Investigation on the Performance of Blanket, Cutoff Wall and Synthetic Cover for the Control of Seepage and Piping in Earth Dams

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Abstract

This study firstly presents a review on the different methods for seepage and piping control of earth dams. Then, the capability of an upstream blanket, cutoff wall, and synthetic cover was compared for reducing of seepage discharge and exit gradient using SEEP/W software as a numerical simulation model. For this, a typical section of an earthen dam was considered. Totally, 54 tests were conducted under the different conditions of the upstream head, situation and depth of cutoff wall and upstream synthetic cover. For each test, the values of seepage discharge and exit gradient at the toe of earth dam were calculated. The results show that the presence of an upstream blanket cannot reduce the seepage discharge and exit gradient, significantly. For example, the design of upstream blanket with the length of 45 m, only reduces the seepage discharge and exit gradient about 0.3% and 7.3%, respectively. On the other hand, by using an upstream synthetic cover the seepage discharge and exit gradient can be more reduced about 67.5% and 65.5%, respectively. The results also show that the best situation of the cutoff wall for the control of seepage discharge and exit gradient is in the middle of the earth dam. This can reduce the seepage discharge and exit gradient about 40% and 23%, respectively. This study presents a comparison about reducing the seepage discharge and exit gradient by using a combination of a cutoff wall with an upstream blanket and synthetic cover as the two different cases. The seepage discharge (exit gradient) was reduced about 40.4% (10.6%) and 63.3% (44.6%) for the two above cases. It is concluded that the best way for reducing the seepage discharge is the use of upstream synthetic cover with a cutoff wall in the middle. It is believed that the optimal design of a drain hole reduces the seepage discharge and exit gradient, simultaneously which requires furthering studies.

Keywords: Seepage, Exit Gradient, Earth Dams, Cutoff Wall, Blanket, Synthetic Cover.

1. INTRODUCTION

Issues related to the security of earth dam while construction and also within operation have special important due to the effective role of those earth dams in supplying hydraulic requirements and also creating potential risks for residents of the downstream. There is the potential seepage water from the foundation and the bodies of these structures due to the difference in water head from the both sides of earth dams. Seepage effects in these structures could categorize into three parts, including uplift force, seepage flow and exit gradient. In designing earth dams, one purpose is achieving to the optimal design of dam section, in which the effects of seepage would be minimized. The aim of this study is evaluating the different methods for decreasing the seepage effects under the earth dams and determine the optimal model. Jaberi (1376) has considered water flow in a porous heterogeneous inconsistence environment [1]. Sedghiasl et.al (1384) have studied the effect of optimal position of cutoff walls in seepage decline under hydraulic structures using numerical model and concluded that the best position for decreasing the seepage discharge and exit gradient is at the toe [2]. Pakbaz et.al (2008) have considered constructing the plastic concrete cutoff wall using SEEP3D model foe decreasing the water seepage at the right and left sides of the bearings of karkhe dam [4]. Their results show that by creating cutoff wall at the left and right sides, water seepage would decrease 60 and 20 percent, respectively.

2. Materials and Methods

2.1. Methods of control and decrease seepage effects

Generally, we could categorize different applied methods for either control or decrease seepage effects from the foundation and body into two groups: first group include methods for sealing or decrease seepage amount and second group include methods for control seepage and its effects. In first methods, components are designed such that the seepage amount decreased. However, in second methods main purpose is seepage effect, such as distribution of uplift pressure and leading leaked water flow in desired path, such that adverse effects be minimized. We could categorize combination of the above mentioned components for either decrease or control seepage effects into vertical (or diagonal) and horizontal components. It should be noticed that in most of cases, a combination of components of both recent groups might obtained optimal results. According to the above model, Figure 1 represents the most common methods which are applied in either decrease or control seepage. It should be mentioned that proper exploitation of these methods requires intensive field studies and identifying environmental conditions of constructing the structure.

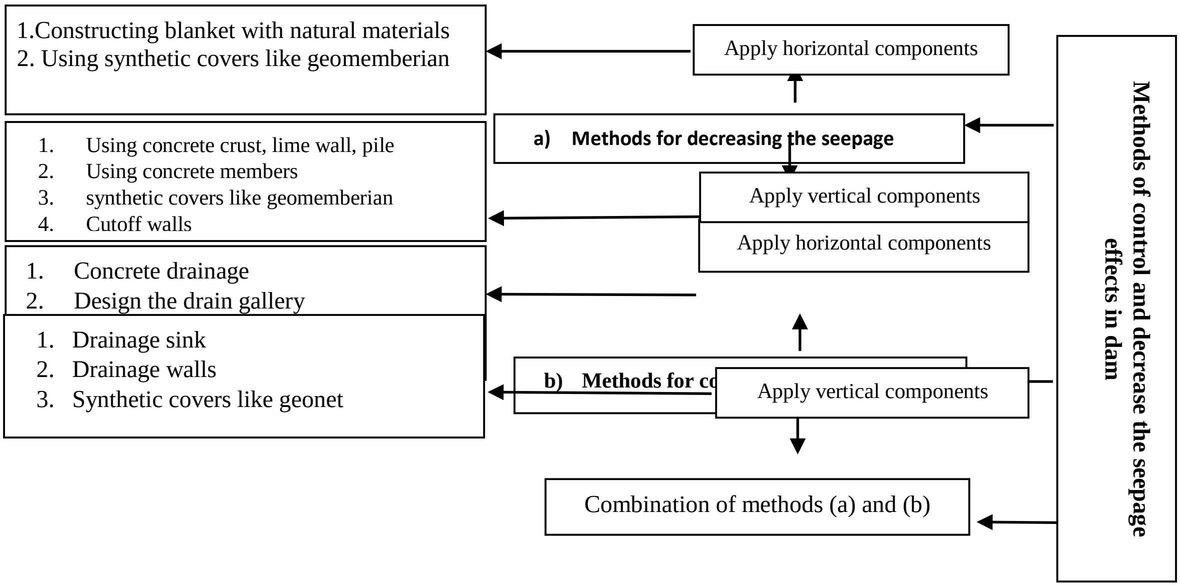

Figure 1. Methods of control and decrease the seepage effects in dam [5]

2.2. Introducing section of under study dam

In this study, the application of the mentioned methods for a section of a heterogeneous earth dam with represented dimensions in Figure 2 has evaluated. Specifications of used materials in foundation, shell, filter and core of the dam are presented in Table 1.

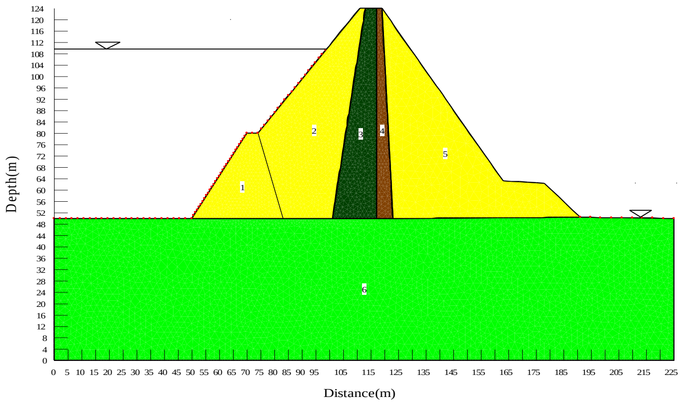

Figure 2. Section of under study dam

Table 1. Specifications of used materials in foundation, shell, filter and core of the dam

Region Number	Material	Saturated Hydraulic Conductivity, K sat (m/s)
1,2,5	Shell	0.001
3	Filter	0.0001
4	Core	0.0000001
6	Foundation	0.00001

At first, water flow and exit gradient in lack of cutoff wall, clay blanket and synthetic covers were calculated using finite element method. Then, mentioned parameters were computed in different models such as the existence of a clay blanket with different length, cutoff wall in different position along the foundation and synthetic covers in different forms and combination of these components. It is not worthy to mention that we estimated above parameters in all modes in a condition that upstream water head and downstream water head was assumed 50 meters. Water flow and exit gradient in all modes were computed using finite element with seep/w software (type of GeoStudio 2004 software package).

2.3. BASIC EQUATIONS USED IN THE ANALYSIS

To find equation of water current in a porous environment, a small and saturated element with dimension of, *dx* and *dy* has considered and current speed along x and y axes are v_x and v_y, respectively. By ignoring changes in volume of an element due different factors like changes in effective tension and writing mass conservative rule, net value of input current into the element is [6]:

$$q_{net} = q_x + q_y + Q.dA = \left(-\frac{\partial v_x}{\partial x} - \frac{\partial v_y}{\partial y} + Q \right).dA \tag{1}$$

where q is net current in both sides and Q is produced water flow in element area. Using relations between rate of water mass changes in solid element and rate of changes in volume water content of solid element and mass conservation rule, we have:

$$-\frac{\partial v_x}{\partial x} - \frac{\partial v_y}{\partial y} + Q = \frac{d\theta}{dt} \tag{2}$$

Equation 2 is known as a differential equation of current continuity. By combination of Darsi relation and differential equation of current continuity, permeation differential equation is obtained:

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial h}{\partial y} \right) + Q = \frac{d\theta}{dt} \tag{3}$$

By enter special store confident in equation 3, we would have:

$$\overline{\nabla}.\left(C.\nabla h \right) + Q = m_w.\gamma_w.\frac{dh}{dt} \tag{4}$$

Equation 2 is Laplace differential equation, in which $\overline{\nabla} = \left\{ \frac{\partial}{\partial x}, \frac{\partial}{\partial y} \right\}$ and C is permeability matrix. As in stable currents, value of h doesn't change with time, permeation equation is simplified to:

$$\overline{\nabla}.\left(C.\nabla h \right) + Q = 0 \tag{5}$$

Finite element method is one of the strongest methods in numeral solving differential equations, such as permeation equation which has found many applications in engineering. In this method, problem area has been divided into limited parts and by assuming an approximate solution for differential equation and minimizing difference between approximate and real solution of the problem (minimizing system energy), the differential equation is transformed into integral form and unknown values in special positions which called nodes are obtained. Using interpolation functions or shape functions and insert in derivative of Laplace differential equation and applying a border condition, the matrix form of permeation equation would obtain:

$$[K]\{H\}+[M]\{H\}_t=\{Q\} \quad (6)$$

Equation 6 is the general form of the Laplace equation in finite element method. As in steady analysis $\{H\}_t=0$, Equation 6 is simplified to:

$$[K]\{H\}=\{Q\} \quad (7)$$

Above matrices are computed using numerical integration methods. To calculate above matrices and applying border conditions and solving equation systems, value of water head considering the location of network nodes is obtained.

3. RESULTS AND DISCUSSIONS

3.1. STUDYING THE EFFECT OF BLANKETS AND SYNTHETIC COVERS ON SEEPAGE AND EXIT GRADIENT

In order to study the effect of blankets and synthetic covers on seepage water flow and exit gradient, a blanket with four different lengths of 35, 25, 15 and 45 meters have considered in upstream. Blanket materials, clay and its hydraulic conductivity in horizontal and vertical directions equal to $2.5*10^{-8}$ m/s have considered. Upstream water head in all modes is assumed 110 meters and values of water flow from foundation and body and exit gradient in both horizontal and vertical directions have computed. It has followed that:

- By increasing the length of the blanket, seepage is decreased, insignificantly, such that when there is a blanket with 45 meters length, water flow from foundation and body have decreased 0.08 and 2 %, respectively. Thus, total seepage has decreased 0.3% than basic condition. The reason could be found in less share of seepage flow from the foundation than from the body.
- Increase in blanket length could cause an increase in exit gradient in both horizontal and vertical directions. However, increasing in the exit gradient in horizontal direction is sharper than in the vertical direction. So, a blanket with 45 meters length cause approximately 23.5% and 7 % increase the exit gradient in horizontal and vertical directions, approximately (Figure 3). In total, exit gradient has increased 3%. However, by increasing the blanket length and as a result increase in length of current lines from foundation, it is expected that exit gradient decreased. Although, by decreasing in the permeability of foundation, congestion of speed vectors in the body has increased and finally causes increases in exit gradient.

Thus, if only there is a blanket in upstream for an earth dam with desired section, it is not an appropriate strategy for decreasing seepage and risk of piping in downstream.

3.2. STUDYING THE EFFECT OF SYNTHETIC COVERS ON CHANGES IN WATER FLOW AND EXIT GRADIENT

a) horizontal synthetic cover: for this purpose, covers made of geo-synthetic with length of 35, 25, 15 and 45 meters in upstream of foundation have considered. Water head in upstream in all modes is constant and equal to 110 meters and values of seepage water flow and exit gradient in each mode have determined. Coefficient of cover permeability in horizontal and vertical directions is equal and has assumed 10^{-14} m/s. Figures 2 and 3 show that,

- Horizontal synthetic covers cause an insignificant decrease in seepage from body and foundation. As a result, horizontal synthetic cover with 45 meters length causes approximately 0.42% and 0.35% decrease in seepage water flow from foundation and body, respectively, than basic condition. So, total seepage water flow in comparison with basic condition would decreased 0.36% (Figure 2).
- Horizontal synthetic cover has insignificant effect on decrease in exit gradient in comparing with basic condition. For example, in situation that there is a horizontal synthetic cover with 45 meters length, exit gradient in both horizontal and vertical directions are decreased 0.35% and 0.45%, respectively, in compartion with basic condition.

Thus we could conclude that only existence of a horizontal synthetic cover couldn't have significant influence on the decrease in exit gradient and seepage water flow at the toe. Although it is more effective than condition with a blanket cover (Figure 3).

b) Complete synthetic cover: complete synthetic cover is a combination of inclined cover in upstream and horizontal cover. Dimensions of horizontal cover is considered 35, 25, 15 and 45 meters, and content of water head in upstream in all modes is constant and equals to 110 meters. Values of seepage water flow and exit gradient are computed in each case and results are presented in diagrams.

- Complete synthetic cover has a significant effect on decrease seepage water flow from foundation and body, and by increasing the length of horizontal synthetic cover, it decreased more. So, in condition with complete synthetic cover with horizontal 45 meters length parts, seepage water flow from foundation and body would decrease 62.2% and 68.2%, respectively. In total, seepage water flow in comparison with the basic condition decreases 67.5% (Figure 2).
- Complete synthetic cover is suitable strategy for decrease exit gradient and creating a piping phenomenon at the toe of the dam.

3.3. STUDYING THE EFFECT OF CUTOFF WALL POSITION ON CHANGES IN SEEPAGE FLOW AND EXIT GRADIENT

For this purpose, cutoff wall in positions of 50 (upstream), 70, 90, 110, 130, 150, 170 and 190 (downstream) meters was moved.

Materials of the cutoff wall include cement grout. Coefficient of permeability of materials in horizontal and vertical directions is considered constant and equal to 10^{-7} m/s. Depth of cutoff wall and upstream water head in all positions is constant and equal to 25 and 110 meters, respectively. Results of computing seepage water flow and exit gradient in all modes have presented in Figures 4 and 5.

- Water flow changes under the effect of cutoff wall position could be grouped into 3 parts (Figure 4):

1- Content of seepage would decrease from the upstream to middle of foundation, intangibility.

2- It is observed from the figure that seepage water flow from foundation and body when approaches to middle of the foundation, suddenly decreased. Intensity of seepage decrease while passing from the body section of the dam is more that the decrease in seepage while passing from the foundation; such that in position with 110 meters height, content of seepage water flow from body and foundation would decreased 18.8 and 43.4 %, respectively, and the content of total seepage water flow in comparison with basic condition would decreased 40.4%.

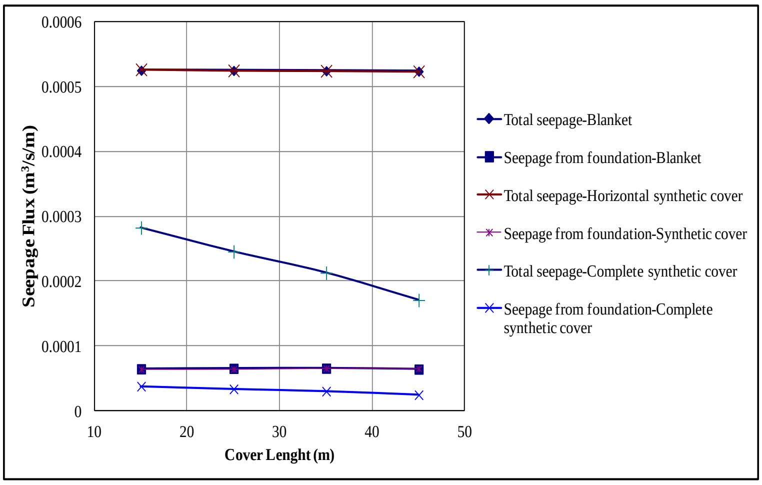

Figure 2. Effect of lengths of blanket, horizontal synthetic and complete on seepage flow

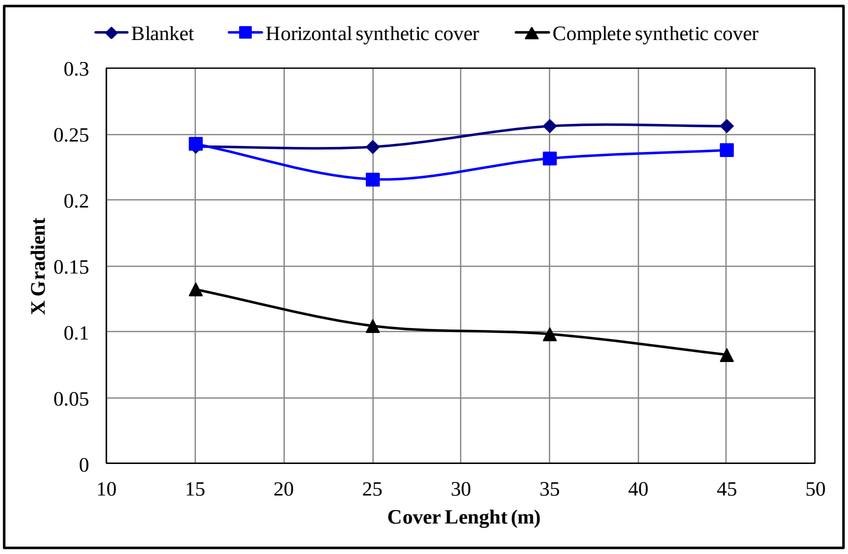

Figure 3. Effect of lengths of blanket, horizontal synthetic and complete on exit gradient

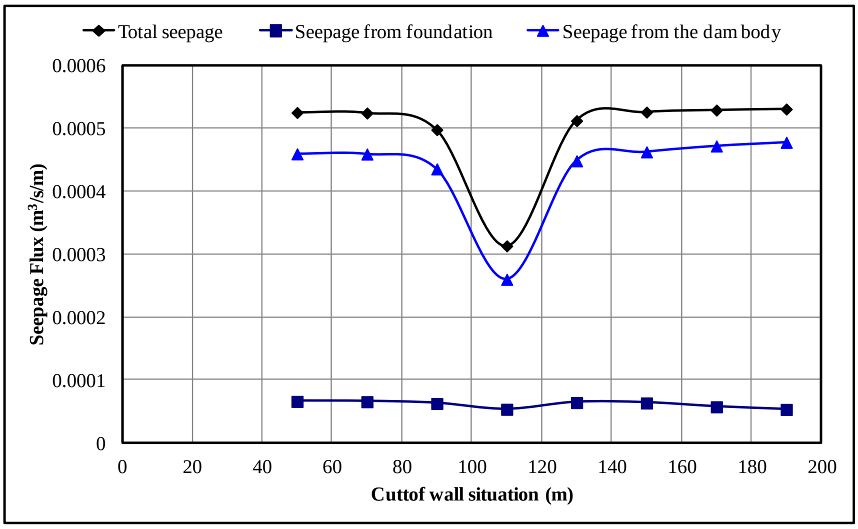

Figure 4. Effect of cutoff wall position on changes in seepage water flow and exit gradient

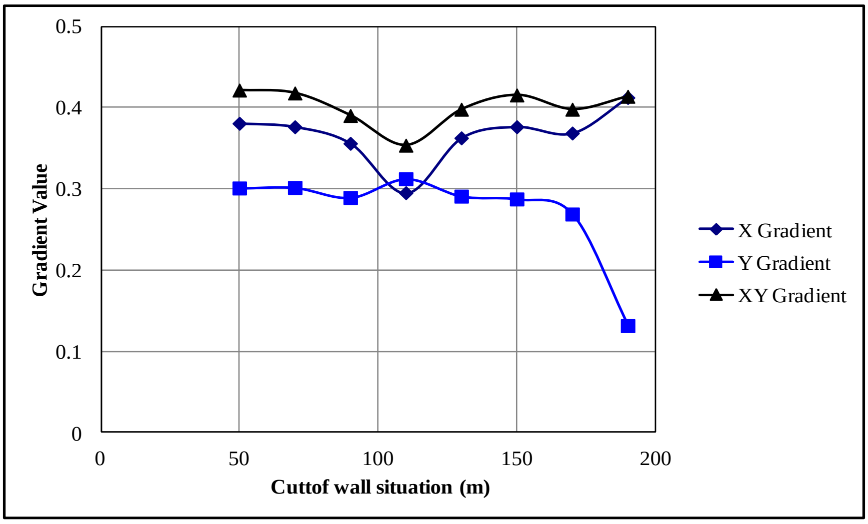

Figure 5. Effect of cutoff wall position on changes in vertical or horizontal exit gradient

3.4. STUDYING THE COMBINED EFFECT OF CUTOFF WALL AND BLANKET ON CHANGES IN SEEPAGE WATER FLOW AND EXIT GRADIENT

It has explained in section 3 that by approaching cutoff wall to middle of the foundation, content of seepage water flow and exit gradient would decrease, suddenly.
Purpose of this section is compartion the influence of blanket and cutoff wall, simultaneously, in condition that only cutoff wall is available. For this, cutoff wall moves in above mentioned positions. In all models, upstream water head and length of blanket have assumed 110 and 20 meters, respectively. Depth of cutoff wall was also assumed 25 meters.

At first section has discussed that blanket has insignificant effect on changes in seepage water flow. So, it is expected that the combination of blanket and cutoff wall for mentioned section has no influence on decrease in seepage water flow in compare with situation with only cutoff wall. It is presented in Figure 6.

- In section 3 it has presented that best position for placement of cutoff wall in order to control piping phenomenon is near middle of the foundation. However, blanket has no effect on decrease in seepage water flow than not using blanket. Although, it is observed from Figure 7 that the blanket along with cutoff wall in optimal position causes 27.6% decrease in horizontal exit gradient, 34.4% decrease in vertical exit gradient and totally 30.1% decrease in whole exit gradient in compare with lack of blanket situation.

3.5. STUDYING THE COMBINED EFFECT OF CUTOFF WALL AND SYNTHETIC COVER ON CHANGES IN SEEPAGE WATER FLOW AND EXIT GRADIENT

For this purpose, complete synthetic cover is considered with horizontal cover length of 25 meters and upstream water head of 110 meters. Cutoff wall moved in above mentioned positions. Depth of middle cutoff wall in all modes has assumed 25 meters.

- Synthetic cover with cutoff wall causes decrease in seepage water flow. When cutoff wall is placed in optimal position of 110 meters, synthetic cover causes 38.5% decrease in total seepage water flow, 36.2% decrease in seepage from foundation and 39% decrease in body seepage in compare with lack of synthetic cover (Figure 6).
- Synthetic cover with cutoff wall causes decrease in exit gradient. Intensity of this decrease is more than decrease in seepage water flow, such that while placing cutoff wall in position of 110 meters, causes 55% decrease in horizontal exit gradient, 59.5% decrease in vertical exit gradient and 56.7% decrease in exit gradient in plate (Figure 7).

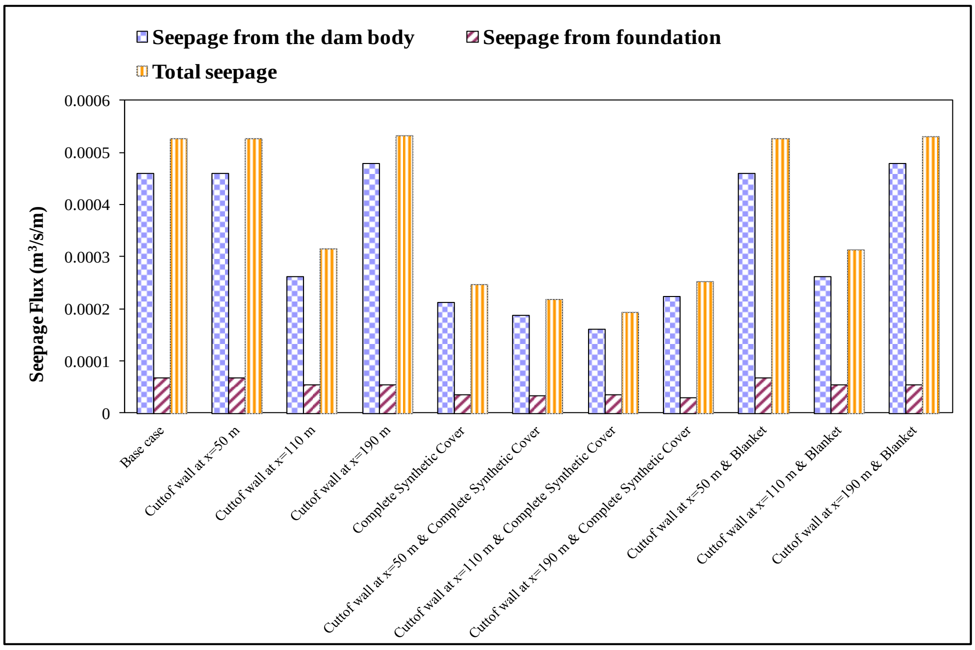

Figure 6. Comparison the combined effect of blanket, cutoff wall and synthetic cover on seepage from body and foundation

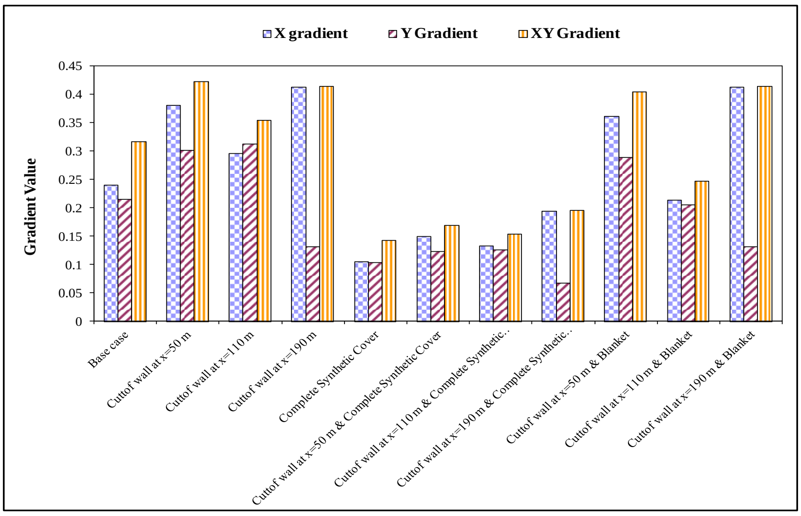

Figure 7. Comparison the combined effect of blanket, cutoff wall and synthetic cover on content of exit gradient

4. CONCLUSIONS

1) Only applying blanket in upstream for earth dam with proper section couldn't have significant influence on the decrease in seepage water flow and risks of piping in downstream.
2) Best position for cutoff wall to decrease in seepage water flow and risks of piping in downstream is middle of the foundation.
3) By ignoring economical, executive and local facilities, for mentioned earth dam, the best method for control seepage and exit gradient is applying cutoff wall in middle of the foundation along with complete synthetic cover.
4) Movement of cutoff wall from middle into downstream cause insignificant increase in seepage water flow from foundation and body. Moreover, cutoff wall in downstream in comparison with upstream cause 19.4%, 4% increase in seepage from the body and totally 1% increase in whole seepage.
5) Form of exit gradient changes under the effect of cutoff wall position is similar to form of seepage water flow changes. In this condition, moving cutoff wall toward the middle of foundation causes intense decrease in exit gradient.
6) Minimum of horizontal exit gradient and 2-dimensional exit gradient has obtained in position of 110 meters with cutoff wall. In this situation, horizontal exit gradient and 2-dimensional exit gradient have decreased 23.4% and 12% than basic condition, respectively.
7) Cutoff wall in downstream in comparison with the cutoff wall in upstream causes 5.6% increase in horizontal exit gradient, a 5.6% decrease in vertical exit gradient and 1.8% decrease in vertical exit gradient.

Thus, we could say that the best position for cutoff wall to decrease in seepage water flow and risks of piping in downstream is middle of the foundation.

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