam body on the right and left sides (Figure 3). The number of these stations is 36 stations, 100 m long for each. According to the dam design, piezometers were distributed over the dam body and on beds at different levels (Figures 6, 7, and 8) [10]. The level readings in these piezometers indicate the efficiency of the grout curtain, the asphalt barrier and the function of the drainage system.

Using the program (SEEP/W2012), these cross-sections of the dam, which the contracting company designed, were drawn as input of the software.

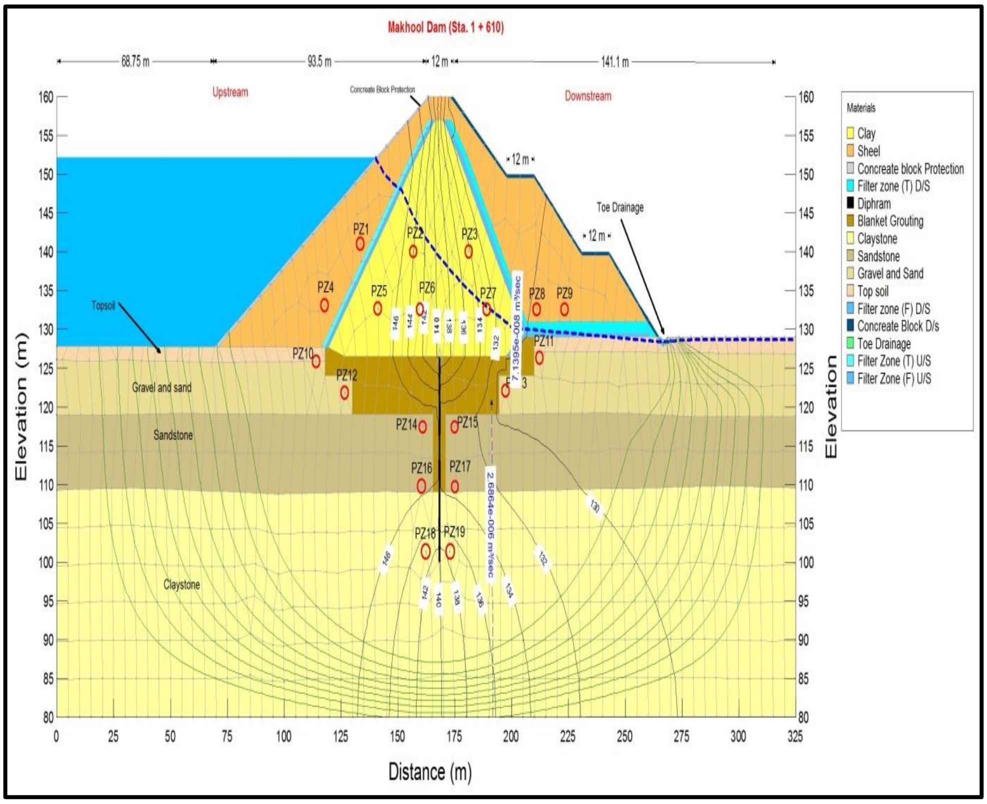

Figure 6: Cross-section of the studied station (ch 1+610) on the left side of Makhool dam [10].

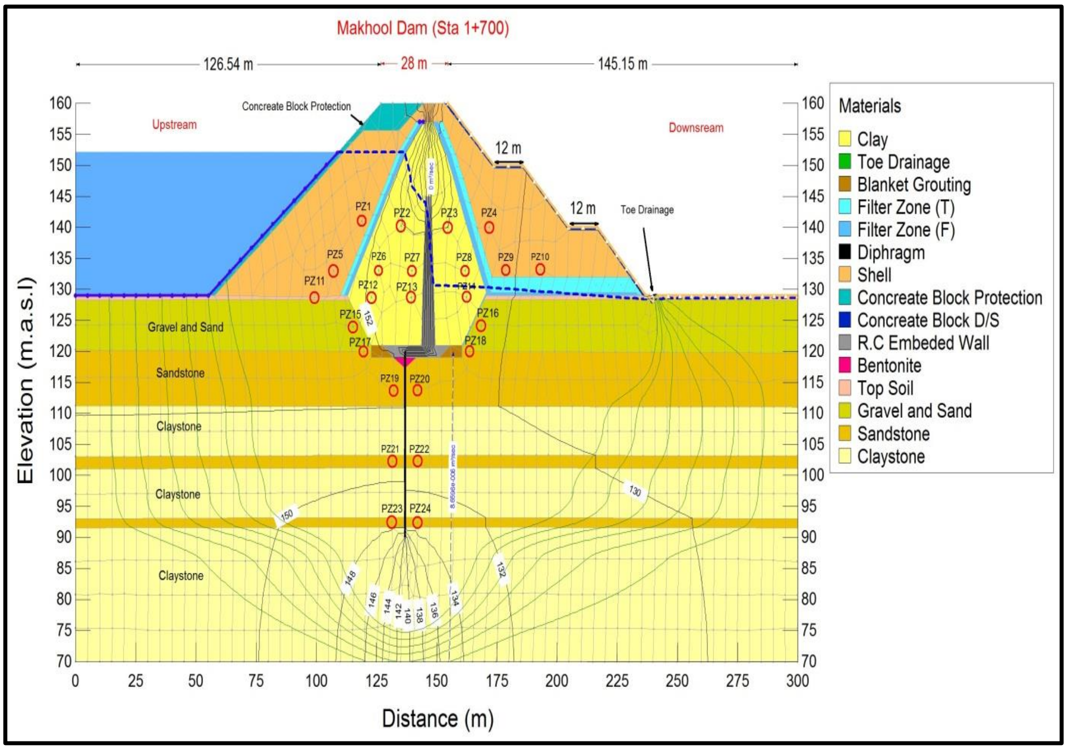

Figure 7: Cross-section of the studied station (ch 1+700) on the left side of Makhool dam [10].

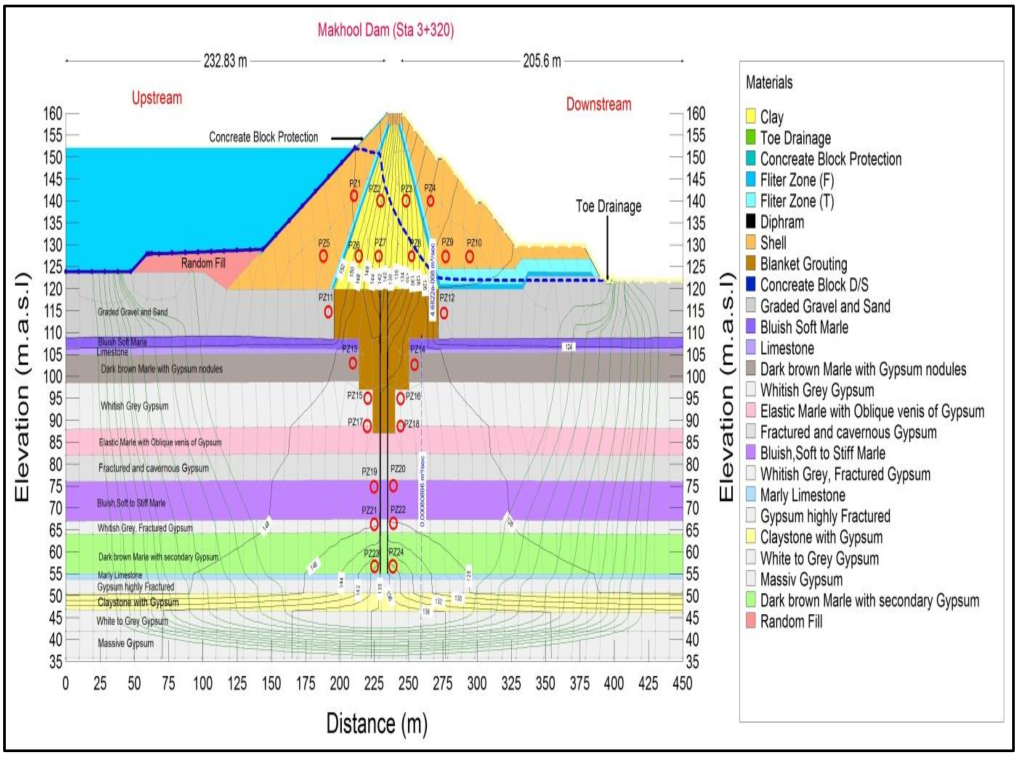

Figure 8: Cross-section of the studied station (ch 3+320) on the right side of Makhool dam [10].

8. Discussion

The seepage of the proposed Makhool dam was simulated and evaluated according to the geological and design data through the cross-sections of stations (ch 1+610) and (ch 1+700) on the left side of the dam and station (ch 3+320) on the right side, by using the computer program (SEEP/W2012). Table 2 and Figure 9 show the relationship between the amount of seepage with the maximum reservoir water level (152.15 m) and the dam operational levels (145, 150 m). It is clear that the amount of seepage discharge increases with the increase of the reservoir water level, but in different ratios, especially on the right side of the dam. The seepage quantity is (69894.14 liter/day) at the station (ch 3 + 320) and (230.17, 748.9 liter/day) at the stations (ch 1 +610, ch 1+700) respectively at the maximum reservoir water level (152.15 m). These results indicate that the amount of seepage on the left side of the dam is low due to the presence of clay beds with low hydraulic conductivity. In addition, the depth of the diaphragm and the grout curtain is very suitable in the foundation zone according to the design drawings of the dam, as they cut all sandy beds with high hydraulic conductivity in the foundation zone. The amount of seepage on the right side of the dam is high compared to the left side. This is due to the high hydraulic conductivity of the rocky beds within the foundation zone, especially the gypsum beds located under the diaphragm with a permeability ranging ($65*10^{-5}$ – $2015*10^{-4}$ cm/sec), which is characterized by the presence of many fractures, veins, and cavitation that act as drainage channels within the foundations [11]. Therefore, it is required to lower the diaphragm in the foundations' zone to a level of 49 m.a.s.l until reaching the low permeability clay bed, as shown in Figure 8. This action may reduce the amount of seepage and flow velocity and avoid more grouting works in the right side at a future time of the dam life. In addition, this action requires continuous monitoring of the seepage at the right side because the gypsum rocks suffer from continuous dissolution processes, which may be formed new drainage channels as the dam continues to operate.

The design limits of the piezometric head (Total Head) were determined at different locations of the dam sections (Table 3). These limits are supposed to be read by the monitoring devices when operating the dam at the maximum level of the reservoir (152.15m) and the standard operating levels (150, 145m). These readings are used to evaluate the efficiency of the grout curtain and diaphragm under the dam depending on their specific properties in the Makhool dam project because this diaphragm and grout curtain cause the head difference between the upstream and downstream piezometers. Therefore, any damage in the diaphragm or the grout curtain after the dam operation means an increase in the water seepage passing through it, which leads to minimizing the difference between the head of opposite piezometers, which are located before and after these barriers.

The results of piezometric readings give the following indications:
A sharp drop in the water level between all opposite piezometers, up to piezometer 22, located before and after the diaphragm and grout curtain indicates these barriers' efficiency at the three selected stations (Table 3).

The little difference in the level between the piezometers (23 and 24) in the station (ch 3 + 320) at the dam right side indicates the presence of areas of weakness in the foundation zone with high drainage. This confirms the reason for the great seepage quantity in this station which, as mentioned above, requires lowering the diaphragm in the foundations zone to a level of 49 m.a.s.l until reaching the low permeability clay bed.

Table 2: Calculated seepage results from the body and foundation of the Makhool dam using the program (SEEP/W2012).

Reservoir level (m)	Amount of water seepage from body of the dam (liter/day)		
	Left Side Dam Stations		Right Side of Dam Station
	ch 1+610	ch 1+700	ch 3+320
152.15	6.17	0	4
150	5.61	0	3.76
145	4.31	0	2.1
Reservoir level (m)	Amount of water seepage from the foundations zone of the dam (liter/day)		
152.15	230.17	748.9	69894.14
150	211	680.53	64926
145	162.23	523.18	53373.6

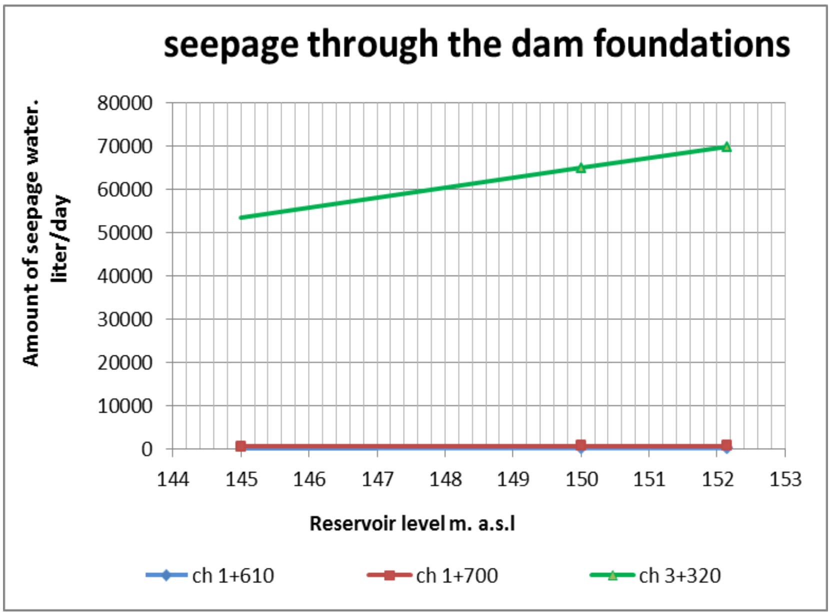

Figure 9: Amount of seepage through Makhool dam at three different stations.

Table 3: The design limits of the total head are supposed to be read by the piezometers when the dam is operating.

Pz no	Station (1+610) on the left side of dam			Station (1+700) on the left side of dam			Station (3+320) on the right side of dam		
	Total Head (m) at reservoir levels (152.15, 150, 145 m.a.s.l)								
	152.15	150	145	152.15	150	145	152.15	150	145
1	151.46	149.37	144.52	152.13	149.98	144.98	151.98	149.84	144.87
2	143.97	142.56	139.3	150.2	148.23	143.64	144.56	142.95	139.2
3	134.24	133.7	132.48	132	131.67	131	132.36	131.62	129.9
4	151.95	149.82	144.86	130.5	130.27	129.8	125.89	125.61	124.95
5	148.24	146.44	142.27	152.12	149.97	145	152.14	149.99	145
6	142.45	141.2	138.22	151.8	149.66	144.7	148.45	146.56	142.2
7	133	132.62	131.64	151.4	149.28	144.4	142.21	140.76	137.4
8	129.92	129.78	129.46	130.6	130.4	130	130.42	129.81	128.4
9	129.6	129.5	129.23	130.13	129.97	129.6	123.1	123	122.8
10	151.99	149.86	144.89	129.7	129.57	129.3	122.4	122.37	122.3
11	129.59	129.48	129.23	152.11	149.96	145	152.14	150	144.98

12	151.93	149.8	144.85	151.94	149.8	144.85	121.94	121.93	121.93
13	129.62	129.5	129.25	151.66	149.55	144.65	147.6	145.76	141.5
14	146.97	145.3	141.38	130.4	130.2	129.8	126.7	126.36	125.57
15	132.7	132.32	131.42	152.3	149.93	144.95	147.14	145.34	141.2
16	146.27	144.65	140.89	130.2	130	129.6	127.1	126.73	125.87
17	133.57	133.1	132	152.1	149.92	144.94	147	145.24	141.1
18	143	141.73	138.64	130.14	129.97	129.5	127.2	126.83	125.96
19	137.2	136.4	134.54	152.04	149.89	144.92	146.53	144.78	140.71
20				130.16	129.99	129.62	127.71	127.3	126.34
21				150.65	148.64	143.95	146.15	144.42	140.42
22				131	130.77	130.22	128.1	127.64	126.62
23				148.3	146.5	142.3	140.24	138.94	135.91
24				133.2	132.73	131.72	134.2	133.23	131.26

9. Conclusions

Based on the results obtained from the program (SEEP/W2012), which included reservoir water levels, and seepage, the following points can be deduced regarding the efficiency of the dam in terms of seepage:

1. The amount of seepage through the left side of the dam is within permissible design limits, while the amount of seepage through the right side is higher than the left side. This was due to the high hydraulic conductivity of the rocky beds within the foundation's zone, especially the gypsum beds located under the diaphragm, which is characterized by the presence of many fractures, veins, and cavitations as drainage channels within the foundations.
2. The water level sharp drop between the distributed piezometers before and after the grout curtain and the diaphragm indicates their efficiency according to their physical and engineering properties in the Makhool dam project.
3. The level difference between the piezometers (23 and 24) in the station (ch 3 +320) at the dm right side boosts confidence once the presence of areas of weakness in the foundation's zone with high drainage.
4. The depth of the grout curtain and the diaphragm is suitable within the foundation's zone on the left side of the dam. The right side of the dam requires lowering the diaphragm an additional 6 m in the foundation's zone to a level of 49 m.a.s.l until reaching the low permeability clay bed located within the foundation's zone to reduce the amount of seepage, and flow velocity and avoiding more grouting works on different periods of the dam's life.

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