Study of the Efficiency of Downstream Blanket in Heading-Up Structures

N. AboulAtta[1], G. Ezizah [2], N. Yousif[3] and D. Anas [4]

[1] Professor of Irrigation Design, Irrigation and Hydraulics Dept., Faculty of Engineering, Ain Shams University
[2] Associate Professor, Irrigation and Hydraulics Dept., Faculty of Engineering, Ain Shams University
[3] Associate Professor, Irrigation and Hydraulics Dept., Faculty of Engineering, Ain Shams University
[4] Assistant Lecturer, Irrigation and Hydraulics Dept., Faculty of Engineering, Ain Shams University

Abstract

In this research, an electrolytic tank is used to study the effect of using a perforated blanket downstream the aprons of heading-up structures on the safety against piping through making different scenarios for length of blanket, intensity of perforations and presence of cutoffs. The study lead to conclude that when a blanket is added downstream the apron of the heading up structure, it acts as if the apron is extended, the uplift head increases at the critical section because the blanket blocks partially the pores of the soil downstream the apron and changes the distribution of the uplift diagram under the apron, so it is needed to increase the perforation ratio of the blanket in order to dissipate the increase in the uplift head at the end of apron due to the addition of the blanket. The conclusions also include determining the optimum length and perforation ratio for the downstream blanket with and without cutoffs.

Key words: Electrolytic tank - Heading-up structures - Perforation ratio - Perforated blanket - Seepage

1. INTRODUCTION

Seepage of water occurs under the aprons of heading-up structures due to the difference between water levels at the upstream and downstream sides of the structure. Seepage is a very important parameter that should be carefully considered in the design of the aprons of heading-up structures as it may cause many problems like undermining and piping just downstream the apron.

Several authors discussed the hydraulic structures stability and seepage control Harr [3], Kashef [6], Leliavsky [8] and U.S. Army Corps of Engineers [11].

Perforated drainage blanket is used just downstream the aprons of heading-up structures to achieve security against piping. Perforations in the blanket are used to relieve some of the uplift pressure underneath it. Many researches were made to study the downstream blanket, they either studied the optimum length of downstream filter only or the optimum perforation ratio only or both using different methods.

Hathoot [4] used Schwartz- Christoffel transformation and seepage formula to study the seepage beneath a concrete dam with a downstream filter. He determined the optimum length of downstream filter. Hathoot et al. [5] used the theory of complex functions and Schwartz- Christoffel transformation to investigate the proper length of a downstream filter for a dam with an end sheet pile. Shehata and Abdel Khalek [9] used finite element method to study the effect of length, thickness, and permeability of the downstream filter on seepage phenomenon downstream a concrete dam with two end cutoffs. Shehata, A. K. [10] solved analytically the seepage problem under overflow spillway founded on complex foundations using fragment method.The spillway was furnished with downstream blanket and two end sheet piles to avoid the uplift and piping effects. The study led to a criterion for designing the blanket and investigating the optimal length of downstream blanket, also the effect of anisotropic soil foundation was indicated.

Zheng-yi Feng and Jonathan [12] employed the finite element program SEEP to analyze flow characteristics of an impervious dam with sheet pile on layered soil. El-Molla [2]used a computer program called SEEP-2D to investigated the flow pattern for 25 models representing aprons of hydraulic structures provided with a single cutoff of different depths and located at various positions with respect to their horizontal length. El-Molla [1] used an electrolytic tank to study the effect of perforation intensities of the blanket created just downstream the apron of control structures on the safety against piping at the critical section of permeable foundation. He kept the blanket length constant and changed only the perforation intensities. Mobasher [7] used an electrolytic tank to investigate models of aprons of irrigation structures provided with cutoffs. He investigated the role of the two faces of a single cutoff under an apron of a control structure, on modifying the hydraulic gradient under which seeping water is motivated.

2. OBJECTIVE OF THE STUDY

This research aims to study the effect of using a drainage blanket downstream the apron of a heading up structure on the exit gradient and the safety against piping by using analogies. The study also includes determining the optimum length and perforation ratio for the downstream blanket, and the effect of the presence of upstream and downstream cutoffs on the efficiency of the blanket.

3. THEORETICAL APPROACH

The variables involved in the problem are as follows: H = Head difference between upstream and downstream the apron, La = Total horizontal length of the apron, Lb = Total length of the blanket, T =Thickness of pervious stratum under the apron, d1= Depth of upstream cutoff from its point of intersection with the apron to its toe level, d2 = Depth of downstream cutoff from its point of intersection with the apron to its toe level, De = Depth of point e under the downstream bed, e = Any point located on the critical (exit) section along the whole considered thickness of pervious stratum (T), He = The piezometric head at point e, Rp = Perforation ratio of the blanket, ρ = Density of seeping water, g = Gravitational acceleration, k = Hydraulic conductivity of the homogeneous pervious stratum of thickness (T) under the apron.

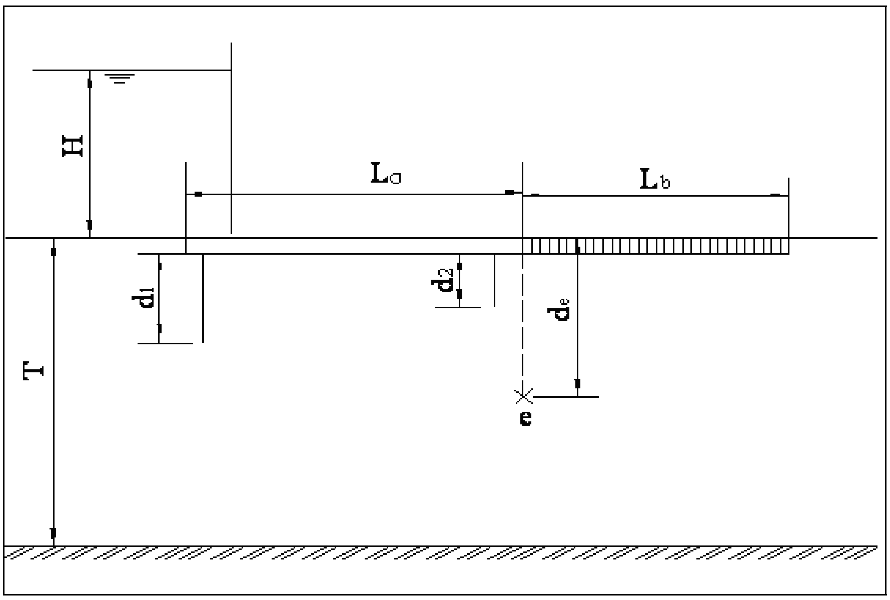

Figure 1: The variables involved in the problem

By using the dimensional analysis the general function representing the considered phenomenon can be written as follows

$$\Phi(H, L_a, L_{b,} T, d_e, H_e, d_1, d_2, R_p, \rho, g, k) = 0 \tag{1}$$

Applying Buckingham's π Theorem and taking Lb, ρ and g as the repeating variables (main magnitudes), the above terms may be arranged in the following dimensionless relationship:

$$\Phi(\frac{H}{L_b}, \frac{L_b}{L_a}, \frac{T}{L_b}, \frac{d_e}{L_b}, \frac{H_e}{L_b}, \frac{d_1}{L_b}, \frac{d_2}{L_b}, R_p, \frac{L_b g}{k^2}) = 0 \tag{2}$$

In the present study a homogeneous soil with a given hydraulic conductivity (k) is used, La is kept constant all over the experiments, thus the term (La g)/k2 reduces to a constant and the functional relationship reduces be:

$$\Phi(\frac{H_e}{H}, \frac{L_b}{L_a}, \frac{d_e}{T}, \frac{d_1}{T}, \frac{d_2}{T}, R_p) = 0 \tag{3}$$

The factor of safety against piping at any point (e) located on the critical section at a depth (de) from the downstream bed, can be represented by the piping index (Pe) which can be calculated as follows [1]:

$$P_e = (\frac{d_e}{T})/(\frac{H_e}{H}) \tag{4}$$

Where:
de/T = Relative depth of point (e), He/H = Average relative piezometric head at point (e).
Finally the functional relationship reduces to:

$$\Phi(\frac{L_b}{L_a}, \frac{d_e}{T}, \frac{d_1}{T}, \frac{d_2}{T}, R_p, P_e) = 0 \tag{5}$$

4. THE EXPERIMENTAL METHOD

In the present study, an electrolytic tank is used as a simple and easy to construct tool that gives reliable observations for simulating the flow of a fluid through a porous media.

The electric analogue is a well known method that uses the analogy between Ohm's law and Darcy's law to represent the analogy between the flow of electric current through an electrical conductor and the flow of a fluid through permeable soil [3].

The flow of an electric current can be expressed by Ohm's law as follows:

$$I = -\frac{1}{R}(\frac{dE}{ds}) \tag{6}$$

Where I is the current intensity per unit area (Amp/m2), R is the specific resistance (Ohm.m), 1/R is the electric conductivity, E is the electric potential (Volt), and dE/ds is the voltage gradient in the current direction.

While the flow of a fluid through a porous media is governed by Darcy's law as follows:

$$v = ki = -k(\frac{dh}{ds}) \tag{7}$$

Where v is the discharge velocity (m/s), k is the hydraulic conductivity (m/s), i is the hydraulic gradient in the flow direction, and s is the distance (m).

By using the electrolytic tank, the head at any point can be represented by the measured voltage at it and the equipotential lines are determined by points of equal voltage and stream lines are those perpendicular to them.

5. THE EXPERIMENTAL SETUP

The Experimental setup used in the study consists of the electrolytic tank shown in the following figures:

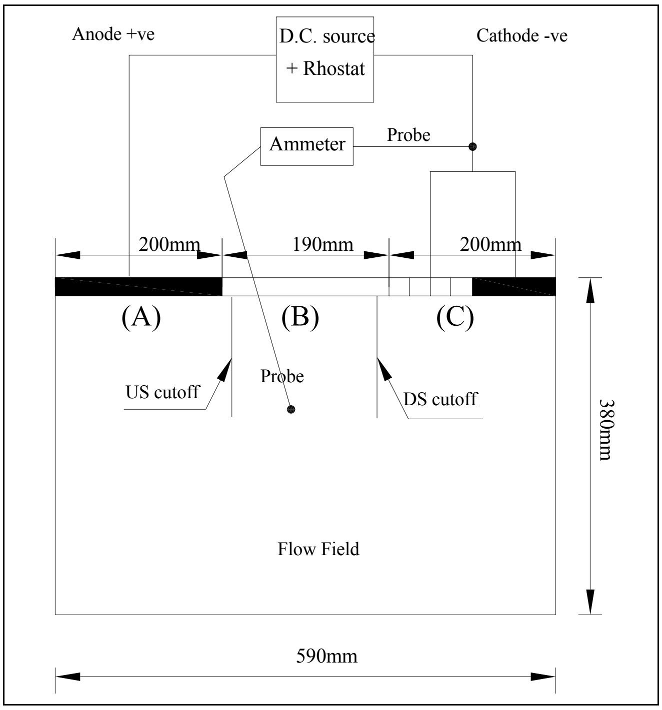

Figure 2: Plan of the electrolytic tank

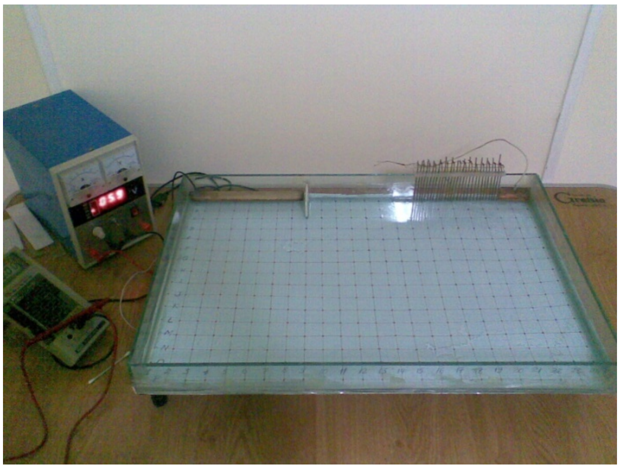

Figure 3: Photo of the electrolytic tank

The electrolytic tank consists of:

- A glass tank of dimensions 590*380*50 mm, thickness of glass is 6mm, tap water is put in the glass tank with a depth of 3mm.

- Part (A) is a 200 mm long copper plate which represents the length of soil upstream the floor from which water percolates; it is used as the anode.
- Part (B) is 190 mm long it's formed of glass to represent the apron of the heading-up structure.
- Part (C) is 200 mm long and is used to represent the different cases of the blanket downstream the floor, it is used as the cathode.

The blanket is represented by a plastic plate with copper rods placed in it, these copper rods have 1 mm diameter (represent the diameter of perforations) and placed at a constant spacing that changes for each perforation ratio. This spacing equals 5 mm for perforation ratio (1), 10 mm for perforation ratio (2), and 15 mm for perforation ratio (3).

Figure 4: The simulation of downstream blanket

Plastic plates are used to represent the upstream and downstream cutoffs. In case of using one cutoff only either in the upstream or the downstream, the depth of the plastic plate representing it is taken 50 mm. In case of using two cutoffs one in the upstream and the other in the downstream, the depth of the plastic plate representing the upstream cutoff is taken 50 mm while the depth of the plastic plate representing the downstream cutoff is taken 25 mm.

D.C. power source with a rheostat is used to convert alternative current into direct current (with anode an cathode) and used also to change the values of voltage. The power source has the possibility to feed the system with a voltage ranging from 0 to 15 volts through the rheostat.

A very sensitive digital Ammeter with two electric probes is used to measure the Voltage (potentials) at different points in the flow field.

In the present work 40 models are investigated in order to cover the various aspects of the problem under consideration. A total number of 160 runs were carried out during the experimental program of the present work.

Different cases for the length of downstream blanket were studied as following:

- Case (1): No downstream blanket (Lb = 0)
- Case (2): Using a Downstream blanket (to study the effect of blanket on piping and flow)

For Case (2) three different lengths (ratios of length) of the blanket are studied as seen in table (1) :

Table 1: Lengths of the studied blankets

L_b	L_b / L_a
5 cm	0.26
10 cm	0.53
15 cm	0.79

For each blanket length four different values of voltage are used to cause the potential difference between the electrodes. The used voltages (potentials) are 3, 4.5, 6 and 7.5 volts. For each blanket length three perforation ratios (Rp) are studied. These perforation ratios are 0.2, 0.1, and 0.067.

Perforation ratio = copper rod diameter/ spacing between two copper rods.

For each perforation ratio the flow is studied using no cutoffs, upstream cutoff only (with a depth of 5 cm), downstream cutoff only (with a depth of 5 cm), or both upstream (with a depth of 5 cm) and downstream (with a depth of 2.5 cm) cutoffs together.

The measuring process should take less than 15 minutes to minimize the time required for each run so that we can avoid the effect of polarization process, which may happen between the electrodes and the electrolyte in the tank during the test. For each run the water should be changed.

6. ANALYSIS OF DATA

The readings obtained from the experimental work were analyzed and used to draw the distribution of equipotential lines in the flow field under the apron of a heading up structure using a computer program (Surfer 8) for a sample of 40 models. This sample was obtained from a potential difference equals 4.5 volts and covers the different lengths and perforation ratios of the blanket and cases of existence of cutoffs. The head at any point is represented by the measured voltage at it and the equipotential lines are determined by points of equal voltage and stream lines are those perpendicular to them.

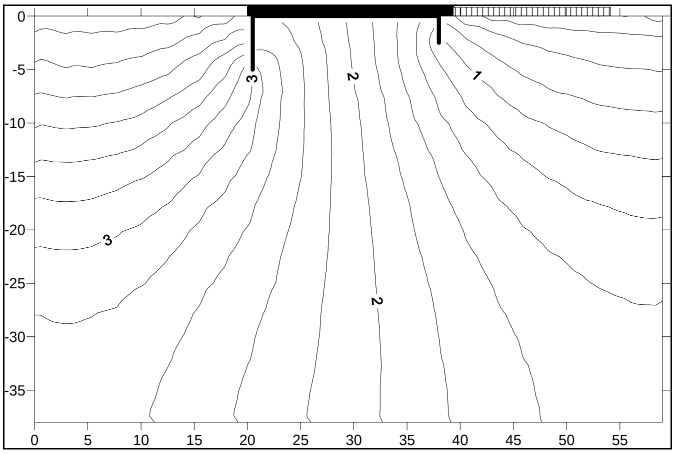

Figure 5: Sample of the equipotential lines H=4.5V, U.S. and D.S. cutoffs (d1=5cm, d2=2.5cm), Lb/La = 0.79, Rp = 0.2

The readings obtained from the experimental work were also investigated and analyzed to determine the effect of both changing the perforation ratio and the blanket length on the factor of safety against piping downstream the aprons of heading up structures.

For each voltage (3V, 4.5V, 6V and 7.5V), the piping index (Pe) was calculated at different relative depths (de/T) of point (e) and then the average piping index (Pe) for each depth (de) was considered in the analysis. The relationship between the piping index (Pe) and the relative depth of point (e) was plotted for all the investigated cases (Figures (6) to (11) show a sample of these curves).

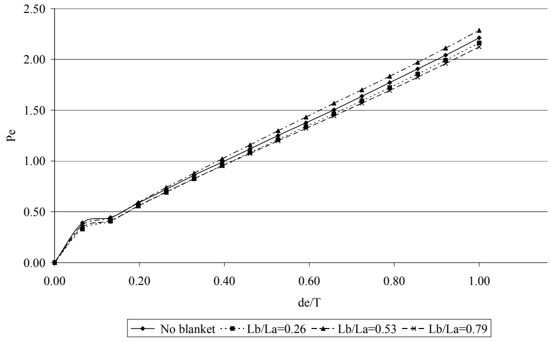

Figure (6): (Pe) versus (de/T),

R_p = 0.2, D.S. cutoff

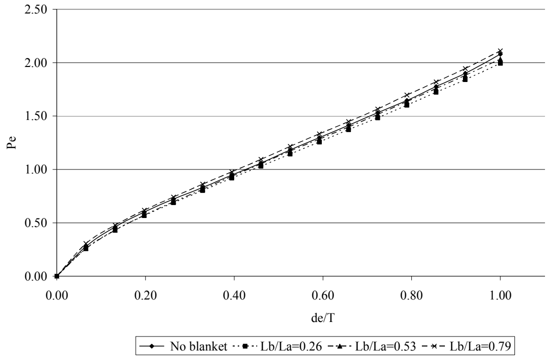

Figure (7): (Pe) versus (de/T),

R_p = 0.2, No cutoffs

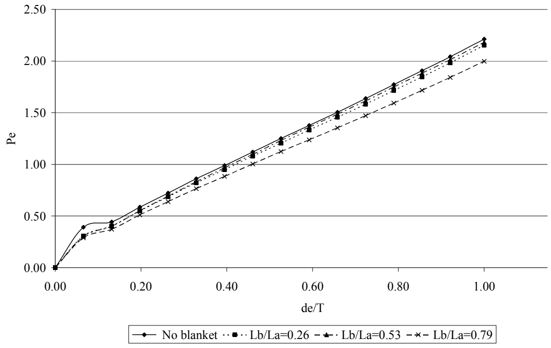

Figure (8): (Pe) versus (de/T),

R_p = 0.1, D.S. cutoff

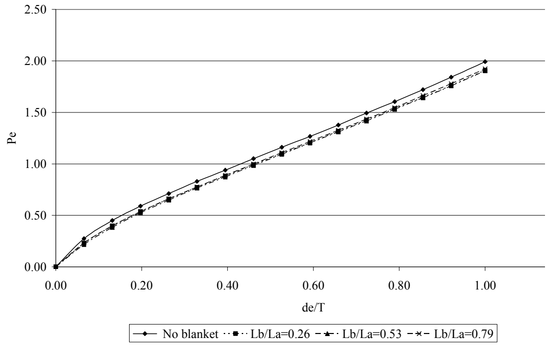

Figure (9): (Pe) versus (de/T), R_p=0.067, U.S. cutoff

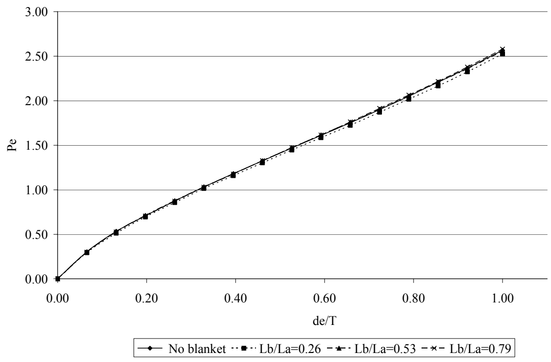

Figure (10): (Pe) versus (de/T),

R_p = 0.2 U.S. and D.S. cutoffs

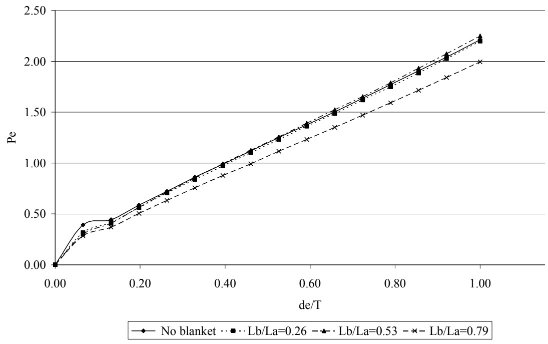

Figure (11): (Pe) versus (de/T),

R_p = 0.067, D.S. cutoff

Previous results were used to draw relationships between piping index (Pe) and perforation ratio (Rp) for different relative blanket lengths (Lb/La). These relations are drawn for the four studied cases (no cutoffs, upstream cutoff, downstream cutoff, and upstream and downstream cutoffs together). The following relations help to determine the optimum blanket length with the optimum perforation ratio for each studied case.

The relative depth (de/T) = 0.79 was chosen to represent the range (de/T) = (0 → 1) used within the present study.

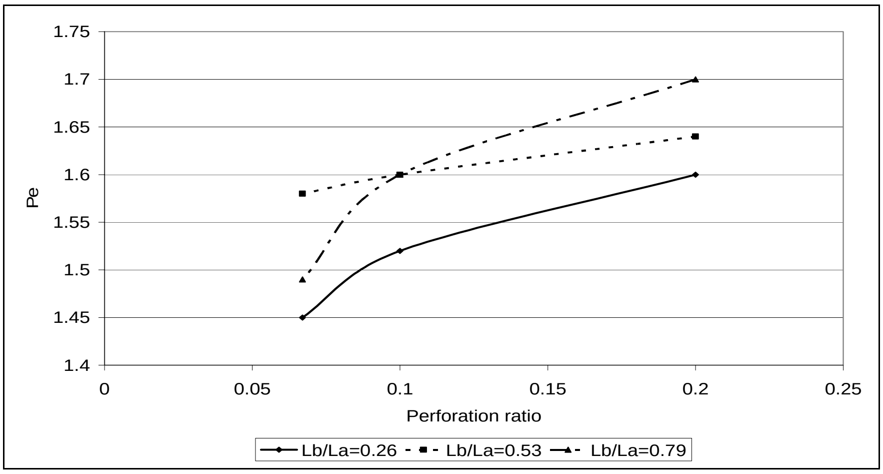

Figure 12: (Pe) versus Perforation ratio and Lb/La at de/T= 0.79, No Cutoffs

Figure (12) shows that when using no cutoffs, the highest value of piping index (Pe) for all cases is achieved when a blanket with Lb/La equals 0.79 and perforation ratio equals 0.2 is used.

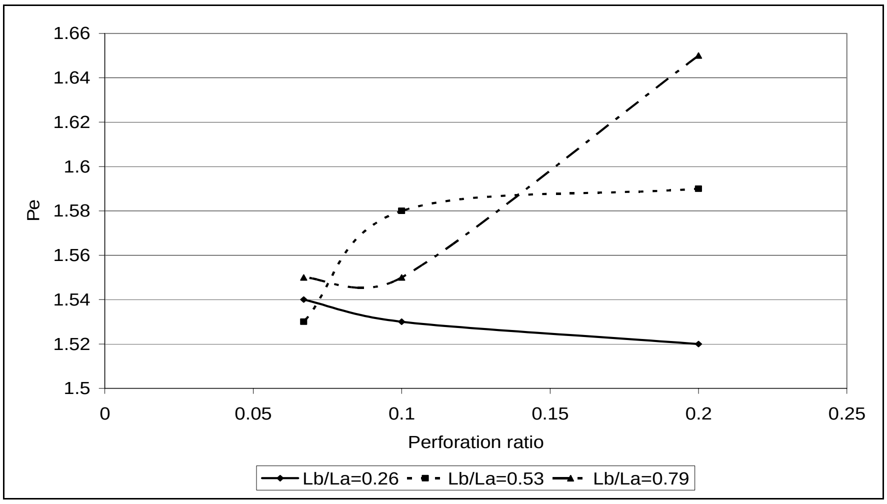

Figure 13: (Pe) versus Perforation ratio and Lb/La at de/T= 0.79, Upstream Cutoff

Figure (13) shows that when using upstream cutoff the highest value of piping index (Pe) was when using a blanket with Lb/La equals 0.79 and perforation ratio equals 0.2.

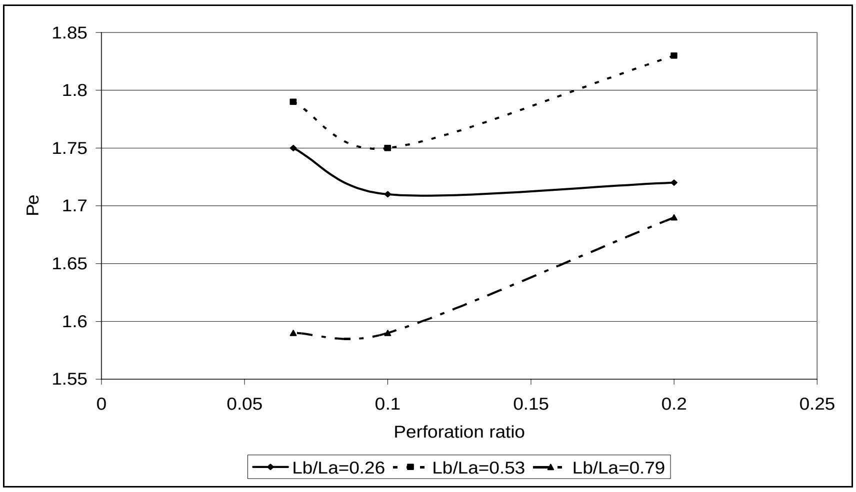

Figure 14: (Pe) versus Perforation ratio and Lb/La at de/T= 0.79, Downstream Cutoff

Figure (14) shows that when using a downstream cutoff only the highest value of piping index (Pe) was when using a blanket with Lb/La equals 0.53 and perforation ratio equals 0.2.

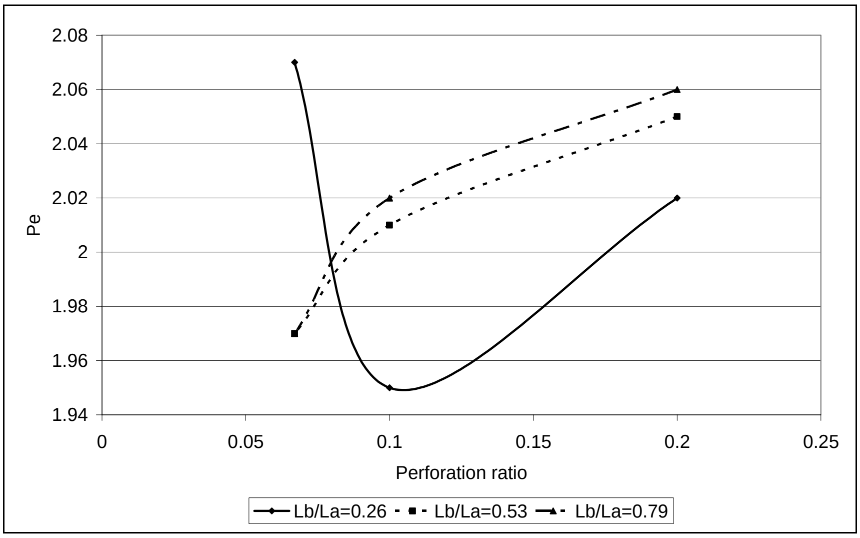

Figure 15: (Pe) versus Perforation ratio and Lb/La at de/T= 0.79, Upstream and Downstream Cutoffs

Figure (15) shows that when using both upstream and downstream cutoffs together the maximum value of (Pe) is reached in the following cases:

- Lb/La equals 0.79 and perforation ratio equals 0.2.
- Lb/La equals 0.53 and perforation ratio equals 0.2.
- Lb/La equals 0.26 and perforation ratio equals 0.067.

The value of (Pe) of the case of Lb/La equals 0.26 and perforation ratio equals 0.067 maybe high because in this case the blanket acts as if the apron is extended by a small value due to the small perforation ratio.

Since there is nearly no difference in the piping index (Pe) between the cases of Lb/La equals 0.79 and perforation ratio equals 0.2, Lb/La equals 0.53 and perforation ratio equals 0.2, it is recommended to use Lb/La equals 0.53 and perforation ratio equals 0.2 for case of using both upstream and downstream cutoffs together with a blanket as it will be more economic.

7. CONCLUSIONS

1. The used electrolytic tank was found to represent efficiently the studied case.
2. The piping index (Pe) increases with the increase of the relative depth (de/T) of point (e) for all lengths and perforation ratios of the downstream blanket.
3. When a blanket is added downstream the apron of the heading up structure, it acts as if the apron is extended, the uplift head increases at the critical section because the blanket blocks partially the pores of the soil downstream the apron and changes the distribution of the uplift diagram under the apron, so it is needed to increase the perforation ratio of the blanket in order to dissipate the increase in the uplift head at the end of apron due to the addition of the blanket.
4. The perforation ratio equals 0.2 with Lb/La equals 0.79 were found to be the best perforation ratio and relative length of the blanket when both using no cutoffs and using an upstream cutoff alone as they give the highest value of piping index (Pe).
5. When using a downstream cutoff only, perforation ratio equals 0.2 with Lb/La equals 0.53 give the highest value of factor of safety.
6. When using both upstream and downstream cutoffs together there is nearly no difference in the piping index (Pe) between the cases of Lb/La equals 0.79 and perforation ratio equals 0.2, Lb/La equals 0.53 and perforation ratio equals 0.2, so it is recommended to use Lb/La equals 0.53 and perforation ratio equals 0.2 as it will be more economic.

8. RECOMMENDATIONS

1. Since it is concluded that perforation ratio equals 0.2 which is the highest perforation ratio studied achieves the most safety against piping, it is recommended to study perforation ratios higher than 0.2.
2. The conclusions of this research didn't consider the case of stratified soil so it would be interesting to study the effect of drainage blanket downstream aprons of heading-up structures on the hydraulic gradient and safety against piping when the soil is stratified.
3. This research assumed homogeneous and isotropic medium, so it is recommended to study other cases of soil homogeneity and isotropy.
4. The thickness of the blanket was not considered in spite of its importance to balance the uplift force acting on the bed downstream the apron, so the proper thickness of the blanket which provides safety against uplift forces under the blanket is recommended to be investigated.

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