Mansoura Engineering Journal, (MEJ), Vol. 33, No. 4, December 2008. C. 22

A STUDY OF SEEPAGE THROUGH EARTH DAMS WITH CHIMNEY OR HORIZONTAL FILTERS

دراسه للتسرب خلال السدود الترابية المزودة بمرشح افقي أوآخر علي شكل (L)

Khalaf allah S.[1], Abdallah M.G.[2], El-Masry A.[3], and El-Alfy K. S.[4]

[1]Assistance lecture, Irrigation and Hydraulics Dept., Faculty of Engineering, Mansoura University, Egypt.
[2] Associ. Prof. Dr., Irrigation and Hydraulics Dept., Faculty of Engineering, Mansoura University, Egypt.
[3] Prof. Dr. of Irrigation works, Irrigation and Hydraulics Dept., Faculty of Engineering, Mansoura University, Egypt
[4] Prof. Dr. of Hydraulics, Irrigation and Hydraulics Dept., Faculty of Engineering, Mansoura University, Egypt.

خلاصة

يهدف البحث إلى دراسة خصائص التسرب الثنائي الأبعاد خلال السدود الترابية المزودة بنظامين مختلفين من المرشحات الرملية كل علي حده وترتكز هذه السدود علي طبقة غير منفذة. نظم المرشحات التي تم تناولها بالدراسة هي ا- المرشح الأفقي ب- المرشح علي شكل حرف (L). لكل نوع من المرشحات تم دراسة تأثير موضع المرشح علي خصائص التسرب. هذا وقد تمت الدراسة عدديا باستخدام نظرية العناصر الحدودية ومعملياً باستخدام جهاز الصندوق الرملي. في الدراسة العددية تم تطبيق نموذج عددي (برنامج علي الحاسب الآلي) معد سلفاً من قبل باحثين أخرين لحل مشاكل التسرب المحصور وقد تم تطويره ليتمكن من حل مشاكل السريان الغير محصور خلال الأوساط المسامية لجميع الحالات السابق الإشارة إليها وذلك باستخدام لغة الفورتران. تم التحقق من صحة نتائج النموذج العددي بالمقارنة مع حلول رياضية لحالات محددة وقد أوضحت المقارنة صلاحية النموذج للتطبيق.

تم مقارنة نتائج الدراسة لكل نوع من المرشحات بحالة التسرب خلال جسم سد ترابي متجانس غير مزود بمرشح وذلك لتوضيح تأثير استخدام الأنواع المختلفة من المرشحات علي خصائص التسرب خلال جسم السد. كما تم مقارنة جميع النتائج للأنواع المختلفة لتحديد الحالات الأكثر تأثيراً علي خصائص التسرب.

ABSTRACT

This research paper aims to study the effect of both chimney and horizontal filters separately on seepage characteristics (free water surface, seepage face length and seepage discharge) through earth dams based an impervious base. This study was conducted through both the experimental method by sand box model and the numerical method by boundary element method (BEM). Also, the effect of position of either chimney or horizontal filters on seepage characteristic was included. Comparison between the experimental data and the corresponding numerical results for each type of filters was carried out. Also, a comparison between chimney and horizontal filters was presented. It was found that for the same cross section of the earth dam, decreasing the distance between the dam inlet face and the filter position (D) for two types of filters resulting in lowering free water surface, increasing seepage face length, and increasing the seepage flow rate. The seepage face lengths S_f for chimney and horizontal filters were less than the height of exit point for dam without filter. Also, the relative seepage face length S_f/S_{WF} for

Accepted December 31, 2008

chimney drain was larger than the corresponding value for horizontal filter by an average difference value of 58.28%. Although the relative seepage discharge $q_{filter}/q_{w.f}$ for horizontal filter was less than that for chimney filter, the Seepage discharge, q_{filter} for both the horizontal and the chimney filters were greater than the seepage discharge through dam without filter. Concerning filter volume, horizontal filter is preferred on chimney filter to reduce the volume of used material.

Key words: Seepage, Earth Dams, Filters, Boundary Element

INTRODUCTION

The problem of seepage through earth dams resting on an impervious base and provided with chimney or horizontal filters was studied since 1931 by Kozeny [15]. Based on the assumption of a parabolic upstream face, Kozeny [15] used conformal mapping to study seepage through an earth dam with horizontal filter. In 1940 Casagrande [6] modified Kozeny's treatment and adjusted the entrance conditions to suit a plane upstream face. Abdrabbo [4] used boundary element method (BEM) to study effect of sloping angle of downstream face of the dam and length of the horizontal filter on location of free surface and seepage discharge. Abd El-Razek and Nasr [3] used sand model to evaluate the height of the horizontal filter in earth dam based on an impervious base. Abd El-Razek and Nasr [2] used Hele-Show model to evaluate the minimum length of the filter downstream an earth dam based on an impervious base. Abd El-Razek [1] used image method to study seepage through an earth dam with chimney filter, in which he developed and plotted an equation of the free water surface according to different values of inclination angle of the upstream face of the dam. El-Masry [10] used BEM to show the effect of chimney filter position on seepage through earth dam upstream slope angle of a dam varied from 30° to 90°. Also, Hathoot [12] solved the problem of seepage through earth dam with horizontal filter using an image method.

EXPERIMENTAL SETUP

The sand box model illustrated in Fig. 1 of dimensions 175cm length, 52 cm height, and 25cm width was manufactured particularly for this study in Hydraulics and Irrigation laboratory, Faculty of Engineering, Mansoura University, in Egypt. The sand box model consists of two parallel perspex plates (thickness of each plate is 1 cm) with perspex plate in base. The models of dam were made from sand placed between the two parallel perspex plates. The grain size distribution of the used sand is shown in Fig. 2. Permeability coefficient for used sand equals 55.3 m/day. A feeder tube (1) was used to supply water for upstream head tank, in which the water was controlled by a valve (2). The overflow tube (9) was used to control the required head in the feeder tank (3). The filter (7) was fabricated from a synthetic material to allow water easily seepage through the filter. Seepage discharge entering the filter passing through hole (11) located at the bottom of the box, and was measured by a graduated tube (8). Fifty piezometers (10) were distributed along the base of the dam to record the head distribution on this base. The free water surface was determined by dyeing the water at the front face of the dam. The sand (5) was wetted and laid inside the sand model almost by the same manner in each experiment, so permeability of the sand was not changed.

Procedure of Experimental Setup

1-For constant dimensions of dam model and head of water (H), the seepage discharge from horizontal filter was measured and the free water surface was recorded by dyeing water.

2-The position of filter was changed, and step No. 1 is repeated for seven positions of chimney filter.

3-The horizontal filter was used instead the chimney filter and steps 1 and 2 were repeated.

NUMERICAL STUDY

Boundary element method (BEM) becomes more widely recognized as one of the most attractive and powerful method to solve seepage problems. The power of the boundary element method derives from the fact that only the boundary is discredited. James and Philip [13], Brebbia [5], Paris et al. [16] and Chang [8,9] stated that the boundary must have one dimension less than the region, which affects a drastic reduction in unknowns to be solved.

Governing Equation

The basic equations of porous media flow are the continuity equation and the generalized Darcy's law. Substituting Darcy's law into continuity equation gets Laplace equation.

$$\nabla^2 h = \frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} = 0 \qquad (1)$$

in which

h total head = H + Y.

H pressure head.

Y elevation head.

x,y x, y directions.

Laplace Equation (1) is the governing equation for steady state seepage through homogenous isotropic porous media.

Boundary Conditions

The considered problem of seepage through homogeneous earth dam provided with chimney drain was modeled for numerical solution. To illustrate the corresponding boundary conditions, the dam was divided into four boundaries, as follows, Fig. (3);

1- Boundary of reservoir "Surface AB", $h = H$.

2- Free water surface "Surface BC"
$h = Y$, $\partial h / \partial n$ in which n is normal direction.

3- Seepage surface "Surface CD"
$h = Y$

In case of horizontal filter Fig. 3c, the seepage surface CD is an equipotential line and

$$h = Y = 0.$$

4- Impervious boundary
$\partial h / \partial y$

Verification of the Applied Model

The program was presented by Paris and Canas [16] to solve confined seepage problems and was modified by the authors to solve unconfined seepage problems. In unconfined seepage problems the position of free surface is one of the unknowns of the problem and consequently are given two boundary conditions along this boundary. To determine the position of the free surface, it is used an iterative procedure starting from a given approximation of its position and solving the linear system for the second boundary condition (q=0). Compare the computed total head of the free surface nodes and their elevation on the free surface. If the difference between them is greater than a set tolerance number, then iterations have to be repeated. If the difference is smaller than the tolerance, than the solution reaches the final iteration, and the solution obtained is the final solution. In order to verify the written computer program, the problem of unconfined seepage through a homogeneous earth dam with impervious base for the case of dry downstream condition, assumed dimensions, and unit permeability in X and Y directions ($K_x = K_y$) shown in Fig. 4, was solved numerically using the above mentioned technique, and compared with the analytical solution by Casagrande [7]. To solve this problem numerically using BEM, the domain under the initial free surface, was divided into 175 linear elements with a total 175 nodal points, and the initial free surface was assumed as straight line contains 60 elements with 60 nodes. After 38 iterations with a prescribed tolerance (0.01) i.e. ($h-y \leq 0.01$), the seepage discharge was 1.56 m^3/day/m, the obtained exit point location (Y_{exit}) was 2.33 m , and seepage face length was 3.30 m. The same problem was solved by Casagrande [7] using conformal mapping (see Harr [11]), the obtained seepage discharge was 1.52 m^3/day/m, estimated exit point location (Y_{exit}) was 2.14 m, and the seepage face length was 3.03 m. The Percentage of difference between BEM and Casagrande [7] is illustrated Table 1.

Boundary Element Mesh

To handle the considered problems of seepage through earth dams provided with chimney drain or horizontal filter, the boundary was discritized into a mesh of boundary elements. Seven cases were modeled to the numerical solution. Table 2 contains the total number of elements, NEL, and nodes, NOD. One of the considered cases, D = 1.43H, is shown in Fig. 5 with the assumed free surface location.

RESULTS AND ANALYSIS

1- HORIZONTAL FILTER

From the obtained numerical results, Fig. 6 shows free water surface locations for the considered cases. From this figure it was observed that, the free water surface location was lowered with decreasing of the distance D. Also, the decreasing in distance D resulted in increasing the seepage surface on horizontal filter. Fig. 7 shows the recorded phreatic surface for the considered cases experimentally. Fig. 8 shows the comparison between the numerical solution and experimental model for the considered cases. From this figure it was observed that, the computed free water surface from numerical solution was lower than that of the experimental one for all cases. This difference was due to the fact that the results of the experimental model were affected by the influence of capillary fringe. A comparison between numerical and experimental results was made for seepage face (S_f/H) as shown in Fig. 9. From Fig. 9, it was noticed that, increasing of relative distance (D/H) resulted in decreasing the relative length of seepage face (S_f /H) for both solutions. Also, for bigger values of D/H, the difference between experimental and numerical results of (S_f /H) decreased.

Fig. 10 shows the comparison between experimental and numerical results for relative seepage discharge (q/KH). It was observed that, the relative seepage discharge (q/KH) decreased with increasing the relative distance D/H for both methods, but the difference between numerical and experimental results was approximately constant. This difference was due to the fact that, the coefficient of permeability in numerical and experimental solutions had some difference.

2- CHIMNEY FILTER

From the numerical results, free water surface locations for the considered cases were illustrated graphically as shown in Fig. 11. Fig. 11 shows that the decreasing in distance (D) resulted in lowering the phreatic surface location starting from the point of intersection between inlet surface with the upstream water level, while the height of exit point decreased with increasing the distance D. From the obtained exit point locations, the locus was drawn as shown in the figure. From this locus, one can estimate the height of exit point corresponds to a certain position of the filter. Fig. 12 shows the recorded phreatic surface for the considered cases experimentally. Fig. 13 shows the comparison between numerical and experimental results of free water surface for the considered cases. From this figure it was observed that, free water surface traced from experimental model was higher than that of the numerical one for all cases, which referred to the fact that the results of experimental model were affected by the influence of capillary fringe. Fig. 14 shows that the increasing of the relative distance (D/H) decreased the relative height of exit point (S_f/H) for both the numerical and experimental results. Also, for bigger values of D/H, the difference between experimental and numerical results decreased.

Fig. 15 shows the comparison between experimental and numerical results of relative seepage discharge (q/KH). From Fig. 15 it was found that, the increasing of relative distance resulted in decreasing relative seepage discharge for both solutions. Also, the figure shows that the difference between numerical and experimental results was approximately constant, which could be referred to the fact that the coefficient of permeability in numerical and experimental solutions had some differences.

COMPARATIVE STUDY BETWEEN HORIZONTAL AND CHIMNEY FILTERS

From the previous numerical and experimental results for two filters a comparative study showed that for all cases, the phreatic surface locations were lowered with decreasing the relative distance of filters as shown in Fig. 16. Also, it was observed that the system of chimney drain slightly lowered phreatic surface than the other system (horizontal filter). A comparison between chimney and horizontal filters for S_f/S_{wF} is presented in Fig. 17. It was shown that for the two considered systems, the decreasing of relative distance (D/H) resulted in increasing relative height of exit point (S_f/S_{wF}). Also, it was cleared that, the heights of exit point Y_{exit} for chimney filter, seepage face length for Horizontal filter were less than the height of exit point for the dam without filter. The relative height of exit point (S_f/S_{wF}) for chimney filter was larger than seepage face length obtained by horizontal filter (an average difference value 58.28% 58.28%). Fig. 18 shows the comparison between chimney and horizontal filters for relative seepage discharge (q_{filter}/q_{wF}). It was noticed that, decreasing the relative distance (D/H) increased relative seepage discharge (q_{filter}/q_{wF}). Also, it was observed that, chimney drain gives slightly higher values than horizontal filter. Concerning filter volume, it is preferred to use horizontal filter system than the chimney drain system to reduce the volume of filter material.

CONCLUSIONS

A sand box model was prepared and used in studying the effect of using either the horizontal or the chimney filters on seepage characteristics through earth dam. Also, the problem of unconfined seepage through homogeneous earth dam was solved numerically and considered as a reference to compare the effect of providing the dam with chimney or horizontal filter. From the obtained results in this study, the following points could be concluded:

1- For the same cross section of an earth dam, decreasing the distance between the dam inlet face and filter position (D) for two drainage systems resulted in;
   A- lowering of free water surface,
   B- increasing the seepage flow rate, and
   C- increasing seepage face length.
2- Chimney and horizontal filters had the same effect on free water surface at the same position.
3- The seepage face length (S_f) for chimney and horizontal filters were less than the height of exit point for the dam without filter.
4- The relative seepage face length (S_f/S_{wF}) for chimney drain was larger than the relative seepage face length for horizontal filter by an average difference value of 58.28%.
5- Seepage discharge (q_{filter}) for either chimney or horizontal filters was greater than seepage discharge through the dam without filter.
6- The relative seepage discharge (q_{filter}/q_{wF}) for chimney drain was larger than that obtained by horizontal one, but the difference was very small.
7- For the filter volume, it is preferred to use horizontal filter than chimney system to reduce the volume of used material in filter construction.

NOTATION

The following symbols are used in this research paper

D = Distance between the point of intersection between inlet surface of a dam with upstream water level and filter position;
H = Pressure head;
h = Total head on dam;
K = Coefficient of permeability;
K_x = Coefficient of permeability in X- direction;
K_y = Coefficient of permeability in Y-direction;
NEL = Total number of elements;
NOD = Total number of nodes;
q = Seepage discharge per unit width;
q_{filter} = Seepage from filter;
q_{WF} = Seepage discharge for dam without filter;
S_f = Seepage face length;
Y = Elevation head; and
Y_{exit} = Height of exit point.

BIBLIOGRAPHY

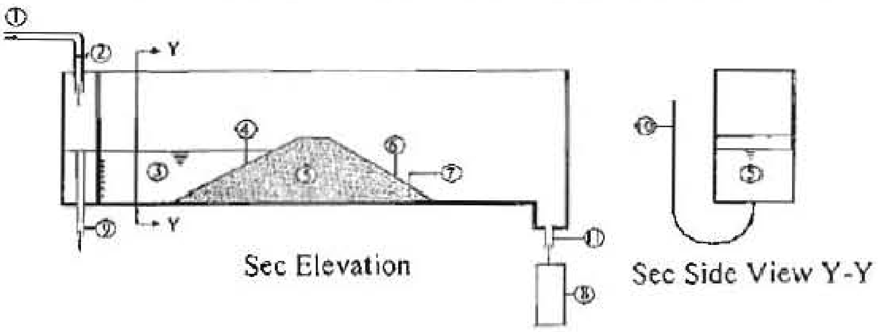
1) Abd El Razek M., "Seepage Characteristic of Earth Dams with an "L" Shape Filter", the Bulletin of the Faculty of Engeg. Alex. Univ. Vol. XXVI, 1986 and Vol. XXVI 1987.
2) Abd El Razek M., and Nasr R. I., "Evaluation of the Minimum Length of Filter in Earth Dams", Journal of Alexandria Engineering, Vol. 32, No. 4, October 1993.
3) Abd El Razek M. and Nasr R. I., "Height of the Horizontal Filter in Earth Dams Based on an Impervious Base", Journal of Alexandria Engineering, Vol. 33, No. 3, July 1994.
4) Abdrabbo F., "An Application of the Boundary Element Method to Seepage Problem, Unconfined Flow Problem", the Bulletin of the Faculty of Engineering, Alexandria University, Vol., XXIV, 1985.
5) Brebbia C. A., "The Boundary Element Method for Engineers", Pentech Press Limited, Plymouth Devon, England, 1978.
6) Casagrande A., "Seepage through Dams", Journal of the New England Water Works Assoc., Vol. 51, June, 1937.
7) Casagrande A., "Seepage through Dams", in 'Contributions Soil Mechenics 1925-1940' Boston Society of Civil Engineers. Boston, 1940.
8) Chang C.S., " Boundary Element Method in Seepage Analysis with a Free Surface", Proc. of Implementation of computer proc. and Stress-Strain Laws in Geotechnical Engrg, Chicago, iii, PP. 421-431, 1981.
9) Chang C.S., "Application of Boundary Element Method in Transient Flow Problems with Moving Boundaries", Proc. 8th International Conf. on boundary element methods in Engrg. Tokyo, Japan, 1986.
10) El-Masry A. A., "Unconfined Seepage through Earth Dams with Chimney Drain by Boundary Element Method", Proceeding of First Engineering conference, Mansoura, March 1995, Vol. III. pp. 357-365.
11) Harr M. E., "Groundwater and Seepage" McGraw-Hill Book Co., Inc., New York, 1962.
12) Hathoot H. M., "Seepage through an Earth Dam with a Horizontal Toe Filter", the Bulletin of the Faculty of Engineering, Alexandria University 1977.
13) James A. Liggitt and Philip L-F. Liu, "The Boundary Integral Equation Method for Porous Media Flow", New York, 1992.
14) Khalaf Allah S., 'Seepage through Earth dams with Filters', M. Sc thesis, Dept. of Irrigation and Hydraulics Eng. Mansoura university , Egypt 2005.
15) Kozeny J., "Grundwasserbewegung bei freiem Spiegel Fluss und Kanalversickerung", wasserkraft und Wasserwirtschaft. No. 3, 1931.
16) Paris F. and Canas J., "Boundary Element Method: Fundamentals and Applications", McGraw Hill Book, Oxford, New York, Tokyo, 1997.

Table (1) Percentage difference between the present and Casagrande [7] solutions

Method	Casagrande [7]	BEM	difference %
seepage discharge	1.52	1.56	2.63
exit point (Y_{exit})	2.14	2.33	8.88

Table(2) Total number of nodes (NOD) and elements (NEL) for dams with chimney drain

D / H	0.94	1.18	1.43	1.68	1.93	2.18	2.43
NEL=NOD	145	145	150	150	160	160	170



1- Source
4- U.S face of the dam
7- The filter
10- Piezometers
2- Valve
5- The sand (dam body)
8- Graduated tube
11- Exit tube
3- Feeder tank
6- D.S face of the dam
9- Overflow tube

Fig. (1) Sand box model

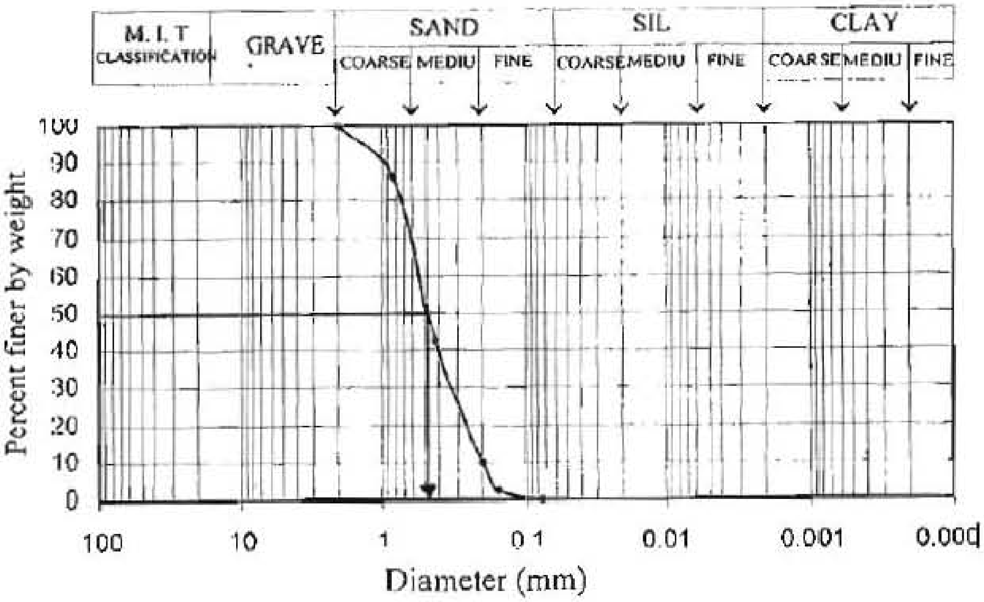
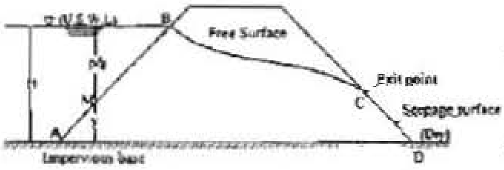
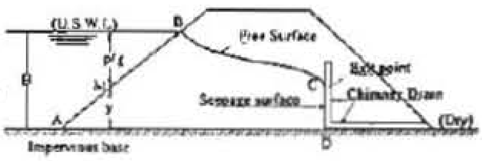


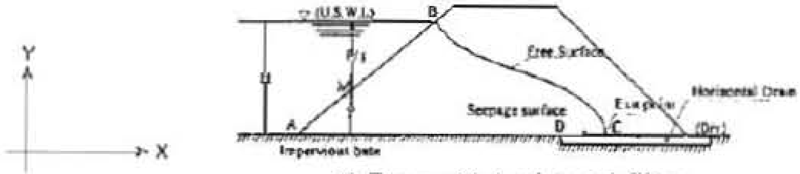
Fig. (2) Grain size distribution of the used sand



a) Dam without filter



b) Dam with chimney filter



b) Dam with horizontal filter

Fig. (3) Flow boundaries for earth dams

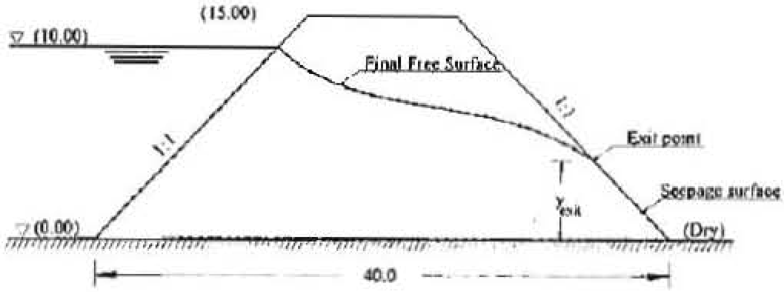
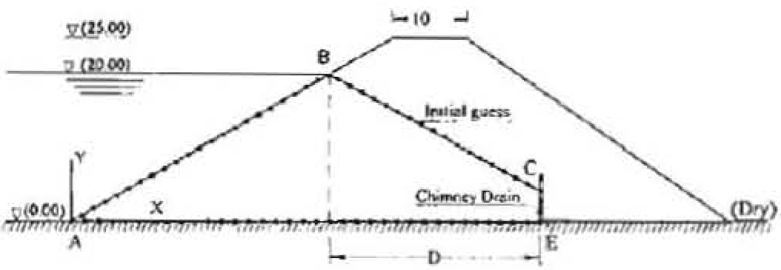
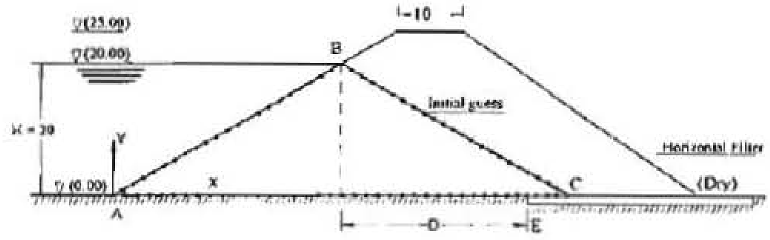


Fig. (4) Considered case for verification process



a) Dam with chimney filter



b) Dam with horizontal filter

Fig. (5) Boundary element mesh for one of the considered position (D=1.43H)

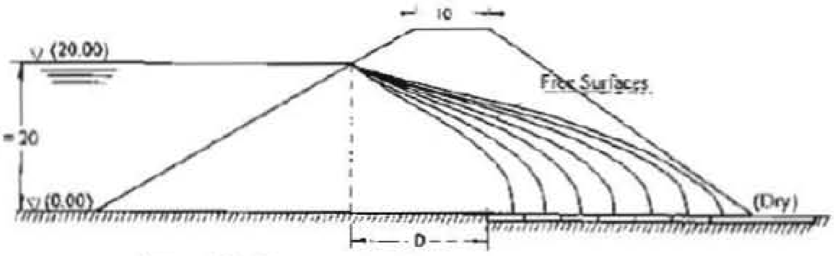


Fig. (6) Phreatic surface locations for seepage through earth dams with horizontal filter numerical

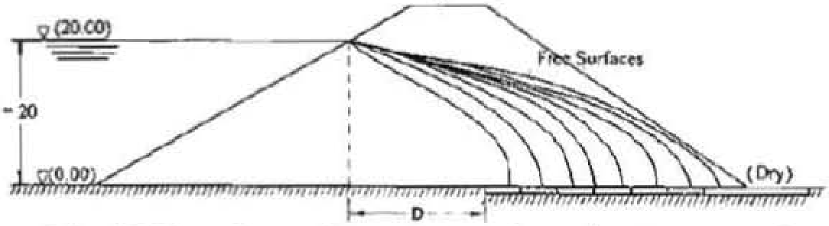
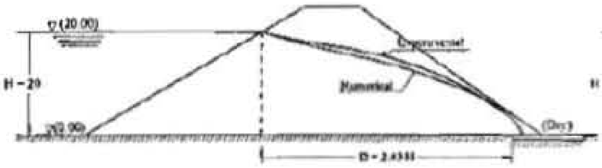
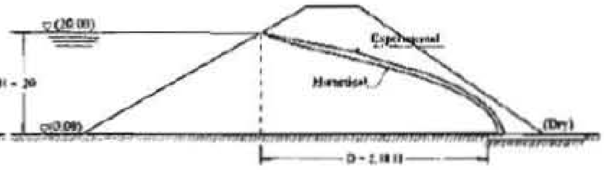


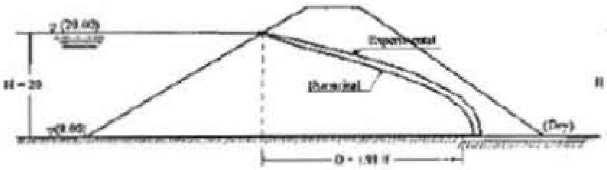
Fig. (7) Experimental traced phreatic surface locations for seepage through earth dams with horizontal filter



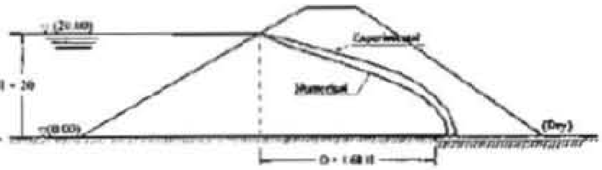
a) D = 2.43 H



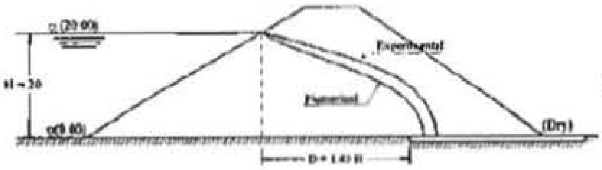
b) D = 2.18 H



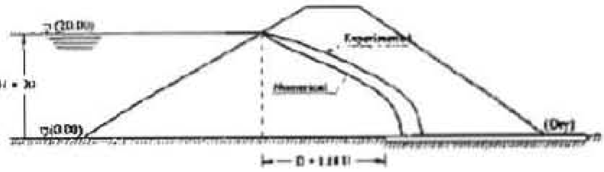
c) D = 1.93 H



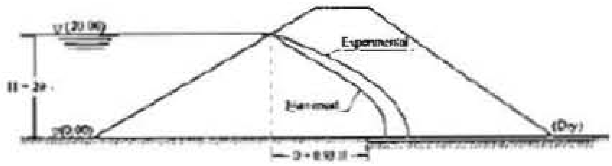
d) D = 1.68 H



e) D = 1.43 H



f) D = 1.18 H



g) D = 0.93 H

Fig. (8) Comparison between numerical and experimental results of free surface locations for dams with horizontal filter

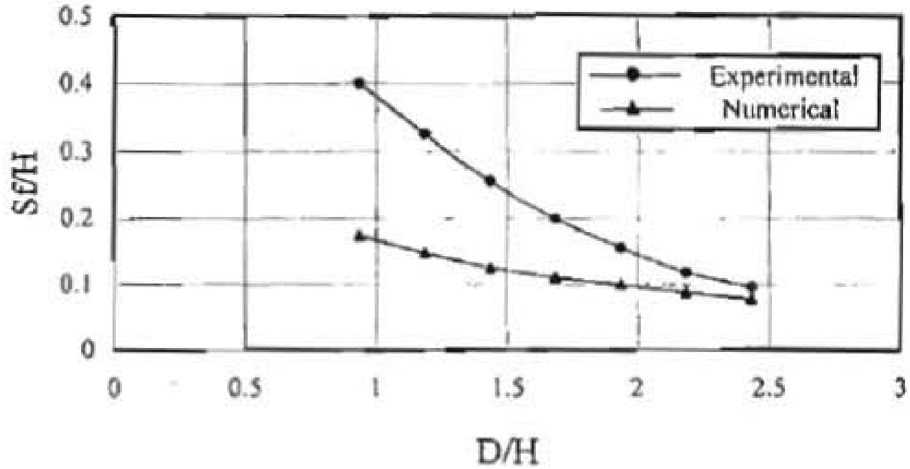


Fig. (9) S $_f$/H versus D/H for earth dam with horizontal filter

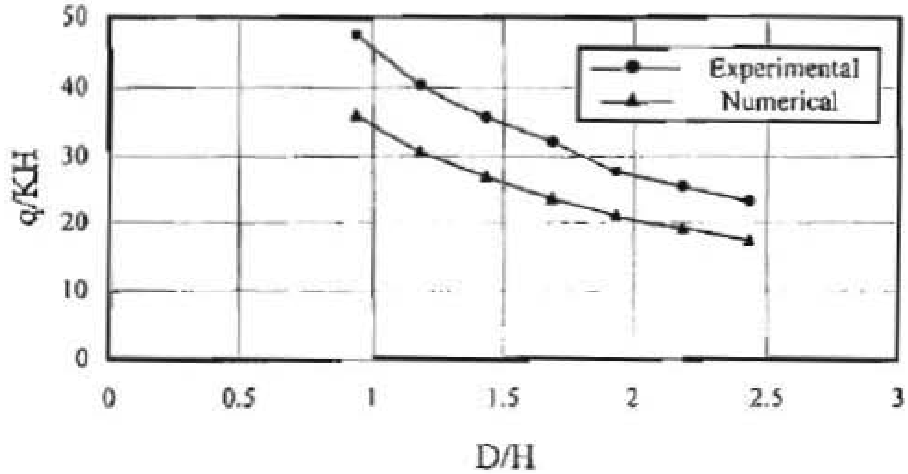


Fig. (10) q/KH versus D/H for earth dam with horizontal filter

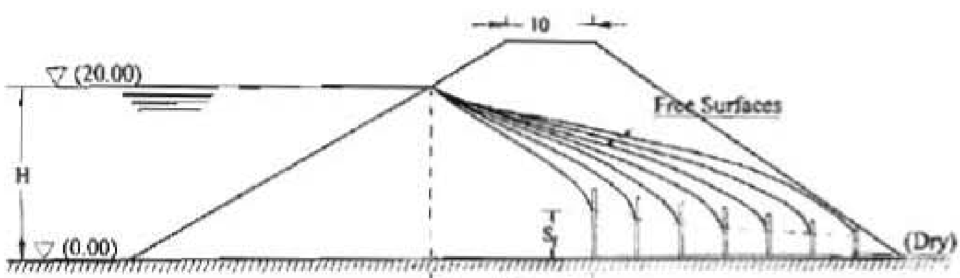


Fig. (11) Numerical phreatic surface locations for seepage through earth dams with chimney drain

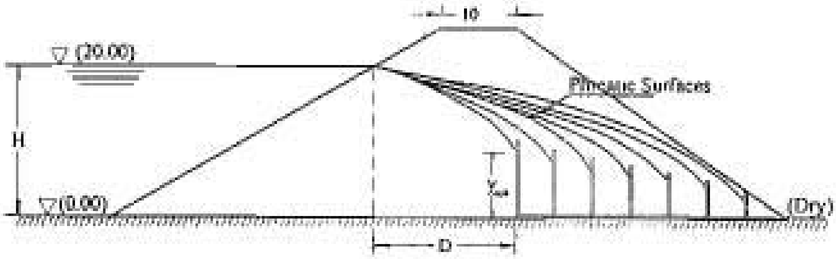


Fig. (12) Experimental traced phreatic surface locations for seepage through earth dams with chimney drain

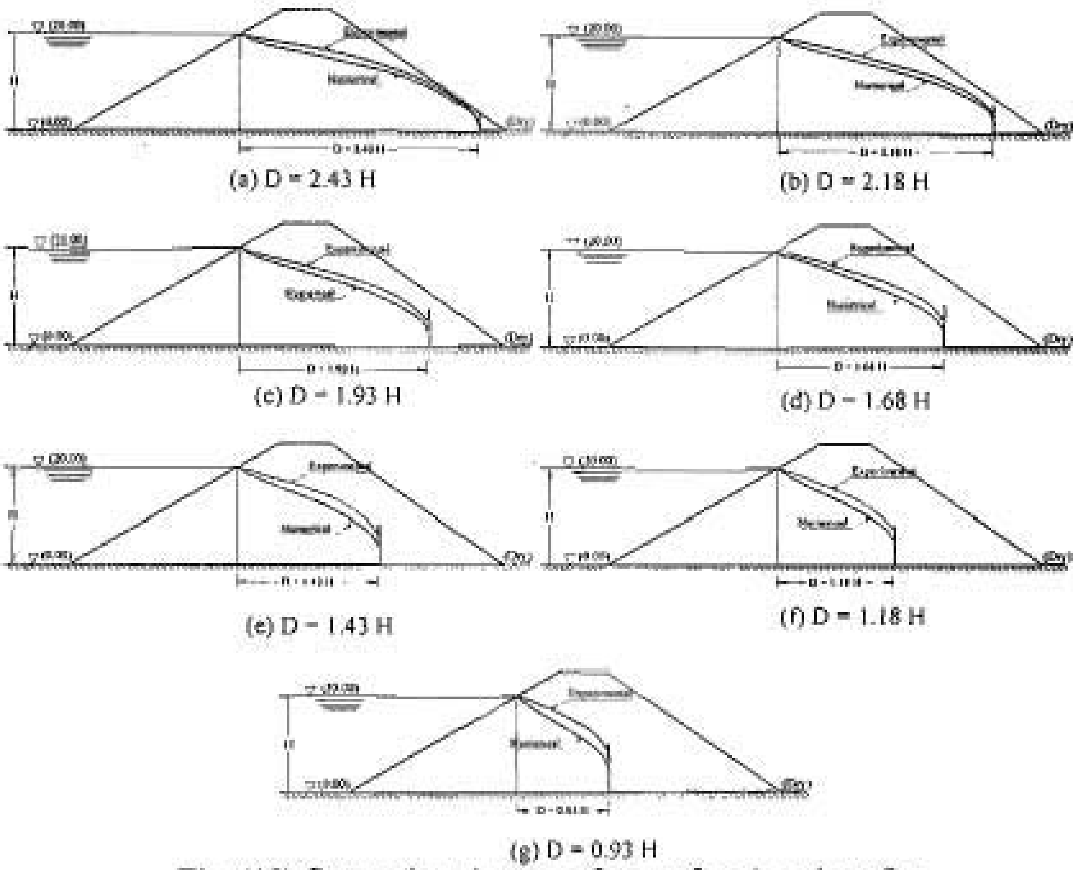


Fig. (13) Comparison between free surface locations for numerical and experimental results for dams with chimney filter

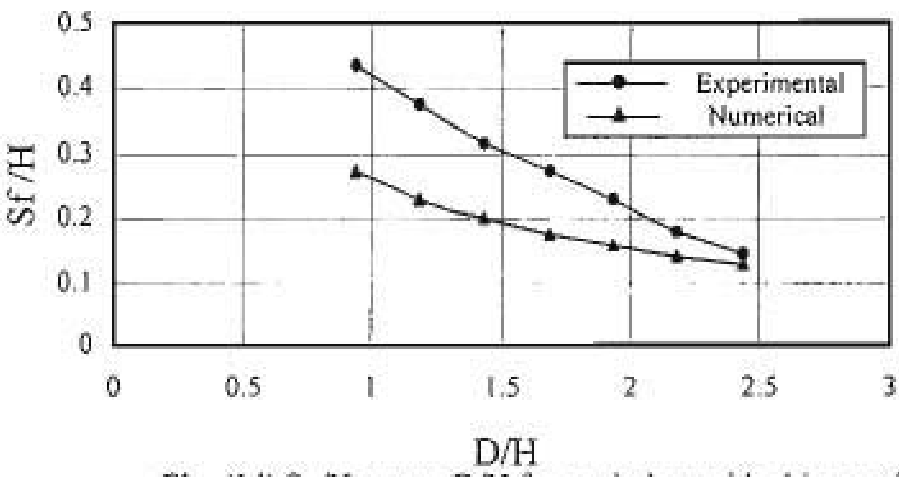


Fig. (14) S_f /H versus D/H for earth dam with chimney filter

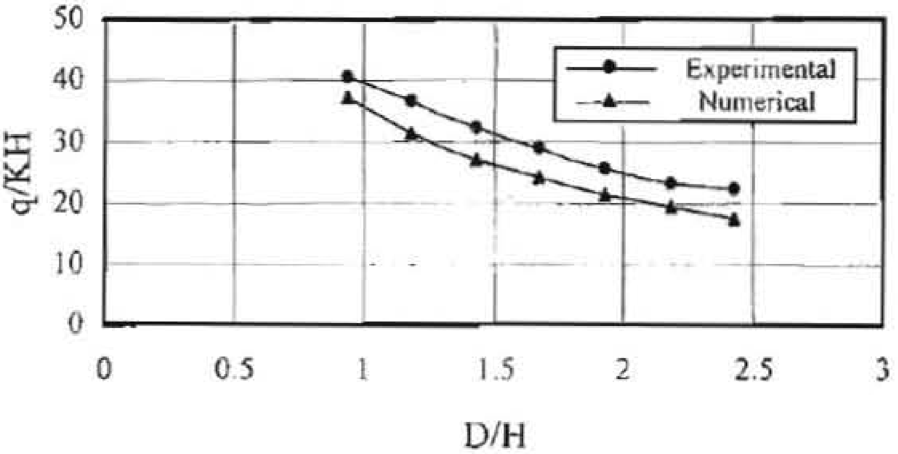


Fig. (15) q/KH versus D/H for earth dam with chimney drain

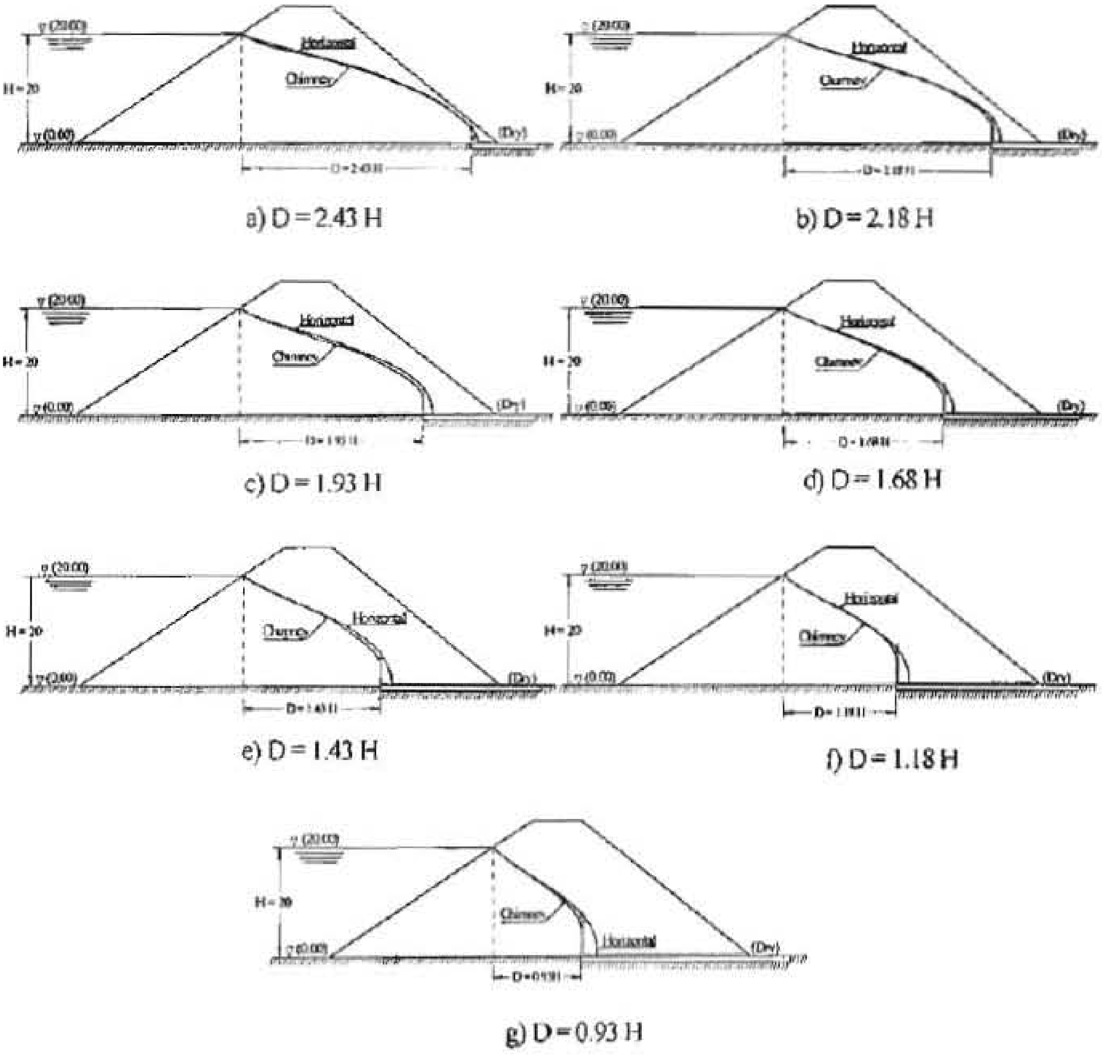


Fig. (16) Comparison between phreatic surface locations for chimney and horizontal filters

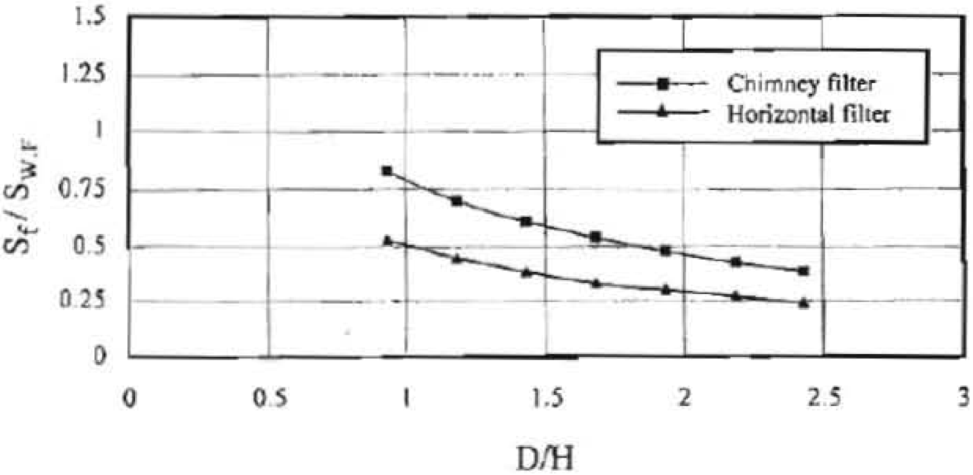


Fig. (17) Comparison between chimney and horizontal Filters for $S_f / S_{w.F}$ (numerical solutions)

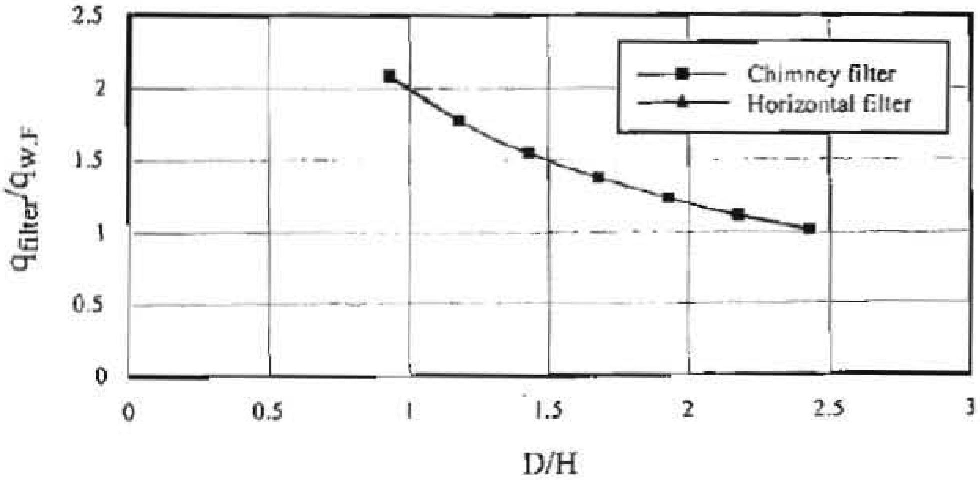


Fig. (18) Comparison between chimney and horizontal filters for $q_{filter}/q_{w.F}$ (numerical solutions)