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The Effect of Clay Blanket Thickness to Prevent Seepage in Dam Reservoir

[1]H. Goharnejad, [2,3,4]M. Noury, [5]A. Noorzad, [6]A. Shamsaie and [7]A. Goharnejad
[1]Department of Civil, Azad University of Research and Science, Tehran, Iran
[2]Iranian Young Researchers Club, Urmia Branch, Iran
[3]West Azarbayjan Regional Water Company (Vezarate Niroo), Iran
[4]Department of Water Resources Engineering,
Science and Research Branch, Islamic Azad University, Tehran, Iran
[5]Department of Civil Engineering,
Shahid Abbaspour University of Water and Power Technology, Tehran, Iran
[6]Department of Civil Engineering, Sharif University, Tehran, Iran
[7]Department of Watershed Management, University Mazandaran, Sari, Iran

Abstract: This study which has been done on Farim Sahra dam located in *Mazandaran* province, of Iran is concerned on the seepage problem. To decrease the seepage in dam's foundation, the effects of upstream clay blankets, its advantages and limitations, and the execution methods are discussed. The SEEP/W software (GEO-SLOPE Company) has been used for modeling and analyzing the seepage. The geometry and dimension of the upstream clay blanket have been studied and the results have been compared with the results of Bennett equation. Based on the above analysis and considering Bennett equation, it is suggested to use the clay blanket with the length of 150 m and thickness of 0.75 m which shall extend over the upstream shell. This will result in a seepage rate decreased by about 73% which seems to be more effective rather than other available methods.

Key words: Clay blanket, seepage, dam reservoir, Farim Sahra

INTRODUCTION

The seepage of water in the body and foundation of clay dams is one of the most important subjects in earth-dam studies. This kind of seepage that is known as drainage water, is important from viewpoints of calculation of water wasting that may be a considerable percentage, stability of dam, calculation of sub-pressure, calculation of thickness and length of drainages, the necessity of injection, dam wall plan and many other factors (Biswas, 2005).

There are different methods to control or prevent seepage of water from reservoir of dams which can be employed based on the kind of reservoir layers, economical studies and available materials and equipments in the region (Shehata, 2006).

Coating the bed of river and reservoir with a pitching layer with low permeability in upstream shoulder of dam core is one of the methods to decrease seepage in foundation of earth-dams which are established on high permeable alluvium layers. This pitching layer is

Corresponding Author: Mojtaba Noury, Iranian Young Researchers Club, Urmia Branch, Shahid Beheshti St., Azad University, Urmia, Iran Tel: +98 9149382757

considerable when it is established with the wall of defective dam or when creation of an upright injection diaphragm or a slope diaphragm wall is impracticable or uneconomical. This kind of layer decreases seepage, seepage pressure of water and their dangerous with increasing the length of stream lines, potential falling and decreasing the energy of water (Dorota and Allen, 2005).

Impermeable upstream blankets with some drainage layers in downstream are used for long years. Lane and Wohit (1961) are discussed comparatively about the function of this system which is employed in Forth-Randal and Gavins-Point dams during 1950s decade over Missouri-River.

Brown (1961) discussed about upstream impermeable blanket systems and drainage trenches to control seepage through the cores of two Chief Joseph and McNary-dams over Columbia-River. In both dams, coarse grained alluvium with 0.5 cm sec^{-1} permeability coefficient was the material of cores. Blankets were stretched 310 to 610 m from upstream of dam (Brown, 1961).

Peterson (1968) has reported about the function of the dam of Saskatchewan-River in Canada which enjoys an upstream impermeable blanket system. This earth-dam is established on about 30.5 m tiny and average grained sand. The dam was refilled with water up to its 52.0 m of depth in 1967 by comparison with its 58 m designed height (Peterson, 1968).

Arrow-dam and more falls dam are two other Canadian dams which enjoy upstream blanket system to control sub-dam seepage through deep alluvium layers. Upstream blanket for Arrow-dam was made by founding refrigerant marble into the water (Wilson, 1979).

One of the biggest upstream impermeable blankets is executed in Tarbela dam in Pakistan with 140 m height. The blanket has 1400 m length and its thickness is 1.52 m at the top and 15.25 m at the bottom and at the point to connect to impermeable core (World Commission on Dams, 2000).

The structure and reservoir of Farim-Sahra Dam (Fig. 1) with 53°, 13' Eastern longitude and 36°, 10' Northern latitude is located on Aroos-va-Damad River between Moji Village from suburbs of Mohammad-Abad section of Sari and conjunction point of two tributary streams of Derazlinge and Resket. According to Morphological data, the structure of location of Farim-Sahra dam has wide valley pattern. Farim valley is broadened after the location of dam and on Aroos-va-Damad River toward the shallow and enters Farim-Sahra field gradually (Consulting Engineers Co., 2006).

Fig. 1: A view of body and situation of Farim-Sahra dam in Mazandaran, Iran (Consulting Engineers Co., 2006)

Governing Equations

Uginchus and Roboty discovered the differential equation of seepage in upstream blanket dams in 1934 and resolved it for the dams with unlimited and limited blanket length (Uginchus, 1935).

Bennett achieved this differential equation by a different method in his paper in 1946 and resolved it. Bennett showed the relations to calculate effective length of blanket in different conditions of limited and unlimited blankets and achieved a very important equation to calculate the most optimized length for blanket (Bennett, 1946).

Whereas, the achieved equations by Bennett are very important to calculate the length and thickness of clay blankets and are referred in this study as the applied equations to calculate length and thickness of upstream clay blanket, the general form of equations are described at following.

Equation 1 is the basic differential equation of Bennett for limited permeability blankets. Resolving this equation represents the length of upstream impermeable blanket.

$$\frac{d^2h}{dx^2} = a^2h \tag{1}$$

Where:

$a^2 = \frac{K_b}{Z_b K_f Z_f}$

h = The difference between head of water at two sides of blanket and in the point to measure discharge

K_b = Permeability coefficient of the material of blanket

Z_b = Thickness of upstream horizontal blanket

K_f = Permeability coefficient of the material of foundation

Z_f = Thickness of foundation

Equation 2 will be achieved when Eq. 1 is solved for the blanket with unlimited length:

$$X_r = \frac{1}{a} = \sqrt{\frac{Z_b K_f Z_f}{K_b}} \tag{2}$$

we will have Eq. 3 for the blanket with unlimited length:

$$X_r = \frac{0.82}{a} = 0.82 \times \sqrt{\frac{Z_b K_f Z_f}{K_b}} \tag{3}$$

In other words, if the length of upstream clay blanket is the best, the optimized length of upstream clay blanket is 82% of the length of unlimited blanket.

Modeling

The analysis of permeability of Farim-Sahra dam is done with GEO-SLOPE (SEEP/W) software. SEEP/W is software to analyze general permeability and is applicable to analyze saturated and unsaturated porous environments. The model is planed for upstream clay blankets with various lengths and thicknesses (Ozkan, 2003).

Geometric Model and Finite Element Mesh

To analyze the permeability of Farim-Sahra dam, cross section at most on the central foundation is selected and is modeled.

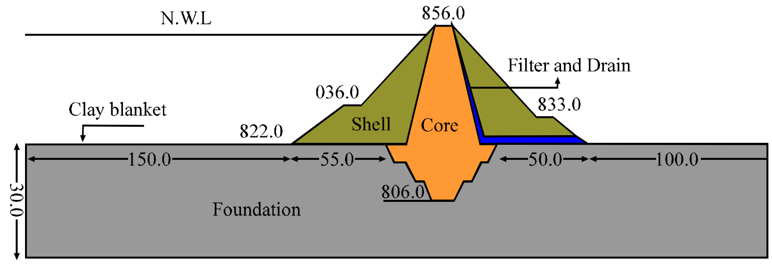

Fig. 2: Geometric model and material division of Farim dam (Consulting Engineers Co., Tehran Sahab, 2006)

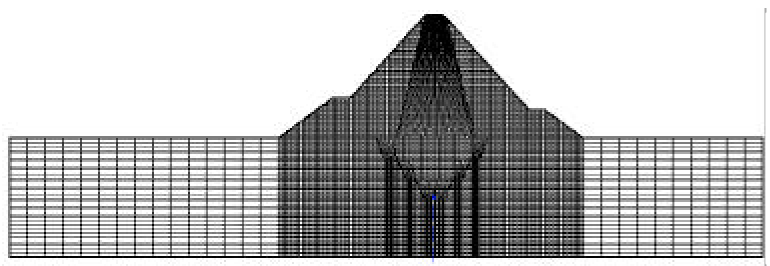

Fig. 3: Finite element mesh in permeability analysis of Farim-Sahra dam

Table 1: Consideration of materials of Farim-Sahra dam (Consulting Engineers Co., 2006)

Dam elements	K_x (m sec^{-1})	K_y (m sec^{-1})
Core and upstream clay blanket	2.236×10^{-7}	4.472×10^{-8}
Shell	1.414×10^{-4}	7.701×10^{-5}
Filter and drain	5.000×10^{-3}	5.000×10^{-3}
Foundation	1.414×10^{-4}	7.701×10^{-5}

In Fig. 2 and 3, geometric model, material division and finite element mesh are shown. Sections of the body and foundation are modeled according to geological studies and the plan of dam. Permeability coefficients of materials are represented in Table 1.

Consideration of Dimensions of Upstream Clay Blanket

The lengths of 50, 100 and 150 m for upstream clay blanket and thicknesses of 0.15, 0.3, 0.5, 1.0, 1.5 and 2.0 m are considered to analyze the model. Studies were done in two general cases. In the first case, only the surface of reservoir is covered by clay blanket. According to analysis for all lengths and thicknesses, it was considered that the influence of blanket to reduce permeability was very little by comparison with lack of any blanket.

So, we developed studies and took a measure to cover the surface of upstream shoulder with a layer of clay. In the second case the surface of upstream shoulder of dam was covered by clay materials. In such these conditions, some problems such as rapid draw down of water in reservoir, stability of clay cover in such this slope and other executive problems will occur. When rapid draw down occurs in reservoir, the ejection of captive water in upstream shoulder into permeable alluvium foundation is inevitable because of similarity of permeability coefficients of upstream shoulder and alluvium foundation and impermeable cover creates no problem. It is recommended to coat the blanket with a thick layer of random fill materials for more stability of blanket as it is shown in Fig. 4. The slope and volume of

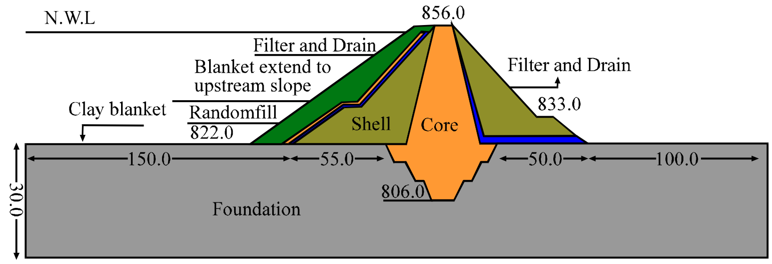

Fig. 4: Execution of clay blanket on upstream body of Farim-Sahra dam

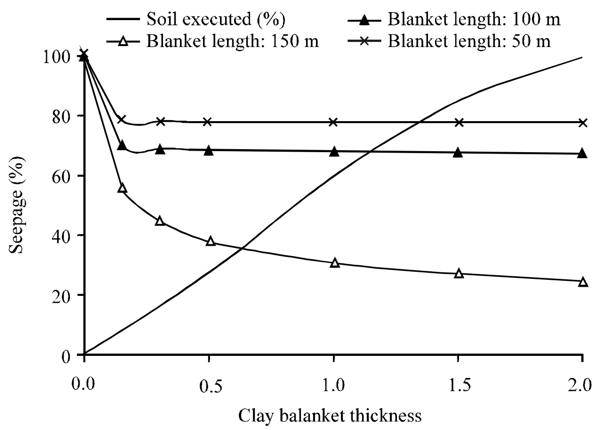

Fig. 5: The effect of increasing thickness of blanket for defined lengths and the volume of increase soil operation

operation is achievable by stability analysis. To execute clay layer in upstream slope of dam, a clay layer with horizontal width of 3 m can be used to let machinery have enough work space in that slope.

According to permeability studies, the execution of clay blanket on upstream body of dam has a significant role to decrease seepage from reservoir, to the extent that the blanket beside clay blanket up to surface of upstream layer reduces seepage from reservoir about 75% by comparison with the situation that there is no cover in upstream of reservoir.

The rate of the role of length and thickness of clay blanket and the volume of soil operation are compared at following. Figure 5 and 6 show that increasing the thickness of clay blanket beyond the specific amount, has practically no considerable effect to reduce seepage and the most effective factor is in fact the increase of length of upstream blanket. Meanwhile, Fig. 6 considers the volume of soil operation and the rate of seepage and represents that increasing the thickness more than 0.15 m for the blankets with 50 and 100 m of length has no attention able effect to reduce seepage from the foundation; so the thickness of 0.15 m is appropriate for blankets with 50 and 100 m of length. For the blanket with 150 m length the diagram shows that the chart of increase soil volume and the chart of Seepage cross each other in thickness point of 0.6 m; so the blanket with 0.6 m of thickness is suggested for blanket with 150 m length.

Table 2 at following represents for equal soil volumes that the rate of seepage will be decreased more with increasing the length of blanket or its thickness.

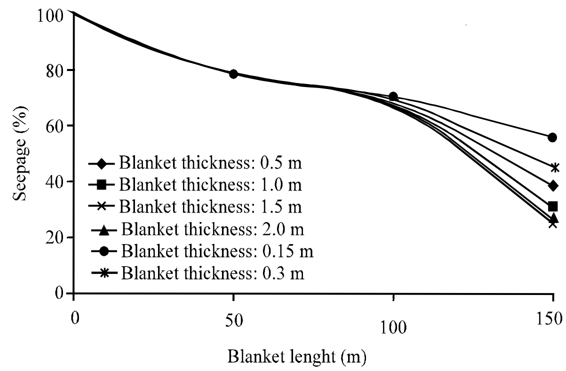

Fig. 6: The effect of increasing the length of blanket for defined thicknesses

Table 2: Consideration of the volume of soil operation and the effect of length and thickness

Soil executed volume ($m^3 m^{-1}$)	Clay blanket length (m)	Clay blanket thickness (m)	Decrease seepage (%)	Effective state
15	50	0.30	21.59	
	100	0.15	29.58	✓
50	50	1.00	21.86	
	100	0.50	31.36	✓
75	50	1.50	21.93	
	150	0.50	61.70	✓
100	50	2.00	22.00	
	100	1.00	31.93	✓
150	100	1.50	32.15	
	150	1.00	69.49	✓

As it is represented in Table 2 the increase of length is more effective than thickness for equal soil volumes. So, this point should be mentioned in blanket designing. It is important to mention that another subject who is effective on the rate of seepage and the role of upstream blanket is that the area of blanket will increase when the length increases. This subject reduces the effect of blanket.

Defining the Thickness of Blanket by Bennett Method

Using equations of Bennett is one of the most popular methods to define the thickness of upstream clay blankets, so we calculate the thickness of blankets with 50, 100 and 150 m of length.

A brief history of calculations and related formulas are represented in Table 3. A comparison between the percentage of seepage decrease, achieved by Bennett equations, and the results of SEEP/W software is shown in Fig. 7. As it is obvious, the seepage in Bennett equations is less than the result of SEEP/W software.

It should be mentioned that regarding theories of Bennett, the results of modeling is compared with the results of equations of Bennett when upstream layer is coated by an impermeable cover that is shown in Table 4.

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Thickness Consideration

Table 5 considers achieved thicknesses by the results of modeling and equation of Bennett and compares suggested thickness amount by two methods for defined lengths and reveals an appropriate thickness which encounters the least seepage.

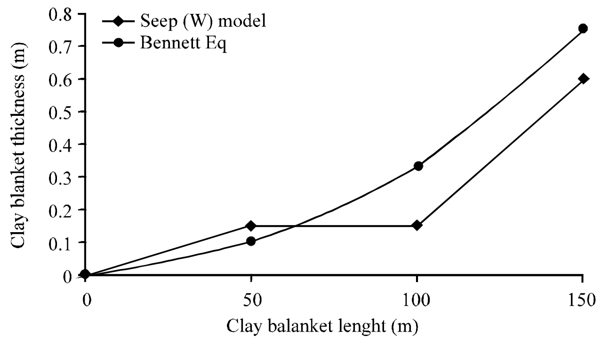

Fig. 7: Comparison of achieved thickness by to methods

Table 3: Calculating the thickness of blanket with various lengths and by method of Bennett

Caly blanket lenght X_f (m)	$\alpha=\sqrt{\frac{K_b}{K_f Z_f Z_b}}$	$X_f=\frac{1}{\alpha}$	Caly blanket thickness (m)	Seepage (m^3/sec/m)	Deacrease seepage (%)
Without clay blanket	----	----	----	4.5×10^{-4}	----
150	$\frac{5.77\times10^{-2}}{\sqrt{Z_b}}$	$173.2\times\sqrt{Z_b}$	0.75	1.2×10^{-4}	73.17
100	$\frac{5.77\times10^{-2}}{\sqrt{Z_b}}$	$173.2\times\sqrt{Z_b}$	0.33	1.6×10^{-4}	64.52
50	$\frac{5.77\times10^{-2}}{\sqrt{Z_b}}$	$173.2\times\sqrt{Z_b}$	0.10	2.4×10^{-4}	47.62

Table 4: Comparison between the results of SEEP/W software and equation of bennett

Eq. bennett			SEEP/W model		
Clay blanket length X_f (m)	Clay blanket thickness (m)	Seepage (m^3/sec/m)	Clay blanket length X_f (m)	Clay blanket thickness (m)	Seepage (m^3/sec/m)
Without clay blanket	---	4.5×10^{-4}	Without clay blanket	---	4.5937×10^{-4}
150	0.75	1.2×10^{-4}	150	0.60	1.7011×10^{-4}
100	0.33	1.6×10^{-4}	100	0.15	3.2349×10^{-4}
50	0.10	2.4×10^{-4}	50	0.15	3.6152×10^{-4}

Table 5: Achieved thicknesses by modeling and equation of Bennett and suggested thickness for specific length

Blanket length	Min. thickness execute	Optimum thickness	Bennett Eq. thickness	Suggested thickness
(m)				
50	0.5	0.15	0.10	0.50
100	0.5	0.15	0.33	0.50
150	0.5	0.60	0.75	0.75

As Table 5 represents upstream clay blanket with 150 m length and 0.75 m thickness is suggested for execution. It should be mentioned that this thickness is the least possible thickness and can be increased according to local and topographical situations.

CONCLUSION

Farim-Sahra dam (Mazandaran) is rarely refilled more than 10 m with water (one third of its normal height of water) since, its establishment in 2000. The main reason is two factors: The first factor is the location of upstream river basin on a micro-climate with less rain average than neighbor basins and the second factor is the seepage of a considerable amount of water in foundation and two sides of reservoir. So, the total amount of seepage has never been measured in normal balance practically. This study considered the foundation in deep water and simulated full level of reservoir and estimated 39.71 m^3 day^{-1} as the rate of seepage from foundation.

According to study and results of considered models in different situations, it seems that we cannot ignore hermetic sealing of upstream layer of dam which has considerable effect to reduce seepage, so the suggested option is to develop clay blanket up to upstream layer of dam with 150 m length and 0.75 m thickness. Seepage in this situation is about 75% less than the time that there is no hermetic sealing blanket. Thickness of 0.75 m is the least possible executive thickness and can be increased according to local and topographical situations.

According to analysis, the effects of upstream clay blankets to increase flow line length is completely obvious.

It should be mentioned that developing upstream blanket up to upstream layer of dam is not practical for all dams and all situations. It is necessary to consider permeability of materials of foundation and shoulders completely.

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