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Investigating the effect of initial values of lozenge and hydraulic gradient on the process of dissolution of gypsum located behind dams (Case study of Marash Dam)

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Abstract

In order to optimally design earthen dams, it is inevitable to know the characteristics of its construction, including geological and geotechnical characteristics, as well as awareness of behaviors such as permeability and bedrock permeability changes during water intake and long-term exploitation of the dam reservoir. When the stone bed of the dam construction consists of materials containing gypsum and anhydrite, then these materials will last longer against the continuation of anti-flow. In the study of Hazdar, the influence of the primary permeability values of the Sedang-Basdter of Merash Dam construction, which consists of joints containing gypsum and anhydrite, and hydraulic gradient values on the speed and process of the expansion of the joint, along with the dissolution rate of materials containing gypsum and anhydrite, has been investigated. The amount of expansion of each joint for the duration of a dam is calculated and considering the amount of hydraulic gradient drop in the body of the dam and manat with gypsum, the water loss rate of the dam is evaluated. The results obtained from the circulation test with the hydraulic gradient find that in the length of the water flow path, the rate of increase in the diameter of the joint decreases gradually. Also, along the length of the water flow, in the places where there is purer gypsum, the rate of increase in the diameter of the seams is higher than the rest.

Keywords: dissolution, expansion of each joint, permeability, hydraulic gradient
2020 MSC: 97M50

1 Introduction

In the last few decades, many researches about the solubility of stone materials have been carried out. Among the comprehensive research conducted, we can mention the study conducted by Calcano and Alzora; who in 1967 investigated the phenomenon of dissolution of sulfated rocks (gypsum and anhydrite). In this study, the way of water seepage at the contact point of calcium sulfate with other materials and the way of formation and expansion of debris were studied [9]. In another study, Zanbak and Arthur [11] considered the dissolution of fine gypsum crystals as a linear function of the normal concentration (C) and the saturated concentration (Cs) of the solution containing gypsum and expressed it in the form of equation (1.1):

$$\frac{dM}{dt} \propto (c_s - c) \tag{1.1}$$

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where dM and dt show the mass and time changes, respectively. In another study, Fabuss and his colleagues [4] presented the following relationship for the dissolution of anhydrite:

$$\frac{dM}{dt} \propto (c_s - c)^2 \tag{1.2}$$

James and Lupton [10] provided a comprehensive review under the title of dissolution of gypsum and anhydrite in the wake of hydraulic structures [1]; which, while summarizing the previous studies based on theoretical and experimental methods for calculating the solubility of gypsum and anhydrite, presented relations (1.3) and (1.4), respectively:

$$\frac{dM}{dt} \propto KA(c_s - c) \tag{1.3}$$

$$\frac{dM}{dt} \propto KA(c_s - c)^2 \tag{1.4}$$

where K is the rate of dissolution, A is the surface in the seal in contact with water. It should be said that the value of K depends on the surface area of the passing water flow and the speed of the water flow; In such a way that the amount of K increases with the increase of the surface area of the water flow. Therefore, in strip gypsum particles (with a large contact surface) and with a high flow rate, it can be expected that the value of the dissolution rate will increase. The solubility of carbonate rocks was investigated by White in 1978. Thus, relation (1.5) was proposed to calculate the solubility coefficient (finding the dissolution rate):

$$\frac{V}{A} \cdot \frac{dc}{dt} \propto K(c_s - c)^n \tag{1.5}$$

where in: V volume of water flow $\frac{dt}{dc}$ show the changes of calcium concentration with respect to time and n, the degree of reaction.

Based on recent experiences, it has been determined that in addition to the possible danger of dissolution of gypsum and hydrite, the presence of another factor is also necessary to reveal the dissolution and its consequences; And the passage of the water flow through the gaps with sufficient speed [8]. During this process, the soluble minerals are displaced by water and instead of them, empty spaces remain in the rock mass, which will cause problems in the dam's stability after dams [5]. It is very necessary to prevent the dissolution of gypsum and anhydrite layers located on the foundation of water structures during the continuous flow of water, in order to ensure the stability of the foundations and supports of dams and water structures located on such materials. Continuity of water flow with high speed and significant gradient can increase the dissolution rate of gypsum and anhydrite materials [3, 2]. The high level of dissolution with the development of cracks and fissures leads to an increase in the permeability of the bedrock, and the increase in permeability can reduce the efficiency of the dam barrier. And after that, the development of empty spaces caused by rock dissolution can cause uneven settlement of the structure.

2 Research method

The study of cracked rocks and the expansion of cracks during the passage of water through them is a significant research topic; However, care should be taken to take into account the rate of expansion of the cracks, their periodicity and also the hydraulic gradient. These things are important and decisive especially in natural conditions. Because the individual cracks created in laboratory conditions and hydraulic gradient are different from what exists in soluble salts in nature. In order to reduce water seepage from relatively small joints, it should be noted that generally, small joints have a lower risk of expansion than larger joints. Every crisis of shakas is different depending on the type of insoluble minerals and the way of expansion of seepage in them is also different.

Usually, the location of the boreholes is chosen according to the geological conditions, type and dimensions of the structure. Therefore, determining the location of exploratory boreholes in the construction of a dam, the route of a tunnel and the construction site of a hydroelectric power plant is done with different conditions. was one, were considered (Figure 1). In this research, the circulation test was performed with different speeds on gypsum and anhydrite materials, and the results will be mentioned in the following.

2.1 How to perform the circulation test

For this purpose, cylindrical samples with a length of about 10 cm were selected from the cores obtained from drilling. The two ends of the cylindrical samples were cut so that they were parallel. Mercury was used to accurately

Figure 1: Samples extracted from boreholes

measure the average diameter of the hole. In this way, the created hole was filled with mercury and the weight of mercury was measured, and with the weight of mercury and the length of the sample, the average diameter of the hole was calculated (Figure 2). The test is presented in table 1.

Figure 2: How to prepare and calculate the volume of the hole (cylindrical sample, measuring the volume of mercury, injecting mercury into the sample)

Table 1: Basic characteristics of gypsum cylindrical sample

V (cm^2)	D (cm)	L (cm)
6.87	0.33	30

After determining the average diameter of the hole, finally, instead of coating the cylindrical sample with wax, a plastic membrane was stretched over the sample. Aquarium glue was used to connect the plastic pipes to the beginning and end of the sample.

In the circulation test, 0.5 liters of Merash Dam water was used for the cylindrical sample. After measuring 0.5 liters of Merash Dam water by means of a graduated cylinder, it was poured into a container inside which the water pump was located, and when the pump was turned on, the water flow started moving inside the sample. The flow rate of this flow was measured by a pinhole test tube. The flow of water passing through the sample returned to the container inside which the pump was located, then the initial concentration of calcium ion and the concentration of calcium ion in the saturated state were measured at different and specific times. The pump discharge was about 52 cubic centimeters per minute. The concentration of calcium ions in the circulating solution is considered as a measure of the amount of calcium sulfate (gypsum) dissolved in water.

Figure 3: Tools and how to perform the circulation test for a cylindrical sample

The circulation current lasted for 23 hours and during all this time, the electrical conductivity of the solution was measured by a conductivity meter. At the beginning of the experiment, the changes in the electric conductivity of the solution are relatively large over time, and these changes become very small over time. The finding of electrical conductivity indicates that the solution has reached saturation. The volume of the liver after performing the circulation test after 23 hours is presented in Table 2.

Table 2: Secondary characteristics of gypsum cylindrical sample

V (cm^2)	D (cm)	L (cm)
9.45	0.33	30

In order to determine the permeability of rock mass, the lozenge test is used. During this test, water is injected under pressure into the drilled borehole at the desired section. The test section is usually chosen to be 5 meters, but in soluble areas, the length of the test section is considered to be less than 5 meters. In this way, and by choosing the appropriate length sections at different depths, the permeability of the rock mass is determined in terms of lozenge (Figure 4). The water pressure test is also used to determine the permeability of soluble and insoluble rock mass. A lozenge is the amount of water that is injected at a pressure of 10 atmospheres along one meter of the borehole per unit of time.

Figure 4: How to perform the lozenge test in field samples

3 Determining the maximum amount of gypsum dissolved in the water of Merash Dam

To determine the maximum amount of gypsum and anhydrite dissolution, powder was prepared from the tested samples for the circulation test. Then, in a certain amount of water, the powder was gradually poured and completely mixed with a stirrer, and the changes in the electrical conductivity of the water were measured by a conductivity meter. By increasing the amount of powder, the electrical conductivity of the solution increases; But in the end, increasing the powder did not increase the electrical conductivity of the solution and the conductivity reached a certain value. However, more powder was added to the solution to be sure. And it was stirred for several hours, but during this time, the electrical conductivity of the solution remained unchanged, and it was a sign of reaching the saturation limit of the solution. The water used was Merash dam water, to which different weight percentages of gypsum were added and the electrical conductivity of the solution (calcium concentration) was measured (Figure 5).

The maximum electrical conductivity and weight percentage of gypsum dissolved in Merash dam water are shown in Figure 6. It is necessary to explain that in the graphs below, the weight unit of gypsum is grams per liter. As can be seen from the figure below, the maximum amount of gypsum dissolved in the water of Marash Dam is $cs = lit/gr$ 5/3 and the maximum electrical conductivity is $cm/\mu sEs = 3100$.

Figure 5: Experiment to determine the maximum amount of gypsum dissolved in Marash Dam water

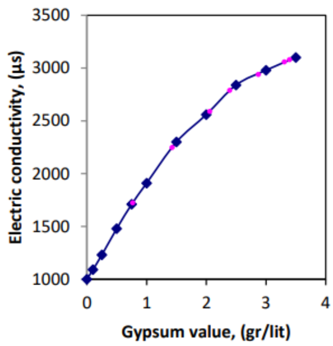


Figure 6: Changes in electrical conductivity versus the weight percentage of gypsum in the water solution of Marash Dam

4 The effect of flow speed on the rate of dissolution

To investigate this issue, several samples of gypsum and anhydrite, which were the same in terms of length, hole diameter, volume of circulating water, temperature and test duration, and only the flow speed in the samples were different, were subjected to circulation test. A volume meter is used to measure the flow rate. In this way, in each test cycle, the filling time of the volume meter was measured and measured, and the volume of water per unit of time or flow rate was obtained in this cycle. With the flow rate and cross-sectional area of the pipe in hand, the value of the flow velocity was calculated in each stage of the experiment. This test was done with four different speed modes and with water from Marash dam, the volume of circulating water was equal to half a liter. In each of the above states, the amount of electrical conductivity and the time to reach the saturation state and find the amount of electrical conductivity were measured and recorded. The results of these tests are shown in Figure 7:

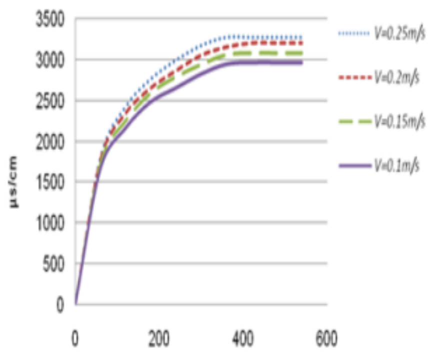


Figure 7: The effect of flow speed on the constant amount of gypsum dissolution

Having in hand the standard diagram (diagrams related to determining the maximum amount of gypsum in the solution) which is the same as the standard diagram of Marash Dam water and the diagrams of changes in electrical conductivity with respect to time from the test to 0.1, 0.15, 0.2, 0.25 m/s speed obtained by circulation, it is possible to obtain changes in the concentration of calcium ions in the solution with respect to time

The changes in the amount of dissolution compared to the different speeds of the circulation test for Marash water are given in the table below.

$V(m/s)$	n	$K((m/s)\times 10^{-5})$
0.1	1.5	**1.02**
0.15	1.57	**1.25**
0.2	1.89	**1.42**
0.25	1.93	**1.76**

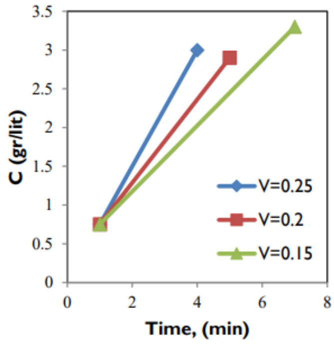


Figure 8: Changes in calcium concentration versus time at different speeds

The above table shows that by increasing the speed of the circulation test, the values of concentration power (n) and dissolution power (K) increase. For the values obtained above, the amount of error obtained for the test results can be seen in the following diagram:

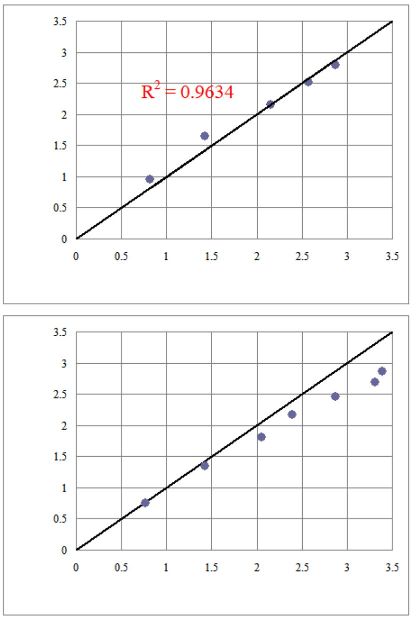
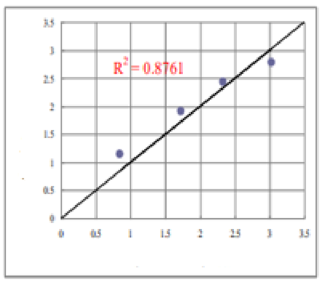


Figure 9: Correlation between calculated and observed values of ion concentration

Calcium with different rates of dissolution changes compared to the flow rate for Marash Dam water is shown in the figure below:



V=0.15 m/s , V=0.2 m/s , V=0.25 m/s

Figure 10: Changes of the dissolution constant in relation to the flow rate for Marash water

5 Calculation of the maximum of each seam

Information related to the characteristics of the boreholes, including borehole number, borehole size, Lujan amount and permeability coefficient, are shown in Table 3.

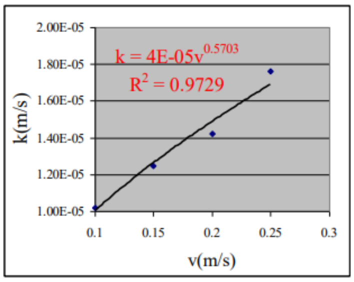


Table 3: Results of lozenge test in Marash Dam with lozenge values higher than one

borehole number	borehole size	(Lu) Lujan	(K) permeability coefficient
50	14.80-16	6.6	0.79
50	17.19-2.80	3.1	0.37
58	**26.26-40.55**	**27.76**	**3.3**
60	12.13-20	5.4	0.65
56	63.64-10.45	2.8	0.34
56	**72.73 – 45.30**	**1.5**	**0.18**

For a specific period of time and by having the calcium concentration in hand at different times and knowing the dissolution rate, it is possible to determine the changes in each seam. In this research, the values of dissolution for different velocities have been obtained with Marash Dam water. By using the experimental data, it is possible to extract the relationship between the dissolution rate and the water flow rate (Figure 10). In order to obtain the dissolution rate in real conditions, the flow rate in real conditions must be known. To determine the flow rate in real conditions, the Lugen test has been used. According to Table 4, knowing the coefficients of permeability (K) and hydraulic gradient (i) in specific areas, the value of the initial flow velocity in the desired section is calculated using Darcy's relation for underground flows (Table 4). Using the relationship of Mohammad Hossein Qabadi in 2016, every element of the seams is calculated:

$$k = \frac{gw^3}{12vb}$$

where in: g: acceleration, b: distance between joints, ν: viscosity of water, which is equal to 0.0101 cm2 per yan, k: permeability coefficient in the lozenge test, w: every element of the joints, we calculate the distance between the joints, which There are one, two, three seams in one meter

Table 4: Values of flow velocity for the initial permeability coefficient for different boreholes

borehole number	**Initial permeability coefficient $\mathbf{k_0(m \cdot s) \times 10^{-6}}$**	**The initial width of the joint $\mathbf{w_0(mm)}$**			**Initial flow rate $\mathbf{V_0(mm)}$**			
		$b = 1m$	$b = 0.5m$	$b = 0.33m$	$i = 0.1$	$i = 0.4$	$i = 0.8$	$i = 1$
50	0.79	0.099	0.079	0.069	0.079	0.316	0.632	0.79
50	0.37	0,077	0.067	0.053	0.037	0.148	0.296	0.37
58	3.3	0.16	0.127	0.11	0.33	1.32	2.64	3.3
60	0,65	0.093	0.074	0.064	0.065	0.26	0.52	0.65
56	0.34	0.075	0.059	0.052	0.034	0.136	0.272	0.34
56	0.18	0.06	0.048	0,042	0.018	0.072	0.144	0.18

Now, according to the existence of the initial flow velocity with different hydraulic gradients, which was calculated from the Darcy equation, and according to the relation in Figure 10, which was obtained from the maximum dissolved gypsum test and the coalescence test, the values of the dissolution rate for the above velocities were calculated as follows it is possible.

Table 5: Dissolution constant values

borehole number	**Initial permeability coefficient $\mathbf{k_0(m \cdot s) \times 10^{-6}}$**	**Dissolution constant $\mathbf{K(m \cdot s) \times 10^{-9}}$**			
		$i = 0.1$	$i = 0.4$	$i = 0.8$	$i = 1$
50	0.79	3.56	7.85	11.65	13.24
50	0.37	2.31	5.09	7.56	8.59
58	3.3	8.05	17.74	26.34	29.92
60	0,65	3.18	7.02	10.43	11.84
56	0.34	2.2	4.85	7.2	8.2
56	0.18	**1.53**	**3.38**	**5**	**5.7**

As can be seen from the above table, the highest amount of jam dissolution is found in borehole 58 with a hydraulic gradient of one and the lowest amount of jam dissolution is found in borehole 56 with a hydraulic gradient of one tenth.

Using equation (5.1), presented by Mohammad Hossein Qabadi [7], the rate of expansion of each joint for a period of one year has been calculated. In order to estimate the maximum expansion of the joint for the above times, the maximum change in concentration is considered and the furnace is set to show that the concentration of dissolved calcium in the flow passing through the desired section at that moment is the minimum value and therefore, the maximum leaching and dissolution The changes of each joint or crack with respect to time are calculated from the following equation:

$$\rho \frac{dw}{dt} = 2k(C_s - C)^n \tag{5.1}$$

where: ρ: Gypsum density, w: each joint, k: dissolution rate for a specific period of time, and by knowing the calcium concentration at different times and knowing the dissolution value, it is possible to determine the changes in each joint. In this research, the values of dissolution for different velocities have been obtained with Marash Dam water. Using the experimental data, it is possible to extract the relationship between the dissolution rate and the water flow rate. The calculated values of joint expansion with different hydraulic gradients for the dissolution period of one year are given in the following table (Table 6).

Table 6: The values of expansion of Herz Darzeh for one year

borehole number	**Initial permeability coefficient**	**w(mm)**				**The initial width of the joint $\mathbf{w_0}$(mm)**
	$\mathbf{k_0(m/s) \times 10^{-6}}$	i=0.1	i=0.4	i=0.8	i=1	b=1m
50	0.79	0.16	0.35	0.53	0.6	0.099
50	0.37	0.1	0.23	0.34	0.39	0.077
58	3.3	0.36	0.8	1.19	1.35	0.16
60	0,65	0.14	0.32	0.47	0.53	0.093
56	0.34	0.1	0.22	0.32	0.37	0.075
56	0.18	**0.07**	**0.15**	**0.23**	**0.26**	**0.06**

As can be seen from the above table, for a period of one year, the maximum expansion of each joint of Marbaa to borehole 58 with a hydraulic gradient of 1 and equal to 1.35 mm and the smallest expansion of each joint of Marbawa to borehole 56 with a hydraulic gradient of 10 and equal to 0.07 mm Is.

6 Calculation of the amount of leakage

After calculating each maximum seam, the amount of leakage is calculated from the following equation

$$q = V \cdot w. \tag{6.1}$$

Using the above relationship, the amount of leakage for different velocities and hydraulic gradients inside the dam is calculated as follows. It should be noted that in this research, the values of hydraulic gradients and flow velocities have been assumed hypothetically, and the range of hypotheses is such that it covers almost all the hydraulic conditions governing a dam, and therefore, if the hydraulic characteristics The desired dam is completely known, from the calculations made in this research, the leakage values can be calculated according to the width.

Gypsum area, estimated. The changes of the amount of leakage against the flow rate for different boreholes and considering different hydraulic gradients are shown in Tables 7, 8, 9 and 10.

Table 7: leakage values after one year with 0.1 hydraulic gradient

w(mm)	$\mathbf{q(m^3 \cdot s \cdot m) \times 10^{-5}}$			
	$V = 0.1m.s$	$V = 0.5m.s$	$V = 1m.s$	$V = 5m.s$
0.16	1.6	8	16	80
0.10	1.04	5.2	10	52
0.36	3.36	18	36	181
0.14	1.44	7.2	14	72
0.10	0.99	4.96	10	49
0.07	**0.69**	**3.45**	**7**	**34**

Table 8: leakage values after one year with 0.4 hydraulic gradient

w(mm)	$\mathbf{q(m^3 \cdot s \cdot m) \times 10^{-5}}$			
	$V = 0.1m.s$	$V = 0.5m.s$	$V = 1m.s$	$V = 5m.s$
0.35	3.54	17	35.4	170
0.23	2.3	11	23	110
0.8	8	40	80	400
0.31	3.2	16	32	160
0.22	2.2	11	22	110
0.15	**1.5**	**7.6**	**15**	**76**

Table 9: Leakage values after one year with 0.8 hydraulic gradientt

w(mm)	$\mathbf{q(m^3 \cdot s \cdot m) \times 10^{-5}}$			
	$V = 0.1m.s$	$V = 0.5m.s$	$V = 1m.s$	$V = 5m.s$
0.53	5.25	3.26	52	33
0.34	3.4	17	34	170
1.19	11.8	59	118	590
0.47	4.7	23	47	235
0.32	3.25	16	32	162
0.23	**2.3**	**11**	**23**	**113**

Table 10: leakage values after one year with hydraulic gradient

w(mm)	$\mathbf{q(m^3 \cdot s \cdot m) \times 10^{-5}}$			
	$V = 0.1m.s$	$V = 0.5m.s$	$V = 1m.s$	$V = 5m.s$
0.6	6	30	60	300
0.39	3.9	19.5	39	195
1.35	13	67	135	674
0.53	5.34	27	534	267
0.37	3.7	18	369	184
0.26	**2.6**	**13**	**257**	**128**

As can be seen from the above tables, with the increase of the flow rate, the amount of leakage increases and also the rate of leakage increases against the flow rate. Also, these changes are less for low hydraulic gradients.

The maximum amount of leakage obtained for one year, with the assumed maximum hydraulic gradient (one) and with the assumed maximum flow velocity (5 m/s) for the biggest leak is equal to 0.00674, cubic meters/s per unit, which is about 212,553 cubic meters per year, which is a relatively large amount.

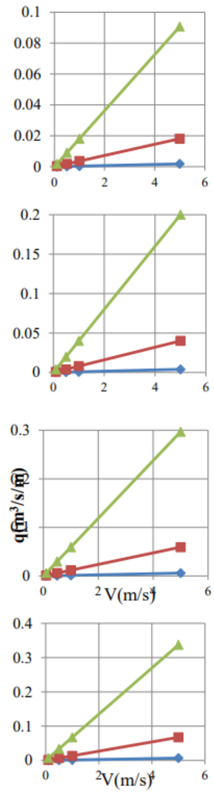


Figure 11: Changes in leakage rate versus flow rate for borehole No. 58 with different hydraulic gradients

As can be seen from the above graphs, with the increase of the flow rate, the amount of leakage increases and the rate of increase of the amount of leakage against the flow rate for the period of fifty years is more than other periods. Also, these changes are less for low hydraulic gradients.
The maximum amount of leakage obtained for the time of one, ten and fifty years, with the assumed maximum hydraulic gradient (one) and with the assumed maximum flow velocity (5 meters per second) for the largest joint, is equal to 0.00674, 0.06743 and 0.34 cubic meters per second. It is in each unit.

7 Results

1- In the short term, the flow rate did not have a noticeable effect on the dissolution rate of gypsum. With the passage of time, the change in the flow rate on the rate of dissolution can be seen, so that with the increase in the rate of flow, the amount of rate of dissolution increased. (n) and (k) increases.

2- According to the obtained values, the highest dissolution of jam is found in borehole No. 58 with a hydraulic gradient of 1 and the lowest dissolution of jam is found in borehole No. 56 with a hydraulic gradient of 1.0. Along the path of the water flow, in the places where there is purer gypsum, the rate of increase in the diameter of the seams is higher than that of the plains.

3- According to the results obtained from the experiments, the highest amount of expansion of each joint for a period of one year is equal to 35.1 mm in borehole No. 58 with a hydraulic gradient of 1, and the lowest expansion of each joint in Borehole No. 56 with a hydraulic gradient of 1.0 is equal to 07.0 mm. . Along the path of water flow, the rate of increase in the diameter of the joint decreases gradually.

4- The amount of settlement with different hypothetical hydraulic gradients increases with the increase of the flow speed. In the same way, the amount of settlement increases against the flow speed. These changes are less for low hydraulic gradients.

5- The maximum amount of subsidence obtained with the maximum hypothetical hydraulic gradient of 1 and the maximum hypothetical flow speed of 5 s/m is predicted to be around 212553 cubic meters per year, which is a significant amount. Also, this prediction for a period of 50 years is more than other times.

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