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INVESTIGATION AND ANALYSIS OF SEEPAGE AND FOUNDATION SEALING OF EZGELEH EARTH DAM

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ABSTRACT

The main purpose of the construction of earth dams is the storage and optimum utilization of the river in order to improve and develop downstream agricultural lands of the dam. In this study, numerical analysis of seepage with finite element method was performed for Ozgoleh earth dam's foundation. The case study is geographically located in Sarpol-e Zahab City, Kermanshah Province. Its rocky foundation is composed of sandstone and its seepage water-debris foundation is composed of silty sand, sandy silt and gravel. The results indicated that rocky foundation has a very low coefficient of permeability and seepage water-debris deposits of both support have a moderate to high permeability. Seep/w software was used for numerical analysis of seepage. The annual seepage rate of water from foundation is 355000m^3 that in the economic point of view, it is equivalent to 30.6% of the volume of reservoir that is not acceptable. So, for sealing the foundation of dam, two cut-off trench and cut-off wall methods were used. After sealing the foundation with cut-off trench, seepage rate of water from foundation would be 23900m^3 that is equivalent to 2.06% of the volume of reservoir and also it is acceptable. In terms of technical view, scouring is an important problem, it was solved after establishing cut-off trench and the seepage rate is eventually reduced to 1.86% of the volume of reservoir.

Keywords: cut-off trench, cut-off wall, scouring, Seep/w software

INTRODUCTION:

Water as a vital element appears in three forms in nature. The first, it appears in an excess mode as destructively and devastatingly such as disasters like flood, ets. The second, it appears in a normal and desirable mode, it can be seen as a flow on/in the ground and it is remembered as surface and subsurface water sources. The third one is the absence or lack of it that it is remembered as drought or water shortages. Lack of water and the gradual unfolding of its true and vital value encourage people and countries to utilize the available water extremely. Among the man-made structures, dams, for various reasons, including the importance of the objective of construction and the intensity and sensitivity of the risks and damages from their possible damages, are in a unique position. In Iran, traditionally, dam and its construction has been paid attention particularly. On the one hand, because of the position of Iran in a region of the planet that has rainfall less than the global average due to its geographical location and on the other hand that the rainfall in most parts of Iran is in a form of seasonal rains, collecting and controlling surface water is more important, especially in the last two decades, the control of surface water and the construction of earth dams have been paid attention considerably [1].

Water molecules flow because of the potential energy in the porous media of soil and lose their energy gradually due to the friction in this way. This is called water seepage into porous media of soil and has adverse effects as follows:

- Waste of water stored behind the earth structure;
- Creation of pore pressure in the porous media and reduction of effective stress between the particles of soil and thus, the reduction of its shear strength;
- Creation of uplift pressure on impenetrable constructs (such as concrete, steel structures, …);
- The movement of soil particles and occurrence of internal erosion in the environment;
- Applying seepage force on the mass of soil in the flow direction.

Each of the above problems can have a negative effect on the stability of earth dams, hence the stability analysis should be considered. To reduce the negative effects of seepage on the soil, it is necessary to use appropriate methods as much as possible to reduce the potential energy of water

molecules and therefore the rate of seepage. Since, in practice, the rate of seepage in soil cannot be reduced to zero, it is necessary to use the methods to control it and prevent the movement of the particles in the environment [2].

Despite the studies carried out before the construction of the dam, the hydraulic behavior of the dam's body or the geological formations adjacent to it cannot be always predicted accurately, so the probability of the occurrence of seepage or penetration after constructing the dam is definite. In many cases, the severity of seepage or penetration is acceptable until the safety of dam has not been compromised. Many cases of dam collapse or at least some of them are due to the inadequacy of detailed information about the hydraulic properties of existing streaks in the geological formation of dam's origin. Many reservoirs of dams constructed in the world have seepage [3], this may occur due to the geological formation of dam's origin or dam's body. However, the occurrence of seepage, for various reasons such as non-uniform seepage or earthquake, …, is inevitable during the operation of reservoir, but, properly constructed dams are less affected by the seepage. According to Nonvieller (1989), the seepage of water from foundation (increasing the flow of underground water from foundation) causes the following consequences:

- Increase of uplift pressure on the surface of foundation which may cause damage and create instability in the structure.
- Flow of drainage at the seams and in gaps and holes of materials used in foundation could cause the erosion, increase the natural permeability of stone and cause the hydraulic failure in granular soil [4].
- Water escape or water waste harm the reservoir's function in storing water and make it unjustified economically [5].

Experiments have shown that seepage from the reservoir will lead to significant economic repercussions and rehabilitation measures are usually expensive, so in this case, the research been done previously can be very beneficial, and that this issue doubles the importance of the problem and makes the needs for such research clear [6].

Ozgoleh village, Sarepol-e Zahab City, Kermanshah Province has suitable land and climatic condition to develop garden and agricultural lands that water supply is essential for it. Regardless of the type of dam that is built in an area, study and investigation are necessary that change

depending on the conditions of the area, flooding situation, the extent of the basin and … . From these discussions, engineering geology, is more important. Due to the large volume of water stored in the reservoir, geological conditions of dam area varies and the changes are due to high hydrostatic pressure on the dam foundation and pillars. The proper design of a dam requires a variety of studies in different fields, including engineering geology and hydrogeology of dam origin, that on the topic of engineering geology, they are used in selection of dam site and dam type and design of cutoff curtain. On the other hand, calculating the amount of seepage and water escape from the foundation and body of dam and finding the ways to prevent and reduce the seepage and water escape are more important. In this research, it was tried to estimate the seepage rate from the foundation and body of Ozgaleh earth dam, Sarepol-e Zahab City, Kermanshah Province by investigating the results of different experiments related to seepage and related calculation and existing software and also provide the best way to prevent and/or reduce the amount of water escape [7].

2- Geographical position and specifications of Ozgoleh dam:

Ozgoleh dam is located in Sarpol-e Zahab City, Kermanshah Province. Access to the site is possible by the asphalted road which begins from Kermanshah City and continues to the beginnings of the way of transmission system (Ozgoleh Town). In mentioned road, at 45km to Kermanshah City, there is a detour which continues to dam origin. It is 4.5 km which ends to the left pillar of dam in downstream option and access to other parts of site is possible through the local trails.

Figure1shows the location of project

Figure1. Geographical position of Ozgoleh earth dam

The specifications of Ozgoleh earth dam can be summarized as follows:

The height of dam from the bottom of the river: 37 m

The dam's crest: 160 m

The level of dam's crest: 1209

Free height of dam: 4 m

Normal level of water in the reservoir (overflow level): 1206 m

Reservoir's area at normal level: 107,959 m^2

Adjustable volume of the dam: 2878363 m^3

The minimum level of operating (intake level): 1173 m

3. MATERIALS AND METHODS

3.1. Specification of the origin of Ozgoleh dam

The origin of Ozgoleh dam is composed of stone and soil that alluvial deposits located on the underneath stone. The thickness of alluvial deposits is different in left and right ridge rims of the dam axis that the thickness of the alluvial deposits in the left and right ridge rims is 15 and 7 m, respectively. Figure 2 shows the stratigraphic section of the dam axis.

Figure 2 Stratigraphic section of the foundation of Ozgoleh earth dam

As shown in figure2, the rocky part of the foundation is composed of sandstone and in the river bed, the ingredients of deposits are coarse materials and made up of gravel, the left ridge rim is composed of silty sand and the right one is composed of sandy silt.

To provide the permeability section, first, the locations of mechanical exploratory boreholes (rotational) were marked on the section of dam axis and a permeability column was defined by the establishment of permeability coefficient values in the testing sections of each borehole. Also, the interval between the boreholes was determined by using interpolation method and then the permeability zones were identified. Figure 3 shows the permeability section of foundation.

Figure3. Permeability section of foundation, Ozgoleh earth dam

3.2. Seepage water-debris foundation

Alluvial foundation, on dam axis, is divided into two parts of impermeable and permeable based on permeability coefficient that the index of impermeability boundary is $1*10^{-5}$ cm/s. The thickness of permeable part in the left ridge rim is more than it in right one. In general, the thickness of the alluvial materials in the left ridge rim is more than it in right one. Alluvial foundation of the dam axis has different permeability in its different parts. The permeability coefficient of the materials in the permeable alluvial part changes from $2.4*10^{-5}$ to $4.8*10^{-2}$. Given to the distribution of different permeability zones in different parts of foundation and also the percentage of different coverage levels of them, the mean permeability coefficient is equal to $7.34* 10^{-3}$ cm/s. The thickness of alluvial deposits in the river bed below the dam's body in upstream and downstream parts is considered equal due to lack of adequate information.

3.3. Rocky foundation

The bedrock of the origin of Ozgaleh damis formed by sandstone that according to Lugeon experiments that have been performed for different boreholes, rocky foundation has low permeability coefficient. Here, the index of impermeability was considered in 3 Lugeon. The depth of the location of rocky foundation in left and right

ridge rim is between 6.5 to 20.5 m and 6.5 to 11.5 m on average, respectively. In all sections except A6, A7 and A8, the rocky part was impermeable and didn't need to scour, so, the bedrock in left and right ridge rim was impermeable and it is just permeable in the river bed. The greatest and lowest depth of the rocky foundation was observed in boreholes BH1 and BH3, respectively. The numbers of Lugeon for all testing sections under one lugeon were obtained. The index of impermeability boundary in the location of the dam axis, based on the permeability of rocks was determined as much as 3 Lugeon and it was obtained $1*10^{-5}$ cm/s for alluvium.

4.3. Seepage rate of water from foundation

To calculate the seepage rate of water from the foundation of Ozgoleh earth dam, 3 assumptions were considered as following:

First assumption:

To calculate the seepage rate, the impermeability boundary below the foundation of dam for alluvial area was considered less than the permeability coefficient of $1*10^{-5}$ cm/s and for rocky area, it was considered less than the permeability coefficient of 3 Lugeon.

Second assumption:

In rocky part, the finite element method was used to numerical analysis. Considering that all analyzes of rocky mass, including stress-strain, rupture, seepage, …, in modeling were performed based on numerical analysis by finite element method. In this assumption, due to the small thickness of rocky layer and also the lack of the use of two analytical methods in software, in rocky part, by considering the common safety factor, the seepage was investigated by finite element method.

Third assumption:

To convert the permeability coefficient of soil part to the permeability coefficient of rocky part, based on the equation written by Barton and Quadros (2003), one lugeon was assumed 10^{-5} cm/s.

Before calculating the seepage rate, in 14 sections (the number of sections can be increased and decreased based on the geological properties of the region and the changes of the properties of soil and rock of that place, obviously, by increasing the number of sections, the seepage analysis is done precisely), based on the thickness of soil and rocky layer, the equivalent permeability were calculated that are summarized in Table 1. To calculate the water seepage through the foundation in the place of each section to determine the geometry of effective foundation and body, according to the location of dam, Table 1 was set.

Table1. The geometry characteristics of Ozgoleh earth dam's foundation and body

section	Horizontal distance of upstream shell (m)	Horizontal distance of downstream shell (m)	Base of core(m)
A1	13	11	8.4
A2	25	26	12.4
A3	40	66	18.8
A4	56	78.5	23.2
A5	86	86	28.4
A6	92	93.5	32.4
A7	91	91	31.6
A8	82	91.5	28.8
A9	70	91.5	29.2
A10	56	51.5	21.2
A11	50	34	15.6
A12	47	16.5	12.4
A13	31	9	8.8
A14	23	4	9.2

After determining the geometry of foundation and body, it was plotted in Seep/w software.

3.5. Features of Seep/w software

- In this software, the numerical analysis is performed based on finite element.

- The software models the hydraulic conductivity and soil moisture as a function of pore water pressure in the form of continuous functions, while other software applications use unrealistic assumptions and model this parameter in as a step that leads to create an error in calculation.

- The scope of this software includes unsaturated soil in addition to saturated soil. This is an important difference between this software and other software of soil engineering.

The final solution of the problem can be achieved with the help of boundary conditions, the following conditions were applied:

All conditions imposed on the nodes so that the nodes located on the surface of reservoir have fixed total load equal to the normal height of the reservoir and the total load of the nodes located on the heel surface of downstream is equal to the gravity load of each node (node height above sea level). In side pillars and impermeable bed of foundation, due to the lack of current exchange, discharge was considered zero.

- After determining boundary conditions and solving equations, the values of the node h is obtained. By calculating h in all nodes, the potential and current contour lines can be drawn, that are shown in following figures.

4. RESULTS AND DISCUSSION

4.1. The models of sections

After modeling the sections and calculating the seepage from all sections, to calculate annual seepage from the dam foundation, first, the speed of seepage for each section was calculated in meter per year and then by calculating the surface area between the sections, the water seepage between the sections were calculated separately. The calculations were summarized in Table2.

Surface area of foundation is 801 m^2 and the average water seepage per 1 m^2 is about 443.2 m^3/year. According to Table2, the total water seepage from the foundation is equal to 355000 m^3/year and according to the volume of reservoir which is equal to 2162131 m^3, the ratio of seeped water volume to the reservoir volume is equal to 30.6%.

2.4. Foundation sealing

One way to deal with the phenomenon of leaching particles from the core to the foundation, which occurs due to thepressure difference between the sides of sealed part and also downstream of the core, is reducing the degree of sealing in sealed part. Of course, this creates another problems which are high permeability of the foundation and significant increase of water seepage. The experience has shown that given above limitations, the best mode for sealed part, in

terms of permeability, is a mode between two above limitations. It means that the permeability of sealed part should not be too low that leads to the pressure difference between two sides of sealed part and also it should not be too high that leads to the increase of water seepage. Based on the experience, the best degree of sealing for sealed part is about 65%, because the spread of pore pressure is easier and the amount of seepage losses would be inconsiderable [8]. Here, it is used as a sealing plan.

Many of dams in the world are built with the main aim of water supply and power generation and controlling floods is considered as a secondary aim. So, the economic aspect is very important in the water supply. Water seepage as an effective factor is discussed in economic feasibility of storage dam projects. So, the amount of water entering into the reservoir is defined as an allowed limit of seepage. In engineering, the limit can be determined with the number of Lugeon or the amount of water seeped at the given pressure for rocky part and it can be determined for soil parts by calculating the piping. This amount is an optimum limit that is determined based on the interaction of two factors: cost of water loss and cost of sealing the environment. Previously, water seepage from the foundation of dam for each

of section was calculated by Seep/w software and eventually, total water seepage was calculated equal to 355000 m³/year.

With regard to the economic value of any plan in which maintenance and storage is important. Allowed amount of water seepage from foundation in a year is considered, on average, about 2-5% of the total volume of the reservoir that in Ozgoleh earth dam, the ratio of the volume of water seepage to the volume of the reservoir is equal to 30.6%, so, in this regard, it is found that in this project, the amount of water seepage has a problem economically. So, to achieve the allowable water seepage, sealing is required and given the features of the plan and alluvial foundation, cut-off trench is used for sealing. The thickness of permeable part and depth and slope of cut-off trench and also the thickness of permeable part after establishing cut-off trench are shown in Table 3.

Obtained number from them, the amount of water seepage from the dam foundation after establishing the cut-off trench was obtained that shown in table 4.

After constructing the cut-off trench, the surface area of permeable layer would be reduced as many as 299.76 m² and would be 501.12 m² and the amount of water seepage per 1m² would be 47.7 m³/ year. According to Table4, the water seepage from the dam foundation would be 239000 m³ that the ratio of the volume of water seepage to the volume of reservoir would be equal to 2.06%. So, given that the allowed water seepage from the dam foundation in a year is considered about 2-5% of the total volume of the reservoir, by constructing the cut-off wall, the amount of water seepage from the dam foundation of Ozgoleh earth dam would be 1.86% that is an allowed limit.

Table2. Water seepage from the foundation of Ozgoleh earth dam, by using Seep/w software

No. of section	Seepage rate (m/s)	Seepage rate (m/year)	Surface area between two sections (m^2)	Amount of water seepage between two sections (m^3/year)
1	4.2E-07	1.21E+01	141.6	9.14E+02
2	2.15E-06	6.36E+01	112.4	8.55E+03
3	2.73E-06	8.82E+01	69.02	4.60E+03
4	1.39E-06	4.80E+01	39.9	1.58E+04
5	2.62E-05	7.85E+02	41.34	1.11E+05
6	1.70E-04	5.15E+03	55.2	3.68E+05
7	2.64E-04	8.54E+03	50.36	2.09E+05

8	1.59E-06	5.23E+01	21.57	7.39E+02
9	4.43E-07	1.33E+01	18.06	1.70E+02
10	1.20E-07	3.37E+00	6.86	3.86E+01
11	2.66E-07	8.17E+00	27.7	2.48E+02
12	2.98E-07	9.18E+00	59.8	3.56E+02
13	6.77E-08	2.07E+00	76.8	8.42E+01
14	6.11E-22	1.80E-14	64.6	6.22E-13
15	0.00E+00	0.00E+00	16.67	0.00E+00
Total seepage from the dam foundation				3.55E+05

Table3. The thickness of permeable layer and the depth of cut-off trench in Ozgoleh earth dam

section	The initial thickness of the permeable layer (m)	The thickness of the sealed part of permeable layer (m)	Remained depth after sealing plan (m)	Slope of trench (m)	Depth of trench (m)	The thickness of the permeable layer after the establishment of cut-off trench(m)
A1	12.35	7.7	3.7	1/1	2	10.35
A2	6.88	5.4	2.5	1/1	2	6.88
A3	4.04	2.3	2.8	1/1	4	2.04
A4	4.87	2.2	2.7	1/1	3	2.87
A5	4.29	3.8	1.5	1/1	3	1.29
A6	5.5	3.2	2.3	1/1	6.5	0
A7	4.1	1.0	1.1	1/1	3.1	0
A8	2.6	2.0	0.6	1/1	1.6	0
A9	2.5	2.0	0.5	1/1	1.5	0
A10	1.2	0.8	0.4	1/1	1.2	0
A11	3.7	1.4	1.3	1/1	1	2.7
A12	8.6	3.9	2.7	1/1	1	6.6
A13	6.1	3.6	2.5	1/1	1	6.1
A14	5.1	2.3	1.8	1/1	1	4.1

Table4. Water seepage from the foundation of Ozgoleh earth dam after the construction of cut-off trench

No. of section	Seepage rate	Seepage rate	Surface area between two sections	The amount of seepage between two sections
	(m/s)	(m/year)	(m^2)	(m^3/year)
1	4.30E-07	1.29E+01	122.5	8.40E+02
2	1.79E-06	5.86E+01	96.4	5.86E+03
3	2.13E-06	6.30E+01	49.8	3.20E+03
4	2.27E-06	6.74E+01	14.6	9.22E+03

5	3.73E-05	1.31E+03	15.7	1.44E+04
6	2.31E-05	7.50E+02	11.43	6.15E+03
7	9.55E-06	2.88E+02	0	0.00E+00
8	0	0.00E+00	0	0.00E+00
9	0	0.00E+00	0	0.00E+00
10	1.34E-09	3.81E-02	0	0.00E+00
11	2.23E-07	7.45E+00	15.5	1.18E+02
12	2.17E-07	6.43E+00	46.5	2.28E+02
13	9.13E-08	2.75E+00	63.4	9.13E+01
14	1.41E-21	4.66E-14	51	1.31E-12
15	0.00E+00	0.00E+00	14.39	0.00E+00
Total water seepage from the dam foundation				2.39E+04

CONCLUSION:

In this study, the amount of water seepage from the dam foundation of Ozgoleh earth dam was examined and following results were obtained from it.

- The project of Ozgoleh earth dam is an inhomogeneous earth dam with clay core which is located in Sarepol-e zahab city, Kermanshah Province.
- The axis of Ozgoleh earth dam is within a shallow and narrow valley that its walls have a moderate to high slope and shape of the valley in the dam axis is V-shaped.
- In the mode without sealing, surface area of permeable foundation of dam is 801 m^2 and the water seepage is equal to 355000 m^3/year. In other words, the mean water seepage from $1m^2$ is about 443.2 m^3/year.
- Since that the ratio of the volume of water seepage to the volume of reservoir is equal to 30.6%, it can be concluded that the seepage of dam foundation is economically problematic.
- After constructing cut-off trench, surface area of permeable foundation of dam is reduced as many as 501.12 m^2 and the mean water seepage from $1m^2$ will be 47.7 m^3/year and the water seepage from the dam foundation will be 23900 m^3/year and the ratio of the volume of water seepage to the volume of reservoir will be equal to 2.06%.

– By constructing cut-off wall, the water seepage become 21700 m^3/year, by reviewing, it was found that the ratio of the volume of water seepage to the volume of reservoir will be equal to 1.86% that is acceptable.

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