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Seepage Analysis of Earth Dam Under Drawdown Condition

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Abstract

Seepage analysis of earth dam is one of the major interesting points in water resource engineering. The amount of water seeping through and under an earth dam together with the distribution of the water pressure can be estimated by using the theory of flow through porous media. This theory is one of the most valuable analytical tools available to the engineer. In this research, the finite element method was used for solving the governing equation of flow within and under earth dam. The program Geo-Studio is used in this analysis via its sub-programs named SEEP/W. It is used to determine the phreatic line, amount of seepage within the dam and its foundation, the distribution of pore water pressure, the distribution of total head, and the exit gradient of homogenous earth dam. Al-Shahabi dam is taken as a case study. It is a homogenous earth dam located in Wasit, Iraq. The dam at actual design was analyzed. When the reservoir is rapidly drawdown, pore water pressures within dam body are reduced in two ways: first way is a slower dissipation of pore water pressure due to drainage and second way is an immediate elastic effect due to the removal of the partial or total water head. During rapid drawdown, the pore water pressure at all points within the dam body decreases. Some points in the dam may be affected by negative pore water pressure during the period of water drawdown, this indicates that the water level becomes below these points. The exit gradient at the downstream of the dam almost reduces during the period of water drawdown, which means that the safety factor versus boiling rises with time. The rate of flow in the dam reduces with time; such decrease is caused by the rapid flow of water caused by emptying the reservoir in a short period.

Keywords: Earth dam; seepage analysis; rapid drawdown; finite elements method; Geo Studio; SEEP/W.

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1. Introduction

All dams have some seepage as the impounded water seeks paths of least resistance through the dam and its foundation. Seepage becomes a concern if it is carrying material with it, and should be controlled to prevent erosion of the embankment, or foundation, or damage to concrete structures [1;2]. The seepage control of any dam must be analyzed by of different available methods. Seepage is the main aspect and its control enjoys main position in the design, maintenance and construction of any dam. Thus a dam engineer must be well versed in understanding problems of seepage, their solution and preventive measures monitoring. The flow conditions of any porous environment can be investigated by using numerical techniques framed in the form of a software solution [3]. Seepage can also cause erosion within an embankment in places where a high hydraulic gradient is present. In the case erosion occurred within a dam voids can be created. These voids take the form of channels, also pipes, which weaken the dam stability [4]. Embankments may become saturated by seepage flow during a long term high reservoir stage. If subsequently the reservoir pool is drawdown faster than the pore water can escape, increase pore water pressures and decreased stability will result. This is named drawdown. In case of rapid drawdown which represents the most critical condition, it was assumed that the pore water pressure in the embankment continues to reflect the original water level. The lag of the phreatic line depending upon factors such as: drawdown rate, permeability of soils, slope gradient and drawdown ratio [5]. In this research, seepage through body and foundation of Al- Shahabi dam was analyzed. Finite element approach was employed to solve the governing differential equations pertaining the seepage through body of Al- Shahabi dam and its foundation. SEEP/W is a useful tool that uses numerical modeling to solve complex groundwater seepage problems [6]. The SEEP/W software (program) is a sub-program of the Geo Slope (software) computer, which is used for seepage problems through porous soil media.

2. Descriptions of Case Study (Al- Shahabi Dam)

Al-Shahabi Dam is homogenous earth dam located in Wassit Governorate in the south east of Baghdad. The city of Kut, center of Wassit, is located about 170 km south east of Baghdad. Figure (1) shows Al-Shahabi Dam Location in Iraq Map.

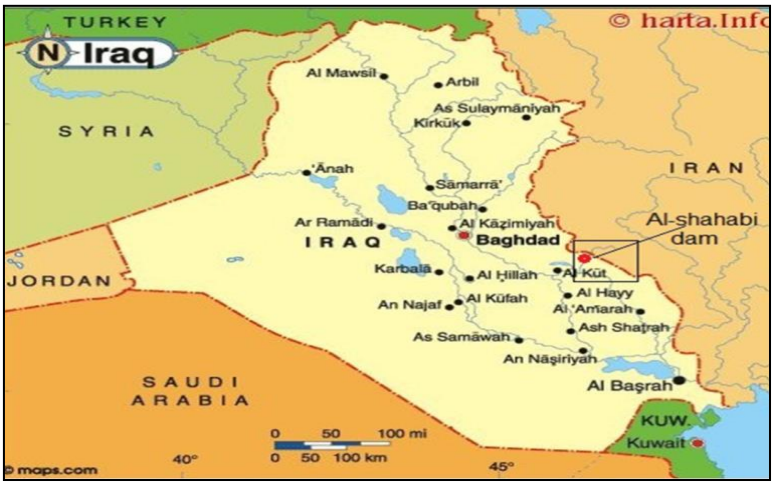


Figure 1: Al-Shahabi Dam Location in Iraq Map [7].

2.1 General Features for Al – Shahabi Dam

- Type of dam; homogenous dam (sandy silt soil)
- Length of dam: 271 m
- Length of reservoir : 3 km
- Crest level : 50 m.a.s.l
- Maximum storage level: 48 m.a.s.l
- Maximum discharge: 769 m^3/sec.

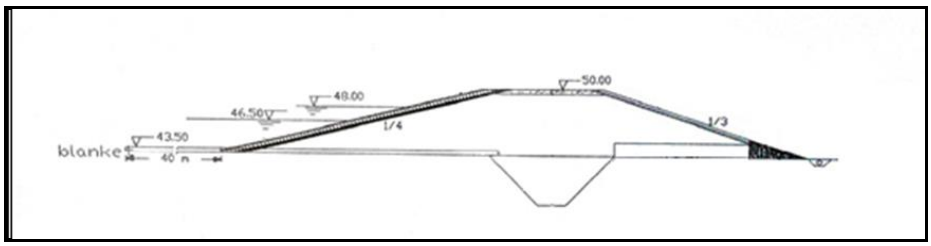


Figure 2: Cross Section of Al-Shahabi Dam [8].

2.2 Materials Properties for Al-Shahabi Da

The permeability of materials for Al-Shahabi dam as shown in Table (1).

Table 1: Materials properties for Al-Shahabi dam [7].

Material	Permeability (m/s)
Shell	$1*10^{-6}$
Cutoff	$1*10^{-8}$
Horizontal drain	0.0001
Toe drain	0.1
Blanket	$1*10^{-8}$
Foundation	$9.5*10^{-6}$

3.Transient Analysis of Seepage during Rapid Drawdown for Al-Shahabi Dam

The transient seepage through and under the earth dam was analyzed using the program SEEP/W. The finite element mesh used for the analysis was shown in Figure (3). The mesh includes elements for all body of dam. The number of elements for all boundaries are 1387 and the number of nodes are 1490.

The dam section is analyzed for different conditions of rapid drawdown. The reservoir is assumed to be emptied within 116 hour and 78 hour. The reservoirs period of evacuation have been chosen base on two cases, these are:

- For the period of reservoirs emptying within 116 hr is the period when the out let pipe is (1/2) open

(50%).

- For the period of reservoirs emptying within 78 hr is the period when the out let pipe is (3/4) open (75%).

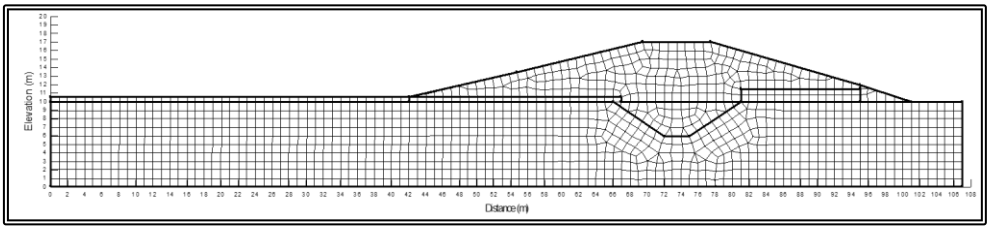


Figure 3: Typical finite element mesh for Al-Shahabi dam.

3.1 Result and Discussion of Seepage Analysis when the Reservoir Emptying within 116 hour

The transient seepage through and under the dam was analyzed for a period of reservoir which is emptying in 116 hr. Figure (4) and (5) show the distribution of the pore water pressure and total head after 116 hr form start rapid drawdown.

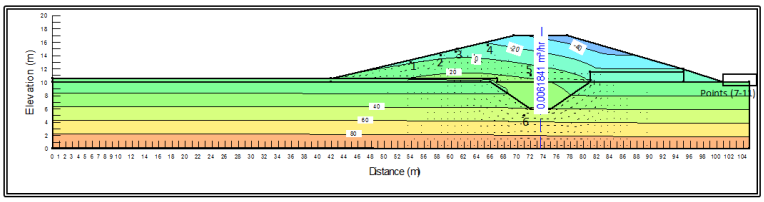


Figure 4: Pore water pressure (Kpa) and water flux value after 116 hr from start rapid drawdown **.**

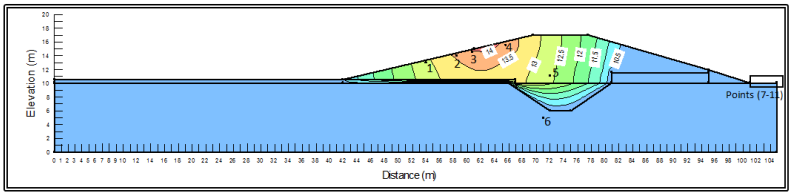
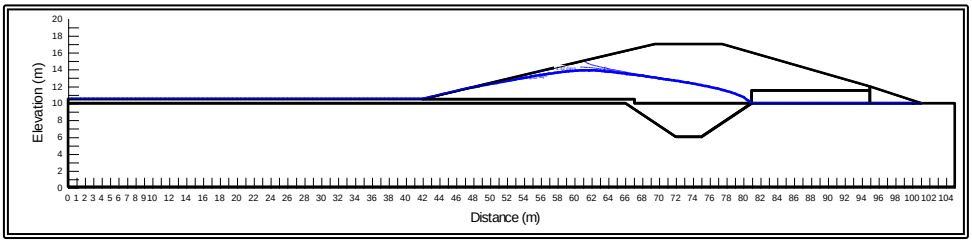
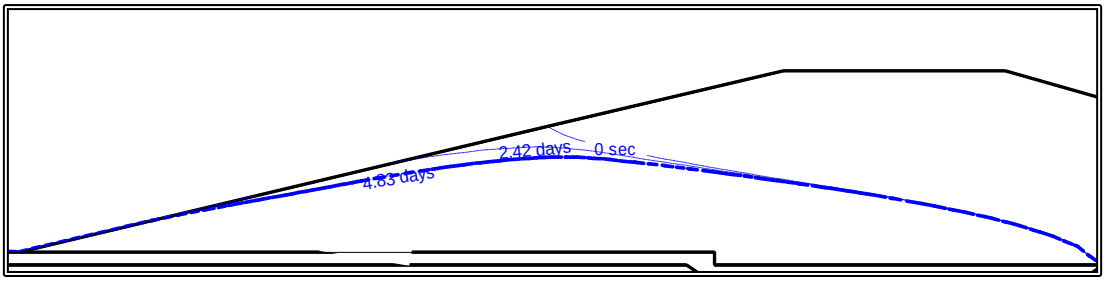


Figure 5: Total head (m) after 116 hr from start rapid drawdown**.**

The Phreatic line of flow at different times of transient flow is shown in Figure (6a and b). Figure (6a) shows whole section of the dam, and Figure (6b) shows upstream section of the dam.



a. Whole section of the dam.



b. Upstream section of the dam.

Figure 6: Phreatic line of flow at different times of transient flow

Table (2) presents the change of pore water pressure values as a result of drawdown, where many points have been selected as random points to study the effect of rapid drawdown on the pore water pressure values at different locations.

Table 2: Pore water pressure in (kpa) with time for a period of reservoir emptying of 116 hr for Al-Shahabi dam.

Time (hr)	Point 1	Point 2	Point 3	point 4	Point 5	Point 6
0	19.352	9.225	3.651	-16.254	16.259	56.007
10	1.835	0.844	-0.415	-16.254	16.162	51.244
20	1.060	-0.197	-1.519	-16.255	16.106	51.211
30	0.687	-0.854	-2.267	-16.258	16.056	51.191
40	0.392	-1.435	-2.881	-16.261	16.008	51.176
50	0.126	-1.952	-3.408	-16.265	15.960	51.162
60	-0.123	-2.412	-3.870	-16.271	15.912	51.149
70	-0.360	-2.826	-4.287	-16.277	15.863	51.137
80	-0.582	-3.173	-4.667	-16.285	15.814	51.126
90	-0.789	-3.490	-5.020	-16.294	15.764	51.116
100	-0.979	-3.760	-5.338	-16.303	15.713	51.106
110	-1.163	-4.012	-5.628	-16.313	15.661	51.097
116	-1.269	-4.159	-5.792	-16.320	15.630	51.091

When the reservoir is rapidly drawdown, pore water pressures in the dam body are reduced in two ways, first way is a slower dissipation of pore pressure due to drainage and second way is an immediate elastic effect due to the removal of the total or partial water load. Table 2 shows the variation of pore water pressure with time after the start of drawdown in the reservoir at points 1 to 6. It can be seen that the pore water pressure at all points decreases with time. Some points in the dam may be affected by negative pore water pressure during the period of water drawdown, which indicates that the water level becomes below these points. In order to follow the critical points in the dam, the XY-gradients have been determined at points 7, 8, 9, 10 and 11 at different times after the start of water drawdown as shown in Table (3).

Table 3: Values of XY- exit gradient for Al-Shahabi dam at selected points for a period of reservoir emptying of 116 hr.

Time(hr)	Point 7	Point 8	Point 9	Point 10	Point 11
0	0.001322	0.001777	0.001614	0.001492	0.001407
10	0.001041	0.001047	0.000384	0.000177	0.000100
20	0.001026	0.001032	0.000378	0.000174	0.000098
30	0.001019	0.001024	0.000376	0.000173	0.000098
40	0.001011	0.001018	0.000373	0.000172	0.000097
50	0.001004	0.001009	0.00037	0.00017	0.000096
60	0.000998	0.001003	0.000367	0.000169	0.000096
70	0.000992	0.000998	0.000365	0.000168	0.000095
80	0.000987	0.000993	0.000364	0.000167	0.000095
90	0.000982	0.000988	0.000362	0.000166	0.000094
100	0.000977	0.000983	0.00036	0.000166	0.000094
110	0.000973	0.000979	0.000358	0.000165	0.000093
116	0.00097	0.000976	0.000357	0.000164	0.000093

The drawdown results of reducing the quantity of seepage and the values of reduction are shown in Table (4).

Table 4: Change in values of water flux for a period of reservoir emptying of 116 hr for Al-Shahabi dam.

Time (hr)	Seepage (m^3/hr)	Time (hr)	Seepage (m^3/hr)
0	0.01738	70	0.00634
10	0.00663	80	0.00630
20	0.00655	90	0.00627
30	0.00650	100	0.00624
40	0.00645	110	0.00620
50	0.00641	116	0.00618
60	0.00637		

Table (4) shows the rate of flow reduces with time; this is caused by rapid flow of water caused by emptying the reservoir in a short period. It can be noticed a significant reduction in quantity of seepage values during first 10 hr after drawdown, after then the seepage quantity reduces slightly.

3.2 Result and Discussion of Seepage Analysis when the Reservoir Emptying within 78 hour

The transient seepage through and under Al-Shahabi dam was analyzed for a period of reservoir emptying of 78 hr. Figure (7) and (8) show the distribution of the pore water pressure and total head after 78 hr form start rapid drawdown.

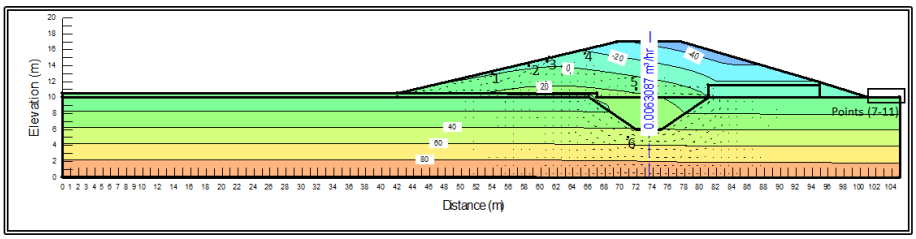


Figure 7: Pore water pressure in (Kpa) and water flux value after 78 hr from start rapid drawdown.

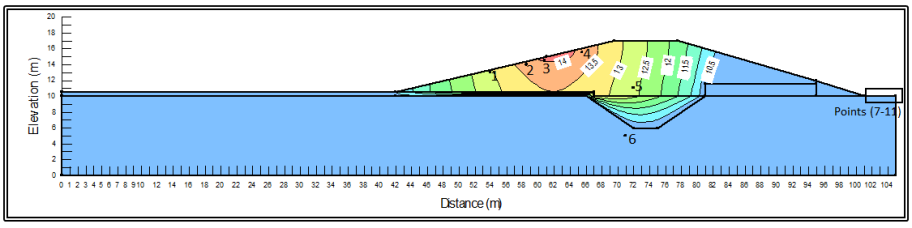


Figure 8: Total head (m) after 78 hr from start rapid drawdown.

Table (5) presents the change of pore water pressure values as a result of drawdown, where many points have been selected as random points to study the effect of rapid drawdown on the pore water pressure values at different locations.

Table 5: Pore water pressure in (kpa) with time for a period of reservoir emptying of 78 hr for Al-Shahabi dam.

Time (hr)	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6
0	19.352	9.225	3.651	-16.254	16.259	56.007
8	2.162	1.160	-0.096	-16.254	16.175	51.257
16	1.276	0.145	-1.125	-16.255	16.127	51.221
24	0.896	-0.472	-1.844	-16.256	16.086	51.202
32	0.624	-0.975	-2.399	-16.258	16.047	51.188
40	0.303	-1.501	-2.906	-16.262	15.990	51.170
48	0.178	-1.855	-3.309	-16.264	15.970	51.165
56	-0.025	-2.233	-3.692	-16.269	15.931	51.154
64	-0.219	-2.586	-4.042	-16.273	15.893	51.144
72	-0.405	-2.898	-4.365	-16.279	15.853	51.135
78	-0.538	-3.106	-4.594	-16.283	15.824	51.129

When the reservoir is rapidly drawdown, pore water pressures within dam body are reduced in two ways, first way is a slower dissipation of pore pressure due to drainage and second way is an immediate elastic effect due to the removal of the total or partial water load. Table (5) shows the variation of pore water pressure with time after the start of drawdown in the reservoir at points 1 to 6. It can be seen that the pore water pressure at all points decreases with time. Some points in the dam may be affected by negative pore water pressure during the period of water drawdown which, indicates that the water level becomes below these points. In order to follow the critical points in the dam, the XY-gradients have been determined at points 7, 8, 9, 10 and 11 at different

times after the start of water drawdown as shown in Table (6).

Table 6: Values of XY- exit gradient for Al-Shahabi dam at selected points for a period of reservoir emptying of 78 hr.

Time (hr)	Point 7	Point 8	Point 9	Point 10	Point 11
0	0.001322	0.001777	0.001614	0.001492	0.001407
8	0.001048	0.001054	0.000386	0.000178	0.000100
16	0.001031	0.001037	0.000380	0.000175	0.000099
24	0.001024	0.001029	0.000378	0.000174	0.000098
32	0.001016	0.001021	0.000374	0.000172	0.000097
40	0.001010	0.001016	0.000372	0.000171	0.000097
48	0.001006	0.001011	0.000371	0.000171	0.000096
56	0.001000	0.001006	0.000368	0.000169	0.000096
64	0.000995	0.001001	0.000367	0.000169	0.000095
72	0.000991	0.000997	0.000365	0.000168	0.000095
78	0.000988	0.000994	0.000364	0.000167	0.000095

The drawdown results of reducing the quantity of seepage and the values of reduction are shown in Table (7).

Table 7: Change in values of water flux for a period of reservoir emptying of 78 hr for Al-Shahabi dam.

Time (hr)	Seepage (m^3/hr)	Time (hr)	Seepage (m^3/hr)
0	0.01738	48	0.00642
8	0.00667	56	0.00639
16	0.00658	64	0.00636
24	0.00653	72	0.00633
32	0.00649	78	0.00631
40	0.00644		

Table (7) shows the rate of flow reduces with time; this is caused by rapid flow of water caused by emptying the reservoir in a short period. It can be noticed a significant reduction in quantity of seepage values during first 8 hr after drawdown, after then the seepage quantity reduces slightly.

4. Conclusions

From the seepage analysis that was carried out on Al – Shahabi earth dam, the following conclusions can be drawn based on the results obtained from numerical analysis, the results obtained from the model analyzed with the SEEP/W show that there are some effects, this depends on characteristics of dam, water level in reservoir, and time required for emptying the reservoir. Now the important conclusions can be given as follows:-

1. When the reservoir is rapidly drawdown, pore water pressures in the dam body are reduced in two

ways: in the first one there is a slower dissipation of pore water pressure due to drainage while in the second one there is an immediate elastic effect due to the removal of the partial or total water head.

2. During rapid drawdown, the pore water pressure at all points within the dam body decreases. Some points in the dam may be affected by negative pore water pressure during the period of water drawdown, which indicates that the water level becomes below these points.
3. The exit gradient at the downstream of the dam almost decreases during the period of water drawdown, this means that the factor of safety against boiling increases with time. When the period of reservoir emptying is long (116 hr), the values of exit gradient are reduced to low values within this period while for short periods (78 hr), the exit gradient values are greater.
4. The rate of flow in the dam decreases with time; this decrease is caused by the rapid flow of water caused by emptying the reservoir in a short period. Generally, the water flux reduces with time and with the water level in the reservoir which indicates that the rate of flow in the all body of the dam shows almost uniform change.
5. When the period of reservoir emptying is long (116 hr), the rate of flow is greater than that in case of short periods (78 hr). When the countervailing upstream water pressure has disappeared, it causes a danger to the upstream slope. Soils inside the dam body remain saturated and seepage commences from it towards the upstream slope. Seepage and hydrodynamic pressures create downward forces acting on the upstream slope. Those are adverse to the stability and create a critical condition to the upstream slope.

5. Recommendations

We recommend as possible to re-analysis the seepage of the dam if there is change in water level.

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