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Sensitivity study of different parameters affecting design of the clay blanket in small earthen dams

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Abstract

Dams are structures that retain water for human services. Dams may be earthen, concrete, timber, steel or masonry made. On the basis of size, they may be small, medium and large. The main purpose of a dam is to divert the flow of water for the intended use. Flow of water cannot be stopped permanently even by the best dam ever made. Water may seep from dam body, abutments or the foundation bed below the body of the dam. To control seepage from the foundation bed, certain available methods like cutoff trench, cutoff walls, diaphragms, grout curtains, sheet pile walls and upstream impervious blankets are used. Upstream impervious blankets are considered more economical compared with the other methods mentioned above. The key parameters playing role in blanket efficiency are length of blanket, thickness of blanket, clay core width of the dam, foundation bed depth up to impervious zone, reservoir head, permeability of blanket material and permeability of bed material. This study is focused on the effect of these parameters in seepage control. Seep/W, a finite element method based software is used to model all the mentioned parameters within the individually selected ranges. The results based on the software analysis show that when the length of blanket is gradually increased, the seepage quantity reduces gradually until a specific length where the effect of further increase in length become meaningless. Same is the case for thickness of blanket but in this case the effect is comparatively less. In case of dam's clay core width, before a certain value, it has almost no effect on seepage reduction. Beyond that value, the seepage starts reducing. When the permeable stratum below the dam body is of more depth, the net seepage is more. The permeability of blanket material and foundation material has same pattern of effect on the seepage. In both the cases, when the materials are more pervious, more seepage will be expected from the dam.

Keywords: Earthen dam; Seepage; Blanket; Permeability; SEEP/W.

1. Clay blanket in small earthen dams

Earthen dams are water retaining structures made up of earthen material like clays and rocks. They are the most economic dams on the basis of material. They may be Small, Medium or Large on the basis of size of dams. USBR (United Stated Bureau of Reclamation) defined small dam as one having maximum height < 15 m (50 ft.).
Small earthen embankment dams are used worldwide. They may be homogenous, zoned embankments or Earth cored rock filled Dams (ECRDs.).

Dams are important engineering structures. The failure of a dam would mean the loss of many lives as well as economy. Table 1 shows the failures of dams occurred in the world along with their causes. About 30% of the dams failures occurred in the world were due to foundation defects.

Table 1. Causes of failure of dams in the world (Thomas, 1976).

S.No	Failure Cause	% of Failures
1	Over topping	34
2	Foundation Defects	30
3	Piping and seepage	20
4	Conduit and valves	10
5	Other	6

The foundation problems may be Sliding stability of foundation material, dissolution of foundation material, liquefaction, differential settlement/ deformation of foundation material and/or uncontrolled foundation seepage.

Seepage control is of prime importance in case of small dams because these dams are constructed on streams of low discharge and smaller catchment areas where the availability of water is minimal. Seepage may occur from dam body, abutments or foundation bed (Asawa, 2006). To control seepage from the dam body, the thickness of clay core must be enough to lower the piezometric line to a safe level like downstream horizontal drain or toe drain where the pressure is atmospheric. Seepage from the abutments can be controlled using available methods like grouting and escarpment if the problem exists.

The streams on which small dams are built, most often have bed rock at a higher depth. The foundation bed over there is of alluvial material of pervious nature. In such case the control of seepage from alluvial bed is of prime importance. If the bed rock is at shallow depth, a cut off trench/wall as in Figure 1a is the best solution (Novak et al., 2007). Grouted cutoffs and diaphragm cutoff walls as in Figure 2b and Figure 3c are other solutions to the problem. For the case when rock is at higher depth, upstream impervious blanket (Fig. 3d) is the best choice (ICOLD, 2011). In all afore mentioned methods, the basic technique is to increase the seepage path. In the last mentioned alternative, clay is used as a construction material for this purpose, due to its economy and availability.

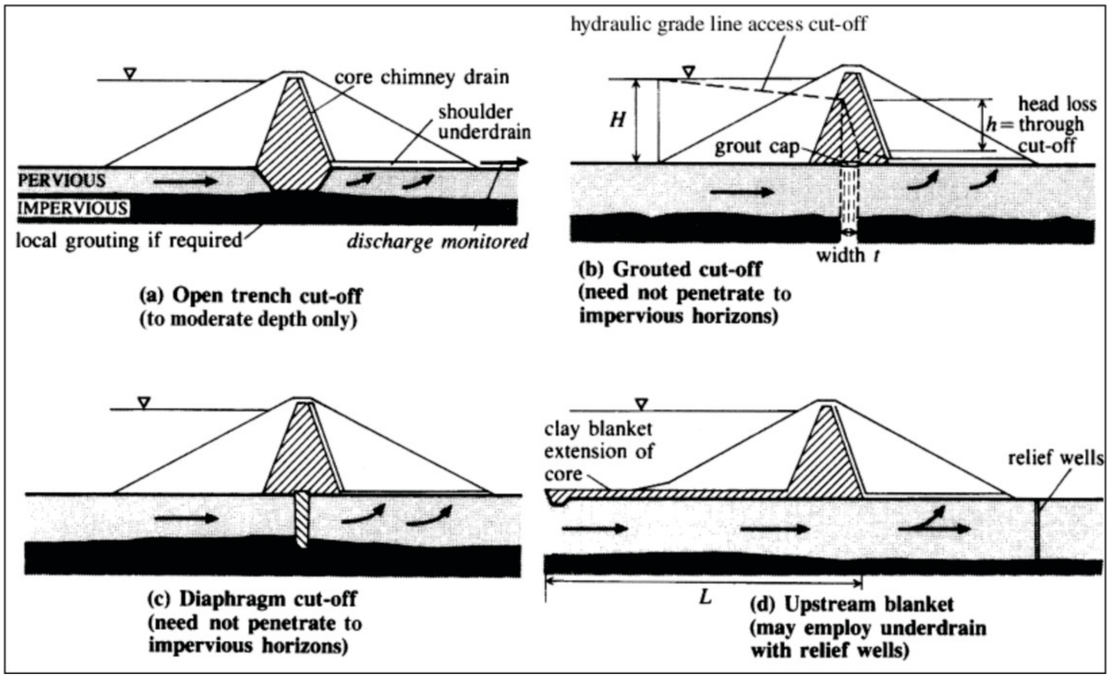

Fig. 1. Foundation Seepage Control methods (ICOLD).

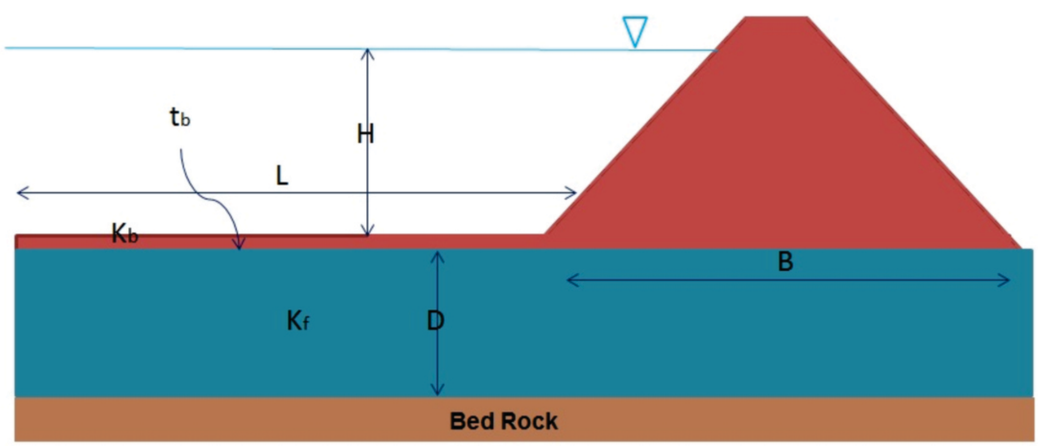

Fig. 2. Influencing parameters in Blanket design.

In the design of upstream clay blanket, length (L) extending to the upstream within the reservoir is the key factor. Other factors like permeability of blanket material (Kb), permeability of bed material (Kf), reservoir head (H), base width of the dam (B) and thickness of blanket (tb) are also major influencing parameters in the blanket design (Goharnejad et al, 2010). These parameters are depicted in Figure 2.

Clay blanket is an impervious layer at the upstream of a dam to control the seepage from the foundation bed. Seepage of water in the foundation of dams is an important subject in earthen dams (Biswas, 2005). Replacing the top layer of a river bed of higher permeability with a lower permeability material is the most economical way of controlling the seepage through foundation. This method along with drainages provision is used for long years (Dorota and Allen, 2005). In the world one of the largest clay blankets is provided in Tarbela Dam in Pakistan. It is 140m high dam with 1400m long blanket (World Commission on Dams, 2000).

Uginchus and Roboty discovered the differential equation of seepage in dam blankets in 1934 and resolved it for limited and unlimited lengths of blankets (Uginchus, 1935). Bennett achieved this equation by another method and described it in his paper in 1946 (Bennett, 1946). Bennett showed calculation of blanket for limited and unlimited length and gave relations for that. He achieved an important equation (1) for optimized clay blanket length calculation.

$$\frac{d^2}{dx^2} = a^2 h \qquad (1)$$

Where

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

h = head difference
Kb = Coefficient of permeability of Blanket material
Zb = Thickness of Blanket
Kf = Coefficient of permeability of foundation bed
Zf = Thickness of foundation bed

Equation 1 is solved for unlimited blanket length, it gives

$$X_r = \frac{1}{a} = \sqrt{\frac{Z_b\, K_f Z_f}{K_b}} \qquad (2)$$

For limited length of clay blanket, it gives equation 3.

$$X_r = \frac{0.82}{a} = 0.82\ x \sqrt{\frac{Z_b\, K_f Z_f}{K_b}} \qquad (3)$$

It means that the optimum length of clay blanket is 82% of unlimited length.

Raghad Samir developed charts for clay blanket design for homogenous dams (Mahmood, 2012). These charts based on Bennett's approach were developed in Visual basics. The length of blankets can be determined by using the developed charts relating the length of blanket, parameter a, reservoir head and base width of dam for uniform thick blankets. This study states that the length is directly proportional to head, base width, blanket thickness, foundation permeability and foundation thickness. The length is inversely proportional to coefficient of permeability of blanket material. These charts are limited to homogenous dams only.

Goharnejad compared the results of Bennett's method with his model study in Seep/W for Farim Sahra dam in Iran (Goharnejad et al, 2010). This study reveals that the seepage calculated by Bennett's method is less than that calculated by Seep/W. Thickness of blanket has important role in Seep/W model as compared with the Bennett's method but in overall, it has less role in seepage control compared with the length. Therefore dealing with length rather than thickness is important.

Before the development in computer area, all analytical works were carried out using time consuming conventional manual methods in which there were more chances of mistakes. One of such procedures was the method of flow nets for seepage analysis and estimation of net seepage quantities. After development in computer technology sector, it became easier for scientists and engineers to analyze such problems which were difficult due to limitations of manual procedures. Computer softwares such as SVFlux 2D / 3D, midasGTS, SEEP2D, SEEP3D, FLAC, Plaxis Professional and SEEP/W are widely used in the field of Civil/Geotechnical engineering. Amongst these, SEEP/W is widely used for seepage analysis.

Seep/W is a package of Geoslope International. It is finite element method based software used for seepage analysis (GEO-SLOPE International Ltd) (Seepage Modeling with SEEP/W, 2007). Geotechnical engineers use SEEP/W for finding seepage/leakage through the foundations of hydraulic structures such as weirs/dams. It is also used for analysis of ground water flow conditions. It can handle both the saturated and unsaturated flow conditions. In this paper, the various design parameters of dam blankets are modeled in Seep/W software. Each parameter is studied and its effect on the design of overall blanket is elaborated.

2. Research significance

In this study, the various parameters that are affecting the design of dam's blankets in small earthen dams are modeled in Seep/W. The role of each of these parameters in seepage control is discussed on the basis of seepage amount from the Seep/W model.

3. Analysis program

To study the sensitivity of each parameter that is affecting the design of blanket, three different types of analysis were prepared. The purpose of doing the three mentioned analysis was to understand the effect of each parameter in more detail and to cover the complete range of each parameter. Table 2 presents the details of these analyses.

In maximum analysis, all the variables are selected between their ranges in such a way that the overall resulted seepage will be maximum. Like selecting lesser value of length, thickness and width and highest value within the range for foundation depth, reservoir head and coefficient of permeability of blanket as well as foundation materials. Similar is the case for Minimum analysis in which maximum values within the range are selected for those having minimum value in the previous set (Maximum Analysis) and vice versa. Average values are selected for the Average analysis in this study.

To study the entire set of parameters in a single model, a model as presented in Figure 3, was developed in Seep/W. This model is flexible enough to model 4 numbers of lengths of blanket, 5 blanket thicknesses, 5 clay core widths of dam and 5 foundation bed depths without need of changes in basic model. In spite of these, it can take a number of reservoir heads and coefficient of permeability for both the foundation, core and blanket material.

This model is able to take all the variables used in this study. The details of these variables are given in Table 3.

Table 2. Parameters details in three types of analysis.

Parameter	Value used in Analysis Type		
	Maximum	Average	Minimum
Length	0	100	200
Thickness	0.5	1.25	2
Width	3	6.5	10
Depth	20	12.5	5
Head	18	11	4
K_f	1	0.001	0.000001
K_b	1.00E-07	5.005E-08	1.00E-10

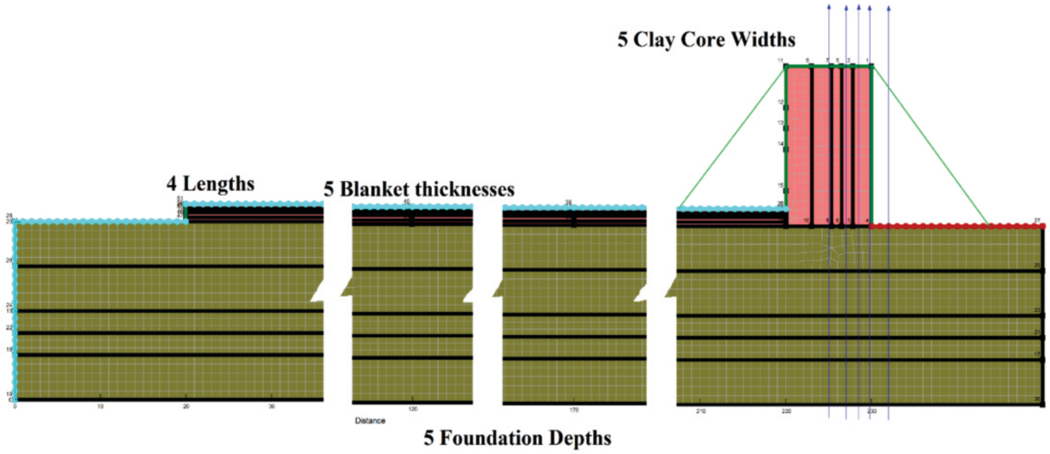

Fig. 3. Basic analysis model for Sensitivity study of parameters.

Table 3. Parameters Values.

Parameters	Values				
Length of Blanket (m)	0	50	100	200	
Thickness of Blanket (m)	0.5	1	1.25	1.5	2
Width of Core (m)	3	5.33	6.5	7.67	10
Depth of foundation Bed (m)	5	10	12.5	15	20
Upstream Reservoir Head (m)	4	8.67	11	13.33	18
Permeability of Foundation K_f (m/sec)	0.000001	0.0001	0.001	0.01	1
Permeability of Blanket K_b (m/sec)	1.00E-10	3.34E-08	5.01E-08	6.67E-08	1.00E-07

4. Results and discussions

Analyses were done in Seep/W software and the results are discussed in the following.

4.1. Length of blanket

The three types of analysis on a single graph (Figure 4a) indicate that the overall effect of Length is similar within the specified range. All the three curves follow the same pattern as clear from the Figure 4(a). In Figure 4(b), the reduction in seepage quantity is plotted against length of blanket for average type of analysis. It indicates that initially the increase in length of blanket has greater effect on seepage control. After attaining about 30% of the total length, the effect becomes less and the curve gradually becomes parallel to the X-axis. After this point, the graph indicates that increase in length has no more considerable roles in seepage control.

4.2. Thickness of blanket

The three specified types of analyses are shown in a single graph in Figure 5(a). The overall effect of thickness parameter is almost similar within the selected range. Curve for maximum analysis has same value because in this analysis, the length of blanket was taken 0m and thus the thickness was no more of importance. As a result the net seepage was same for all values in this analysis (Table 4). The remaining two curves follow almost the same pattern as clear from Figure 5(a). Figure 5(b) is the presentation of average analysis on a graph with thickness plotted against the percentage of seepage reduction. It suggests that at the start the seepage quantity decreases rapidly. After adding some more thickness to the model, the decrease in quantity of seepage becomes smaller and the curve gets mild.

4.3. Width of dam core

The maximum, average and minimum types of analysis are plotted on a single graph and are presented in Figure 6(a). It shows that the overall effect of width parameter is almost similar within the specified range. Curve for average analysis is shown in Figure 6(b) which is plot of core width Vs seepage reduction in percentage. From Figure 6 it is evident that up to certain width, there is not enough reduction in seepage. After some specific width, the seepage starts reducing in a rapid manner. It indicated that there should be a minimum value for dam core width, less than which there will not be enough reduction in seepage quantity.

4.4. Depth of foundation bed

Figure 7(a) is the plot of seepage Vs foundation bed depth for the three types of analysis. It indicates that the overall effect of foundation depth parameter is similar within the selected range. All the three curves follow the same pattern as clear from Figure 7(a). Figure 7(b) shows plot of average analysis on a graph. It shows that when the depth of impervious bed is increasing, the seepage quantity increases as a result.

4.5. Reservoir Head

The three types of analysis are shown in a single graph in Figure 8(a). This graph indicates that the overall effect of Head is almost similar within the specified range. All the three curves follow the same pattern as clear from Figure 8(a). Figure 8(b) is the presentation of average analysis on a graph. It suggests that by increasing the reservoir head, the seepage will be increased.

4.6. Permeability of foundation

Figure 9(a) shows the three types of analysis on a single plot. It is clear from Figure 9(a) that the overall effect of foundation material permeability shows similar pattern of effect within the specified range. All the three curves follow the same pattern. Figure 9(b) is the presentation of average analysis on a graph with respect to seepage reduction. It suggests that when the foundation material permeability increases, the seepage quantity also increases directly.

4.7. Permeability of blanket material

The three types of analysis i.e. maximum, average and minimum, are shown on a single graph in Figure 10(a). The plot of maximum analysis is a horizontal line because in this type of analysis, blanket length was taken as zero. Therefore the seepage quantity is same during the incremental analysis. The plot of average and minimum are different from each other. Curve for average analysis is mild while for minimum, it shows a prominent bend. In minimum analysis all the parameters are such selected to minimize the seepage, therefore the third curve is different. Figure 10(b) is the presentation of average analysis on a graph. It suggests that by increasing the blanket material permeability, the seepage increases.

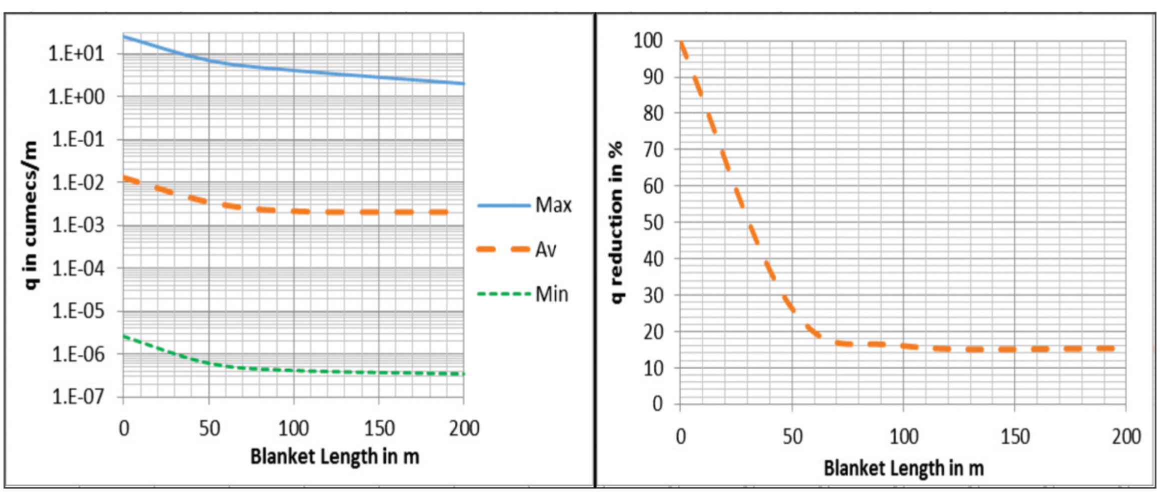

Fig. 4. Blanket Length Vs seepage (a) for three analysis types (b) Plot of Average analysis.

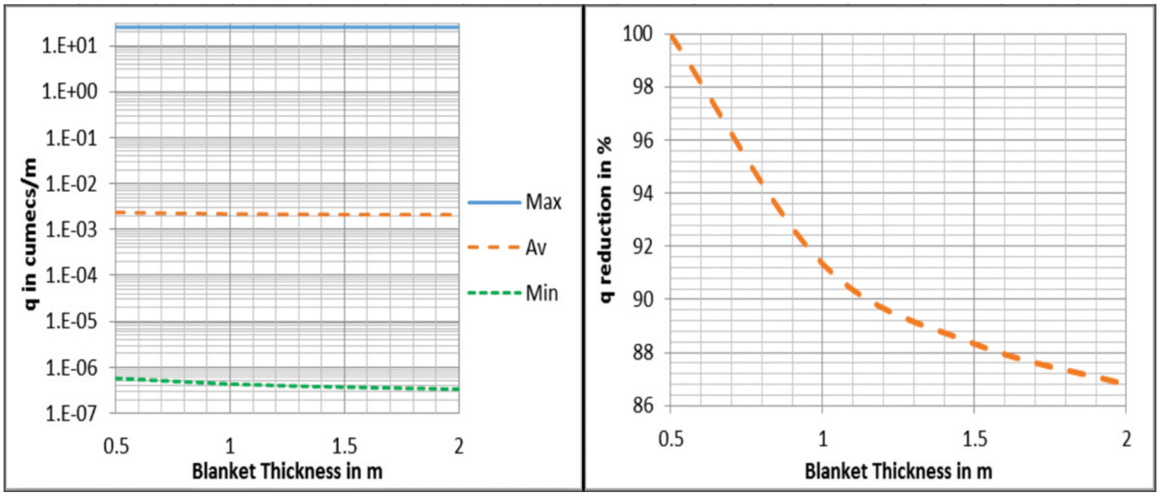

Fig. 5. Blanket Thickness Vs seepage quantity (a) for three analysis types (b) Plot of Average analysis.

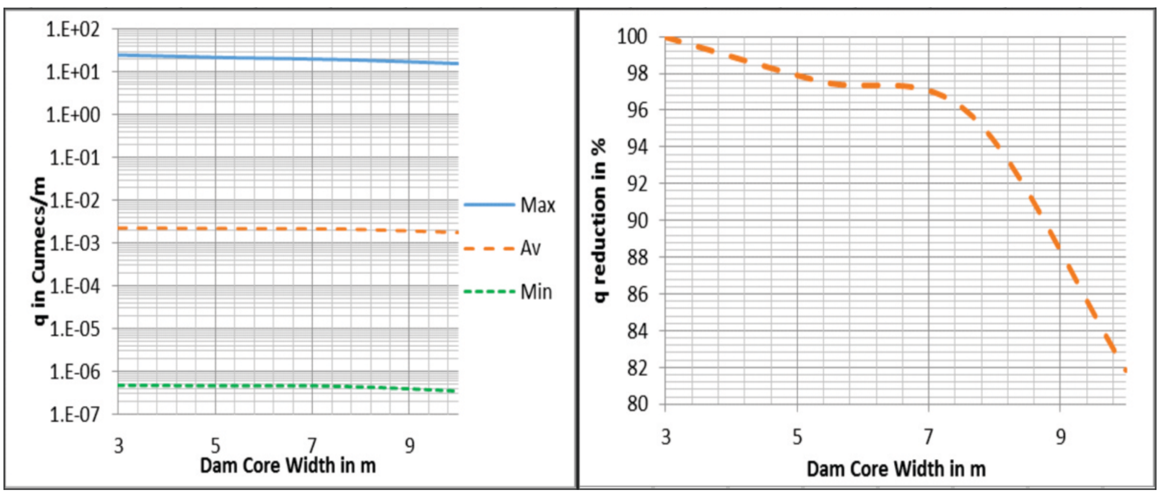

Fig. 6. Dam core Width Vs seepage quantity (a) for three analysis types (b) Plot of Average analysis.

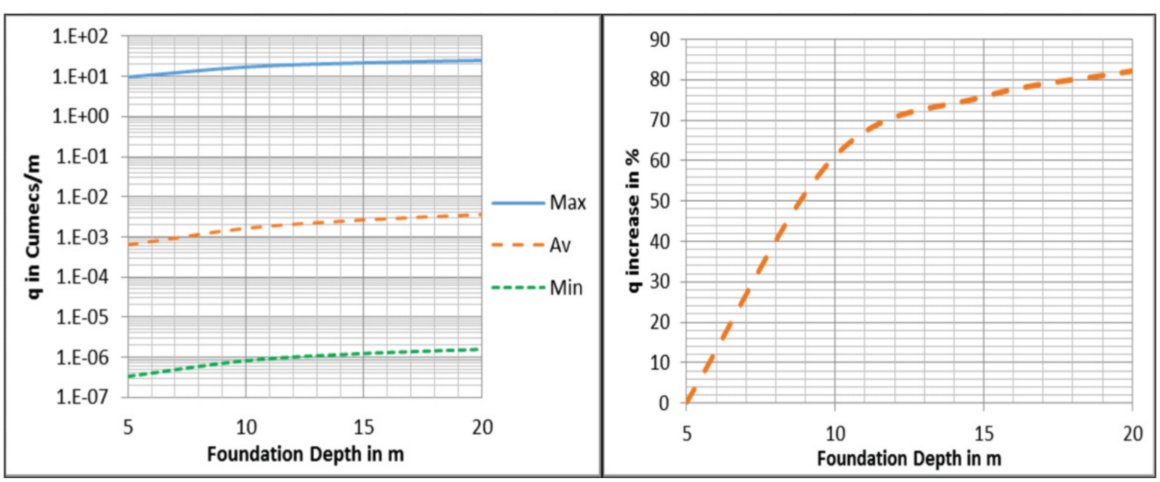

Fig. 7. Foundation bed depth Vs seepage quantity (a) for three analysis types (b) Plot of Average analysis.

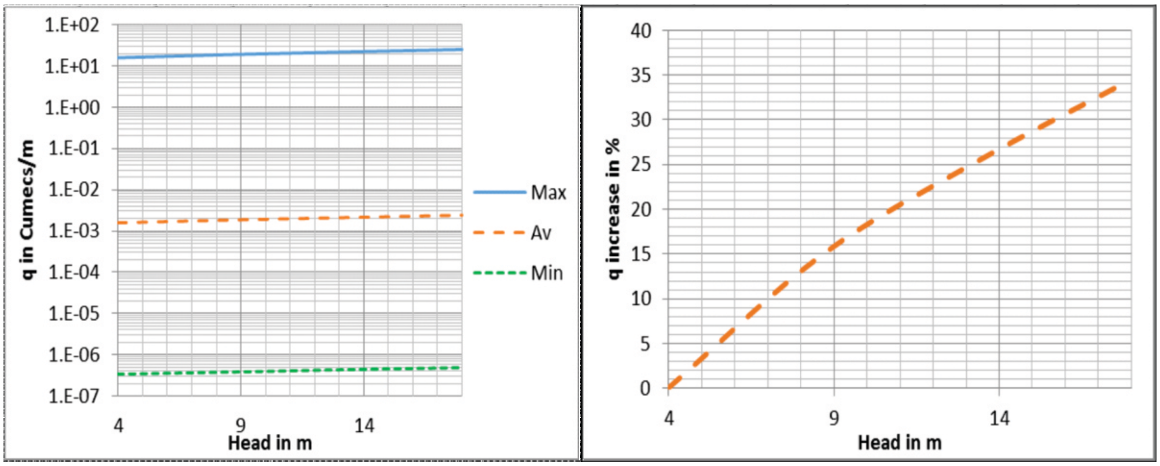

Fig. 8. Reservoir Head VS seepage quantity (a) for three analysis types (b) Plot of Average analysis.

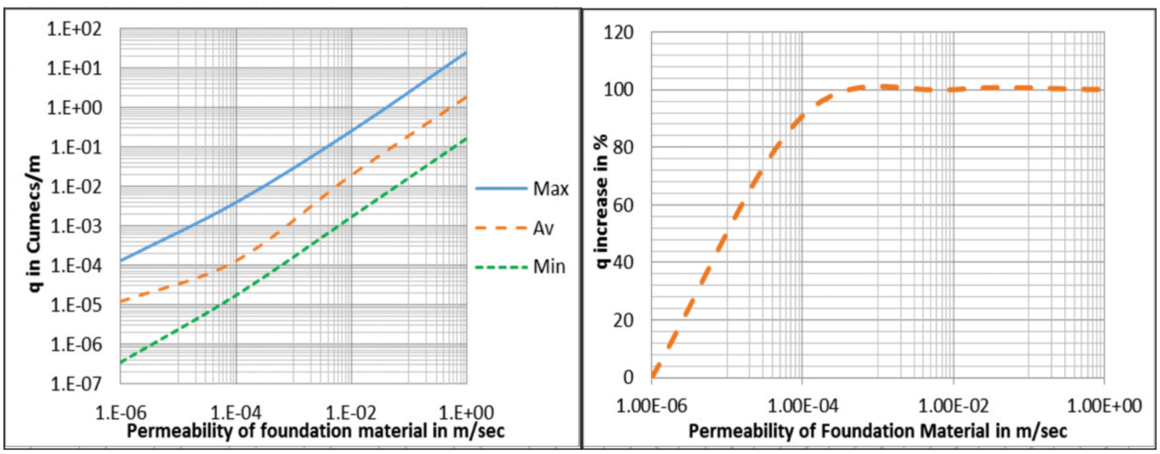

Fig. 9. Permeability of foundation material Vs seepage quantity (a) for three analysis types (b) Plot of Average analysis.

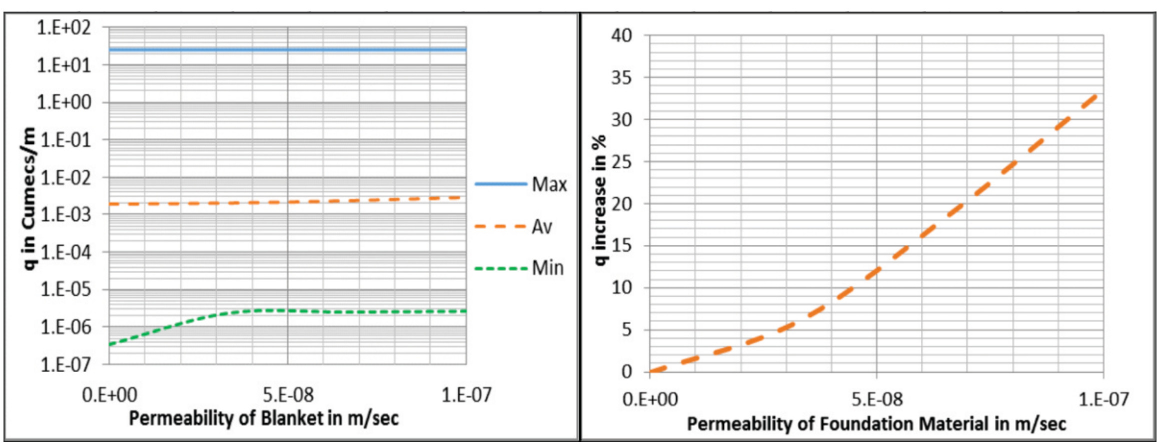

Fig. 10. Permeability of Blanket material Vs seepage quantity (a) for three analysis types (b) Plot of Average analysis.

5. Conclusions

From the results based on the software, it is evident that when the length of blanket is increased, the seepage reduces up to 84% of original at 30% of total length after which the effect of further increase in length becomes nominal. Same is the case for thickness of blanket but in this case the effect is comparatively less (seepage is reduced up to 13% of original). In case of dam's clay core width, up to certain value (7m), it has no considerable effect on seepage reduction (2% reduction). After reaching that specific value, the seepage reduction starts with increase in width of core (18% reduction at 10m). When the permeable stratum below the dam body is of more thickness, the net seepage also is more (up to 80% increase in 20m). Similar is the case for reservoir head. When there is more head, more seepage is expected (up to 37% increase in 18m). The change in the permeability of blanket material and foundation material has same pattern of effect on the design of blanket. In both cases, when the material is more pervious, more seepage will be expected from the dam.

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