SEEPAGE THROUGH EARTH DAM FOUNDED ON LAYER OF FINITE DEPTH WITH CUT-OFF WALL

Mahamed Abd El-Rezk M.R. and Rabiea I. Nasr
Irrigation and Hydraulics Department, Faculty of Engineering,
Alexandria University, Alexandria, Egypt.

ABSTRACT

The problem of seepage through earth dam founded on layer of finite depth with cut-off wall is carried out experimentally by a Hele shaw model. The study aims to investigate the effect of the problem variables which are; the thickness of the pervious layer, the location and penetration depth of the cut-off wall, and the retained water head on the seepage characteristics. These characteristics are; the total quantity of seepage discharge through the dam, the quantity of seepage discharge which is drained through the filter, and the loss of head due to the cut-off wall. Herein, the case of earth dam without cut-off wall is also studied. The results are plotted in the form of curves. They can be used as design charts. A solved example is made to illustrate the use of these charts.

NOTATION

- a — half distance between the two prespex plates of the experimental set-up,
- d — penetration depth of the cut-off wall measured from the upstream base level of the dam,
- D — depth of the pervious layer measured vertically from the upstream base level of the dam,
- g — acceleration due to gravity,
- h — loss of head due to cut-off wall,
- H — the retained water head upstream the dam,
- k — hydraulic conductivity of the soil,
- L — base width of the earth dam (= 54.6 cm),
- q_f — seepage discharge entering the filter $cm^3/sec/cm$,
- q_s — seepage discharge passing through the pervious layer $cm^3/sec/cm$,
- q_t — total seepage discharge $cm^3/sec/cm$, $q_t = q_f + q_s$
- X — distance of cut-off wall measured from the heal of the dam,
- α — angle of inclination of the upstream face of the dam (= 60^o) and,
- ν — kinematic viscosity of the oil at the experimental temperature cm^2/sec.

INTRODUCTION

The problem of seepage through earth dam founded on layer of finite depth with cut-off wall was investigated by Oshchinin [7], Polubarinova-Kochina [5], Mkhitarian [2] and Shornyakov [4]. Rozanov [6] solved the problem mathematically in case of cut-off has a different permeability than that given in the dam body. Mohamed Rezk and Rabiea Nasr [3] solved the same problem of seepage through an earth dam with cut-off wall using an inclined impervious base.

In this paper, the problem of seepage through an earth dam founded on layer of finite depth with cut-off wall, as represented by the geological section in Figure (1), is studied experimentally taking into consideration the following :

1- Cut-off wall is of impermeable material, its penetration depth (d) is measured from the upstream horizontal base level of the dam and distance (X) is measured from the heal of the dam.
2- Downstream face of the dam acting as a filter.
3- The dam and supporting soil are of the same homogeneous material. The upstream and the downstream base of the dam at the same level.
4- The total seepage discharge is divided into; seepage discharge entering the filter and seepage discharge escaped to the soil layers.

Experimental work is carried out to study the effect of the retained water head (H), the penetration depth of the cut-off wall (d), cut-off wall distance (X) and depth of the pervious layer (D), measured vertically from the upstream base level of the dam, on both head loss due to cut-off wall (h), seepage discharge to the filter (q_f), and total discharge (q_t).

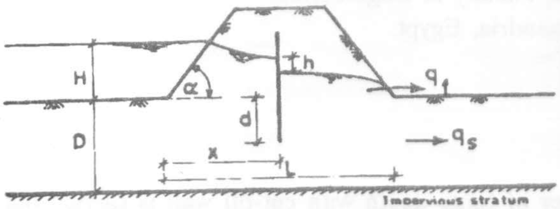


Figure 1. geological section.

EXPERIMENTAL SET-UP

The experimental set-up is shown in Figure (2). It mainly consists of two parallel transparent plates 1.5 mm apart. The interspace being kept constant by fixing washers 1.5 mm and distributed along the flow domain region. The front plate is 1523 mm long, 1190 mm high and 10 mm thick. The back plate is 10 mm thick and has the dimensions of the flow domain (the dam and the pervious layer). A number of strips of the Klingarite sheet (14) is prepared to change the depth of the pervious layer under the dam (D) several times; 0.0, 50, 100, 150, 200, 300, 400, 600 and 890 mm. A vertical strip represents the cut-off wall is made from the same Klingarite sheet having a constant width 20 mm. The upstream face is fed from tanks (4) and (6). The later have an overflow tube (5) to get different values of the effective retained head at the upstream (H). The main supply tank (1) is connected to the feeder tank (6) by a tube (3) and the flowing oil (Super 7500-20 w/50) is controlled by a valve (2). The drained discharge to the filter (q_f) which is represented by a wide channel (11), is collected by a hole (9) to a tube (10). The seepage discharge through the soil (q_s) is collected by a vertical channel (12). The filter and soil discharge are measured by using graduated vessels (13). The loss of head due to the cut-off (h) is recorded at the same time. The overflow tube (5) and drained tube (15) discharges the excess oil to the collecting tank (16), and the oil is lifted again to the main supply tank (1) by a small centrifugal pump (18) through the pipe (19).

EXPERIMENTAL PROGRAM AND RESULTS

This paper aims to study the effect of any variation on the dimensions of the problem which shown in Figure (1) on the seepage characteristics. The variables are : the depth of the pervious layer under the dam (D), the distance of the cut-off measured from the upstream edge of the dam (X), the penetration depth of the cut-off wall through the pervious layer (d), and the retained head of water upstream the dam (H). In this problem, the seepage characteristics are : the quantity of seepage discharge which is drained through the filter (q_f), the quantity of seepage discharge through the pervious layer (q_s) and the loss of head due to the cut-off wall (h). This study is carried out on a Hele-shaw model which is shown in Figure (2). For all experiments, the outline dimensions of the dam are kept constant. The base length (L) equals 546 mm and the face and flank angles are constant and equal 60°. To overcome the requirements, all variables (D, X, d, and H) was changed in the model to simulate all cases. Experimental runs are divided into three groups shown in Table (1).

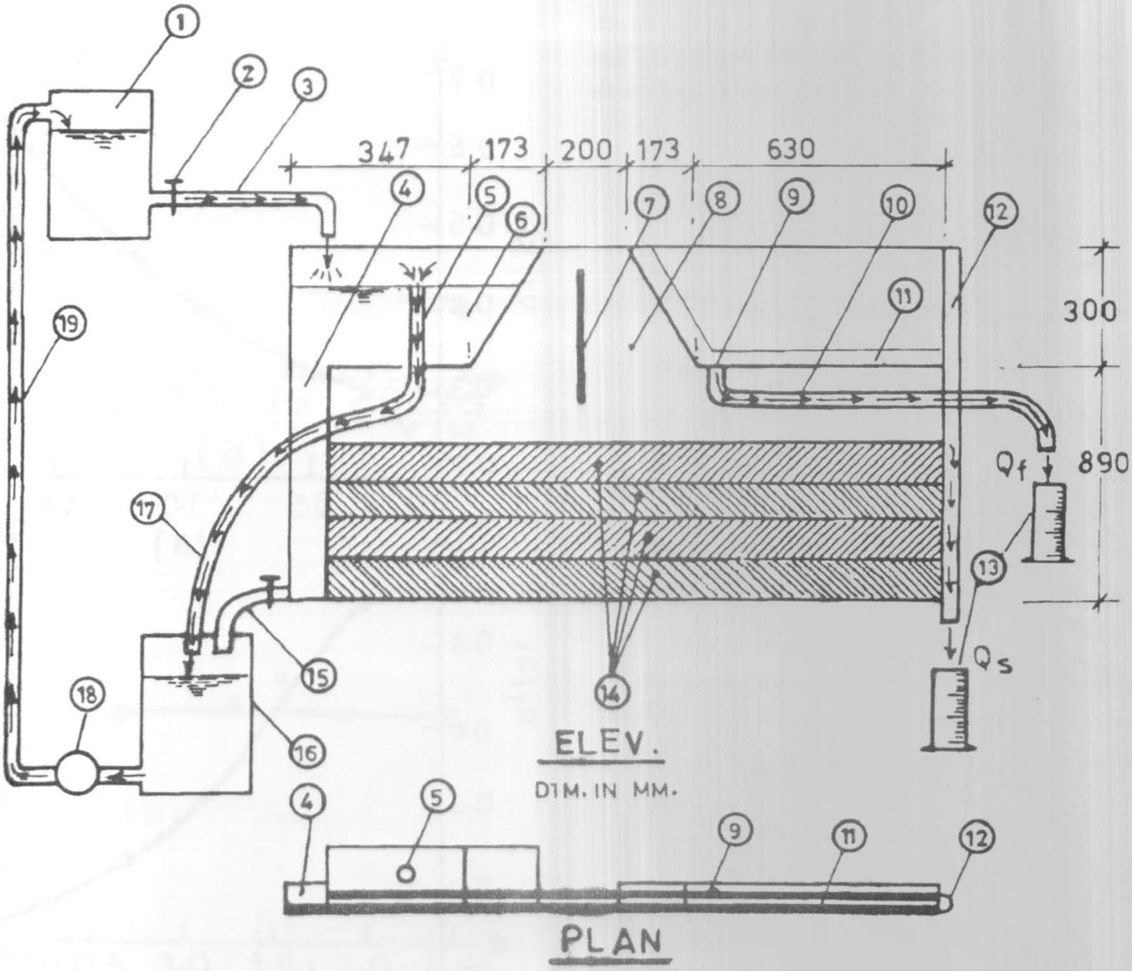
Table (1).

Group	No.of runs	D cm	x cm	d/D	H cm	Remarks
I	25	5,10,15, 20, and 30	---	---	4, 8, 12, 16, and 20	case without cut-off
II	100	5.0	10,20,30, and 40	0.0, 0.2, 0.4,0.6 and 0.8	4,8,12, 16, and 20	for x=10 cm H=4,8 ,12,16 and 18
III	100	10,15,20, and 30	20	0.0.0.2, 0.4,0.6, and 0.8	4,8,12,16, and 20	-

For all runs (225 runs), the quantity of seepage discharge which is drained through both the filter (q_f), and the soil (q_s) are measured and then, they are recorded as a total value, $q_t = q_f + q_s$. The ratio q_f/q_t is also determined and recorded. The experiments are made at a room temperature ranging between 23°C and 28.4°C. The hydraulic conductivity of the model which represents the coefficient of permeability of the soil (k) was calculated for each degree in this range from the following relation [1] :

$$K = \frac{a^2 g}{3 \nu}$$

Before taking readings, steady conditions are to be maintained. The results are presented in the form of curves. The variables and requirements are plotted in dimensionless form. Figure (3) represents the results of the case without cut-off (group-I). Figures (4,6,7,8, and 9)



Figure(2) Experimental set-up

1- The main supply tank.
2- Control valve.
3- Feeder tube.
4- Vertical deep tank.
5- Over flow tube.
6- Feeder tank.
7- Cut-off wall.
8- Model of the earth dam.
9- Filter drained sump.
10- Filter drained tube.
11- Horizontal wide channel (filter).
12- Vertical channel.
13- Graduated vessels.
14- Impervious layers.
15- Drained valve and tube.
16- Collecting tank.
17- Over flow draind tube.
18- Centrifugal pump.
19- Delivery pipe.

represent the results of group-II. Figures (5,10,11,12, and 13) represent the results of group-III.

ANALYSIS

Effect of Pervious Layer Thickness (D)

As shown in Figures (3) and (4-a & b), for constant values of X/L = 0.366, H/L = 0.293, and d/D = 0.0, the total quantity of seepage discharge through the dam (q_t) and the relative quantity of seepage which is drained through the filter (q_f/q_t) are affected by the variation of thickness (D). When the depth (D) is increased, the value of (q_t) is increased, while the ratio (q_f/q_t) is decreased.

Figure (4-c) indicates that, the loss of head due to the cut-off (h) has a slight effect by the variation of the depth (D). Therefore, it can be noticed that the depth (D) has the same effect on both earth dam with cut-off and earth dam without cut-off.

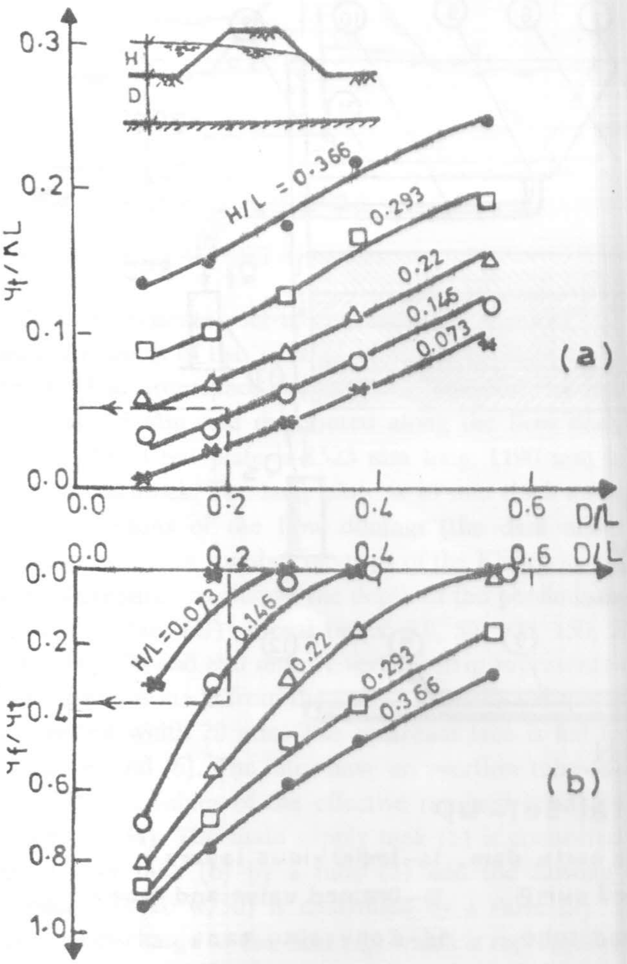


Figure 3. Group I (case without cut-off).

Effect of Distance of Cut-off Wall (X)

As shown in Figures (5-a & b), for constant values of D/L = 0.092, d/D = 0.4, and H/L = 0.293, the total quantity of seepage discharge through the dam (q_t) and the relative seepage discharge which is drained through the filter (q_f/q_t) are not affected by the variation in distance (X). Figure (5-c) indicates that the loss of head due to the cut-off wall has to be decreased when the distance (X) is increased. So that, the cut-off wall should be located at the upstream as possible.

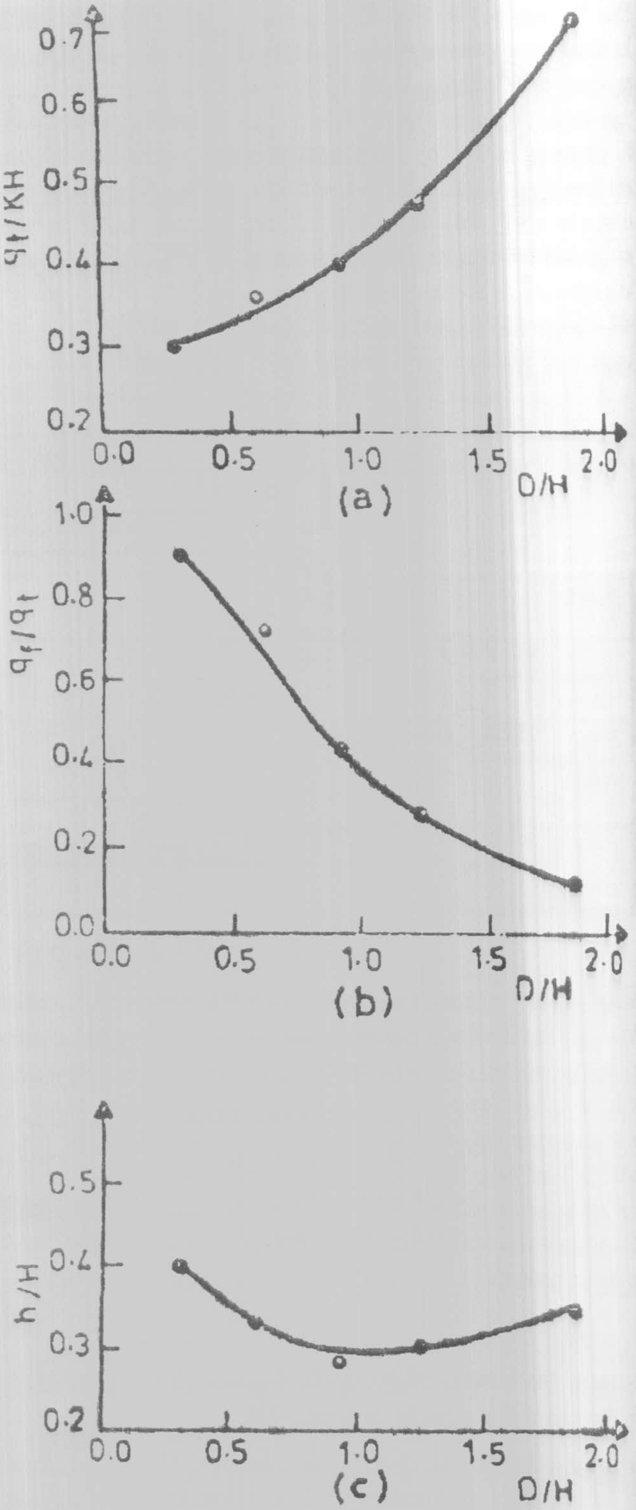


Figure 4. d/D = 0.0, x/L = 0.366 and H/L = 0.293.

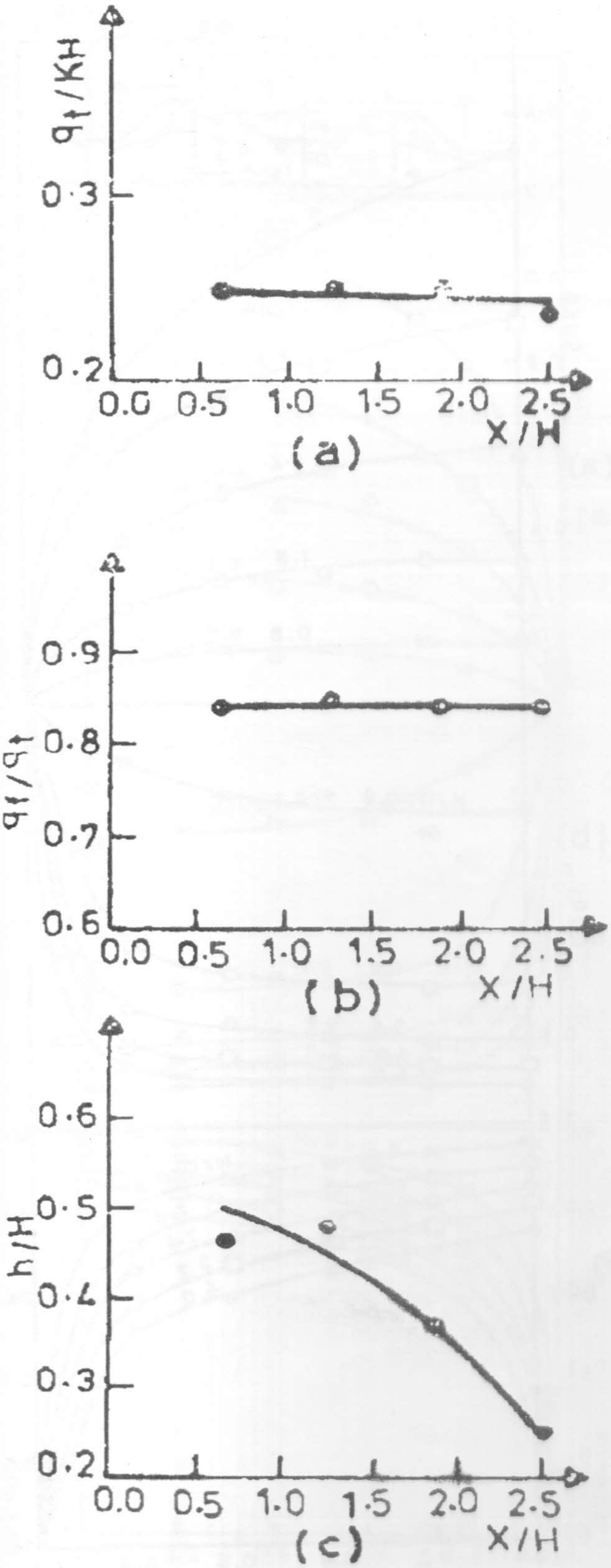


Figure 5. d/D = 0.4, D/L = 0.092 and H/L = 0.293.

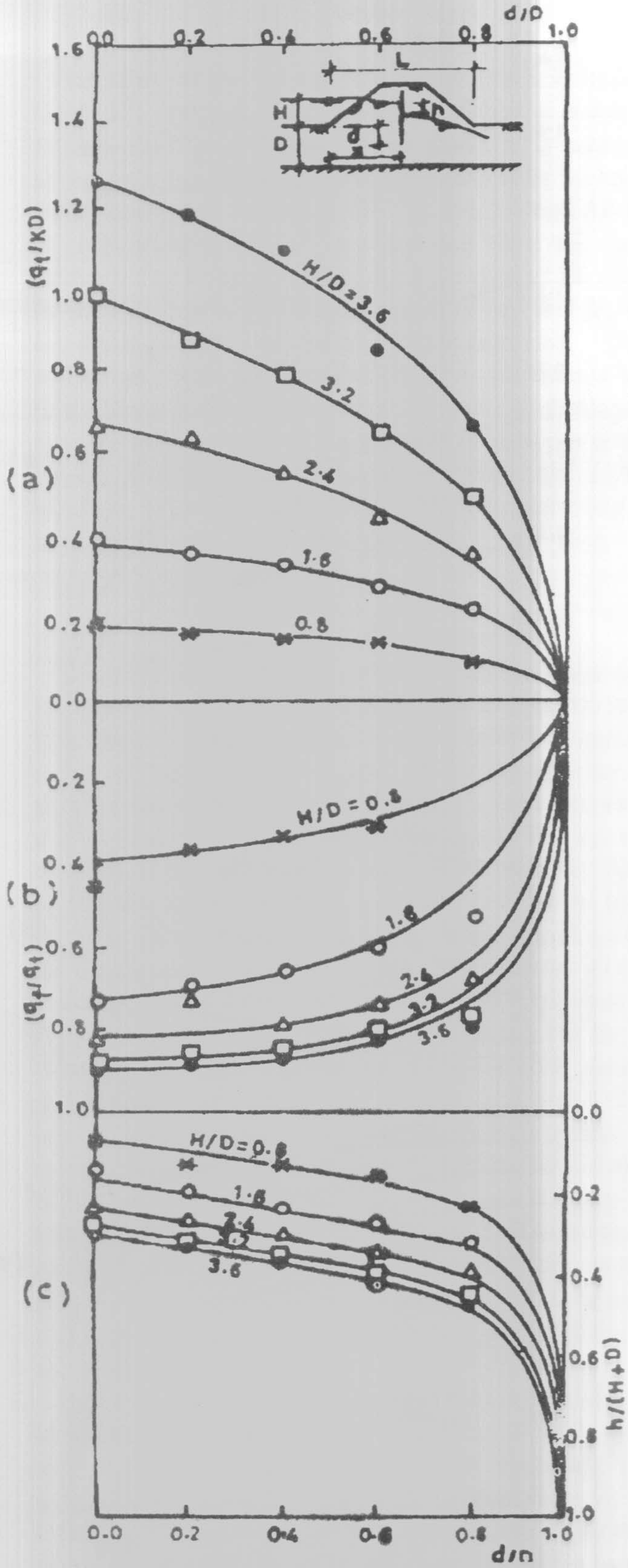


Figure 6. Group II (D/L = 0.092) X/D = 2.0.

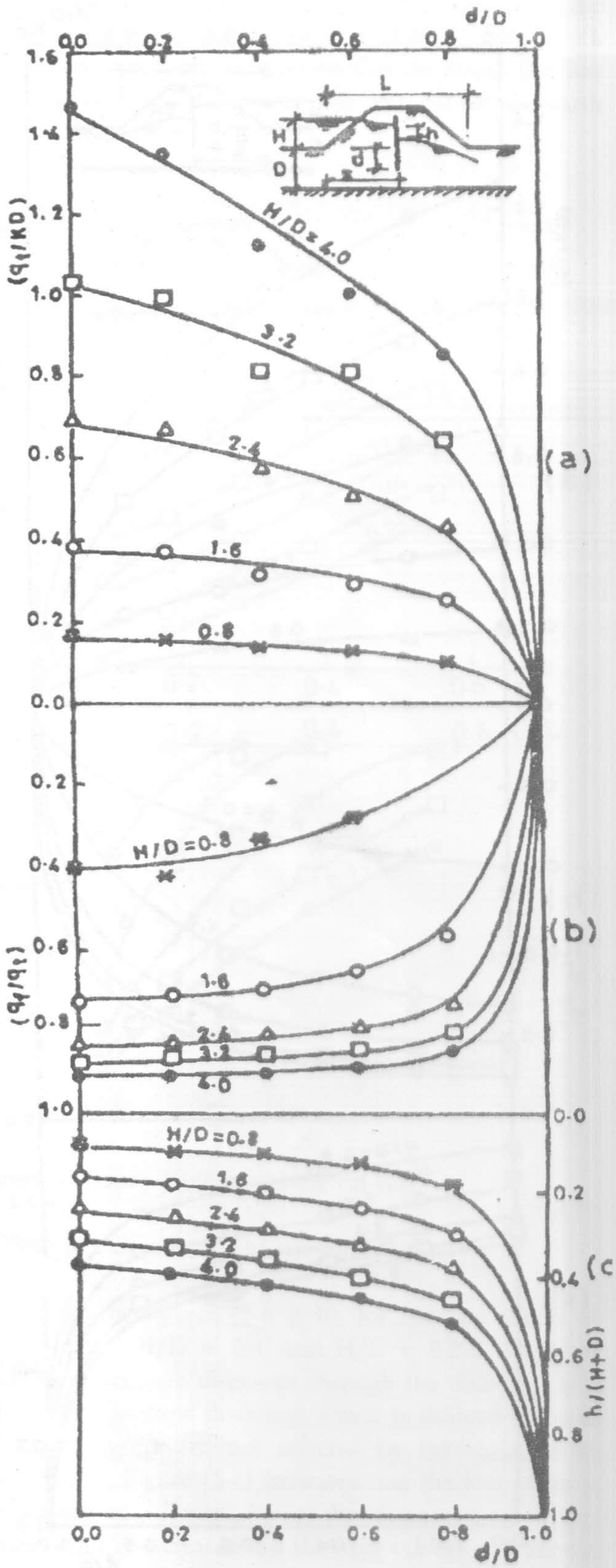


Figure 7. Group II D/L = 0.092) X/D = 4.0.

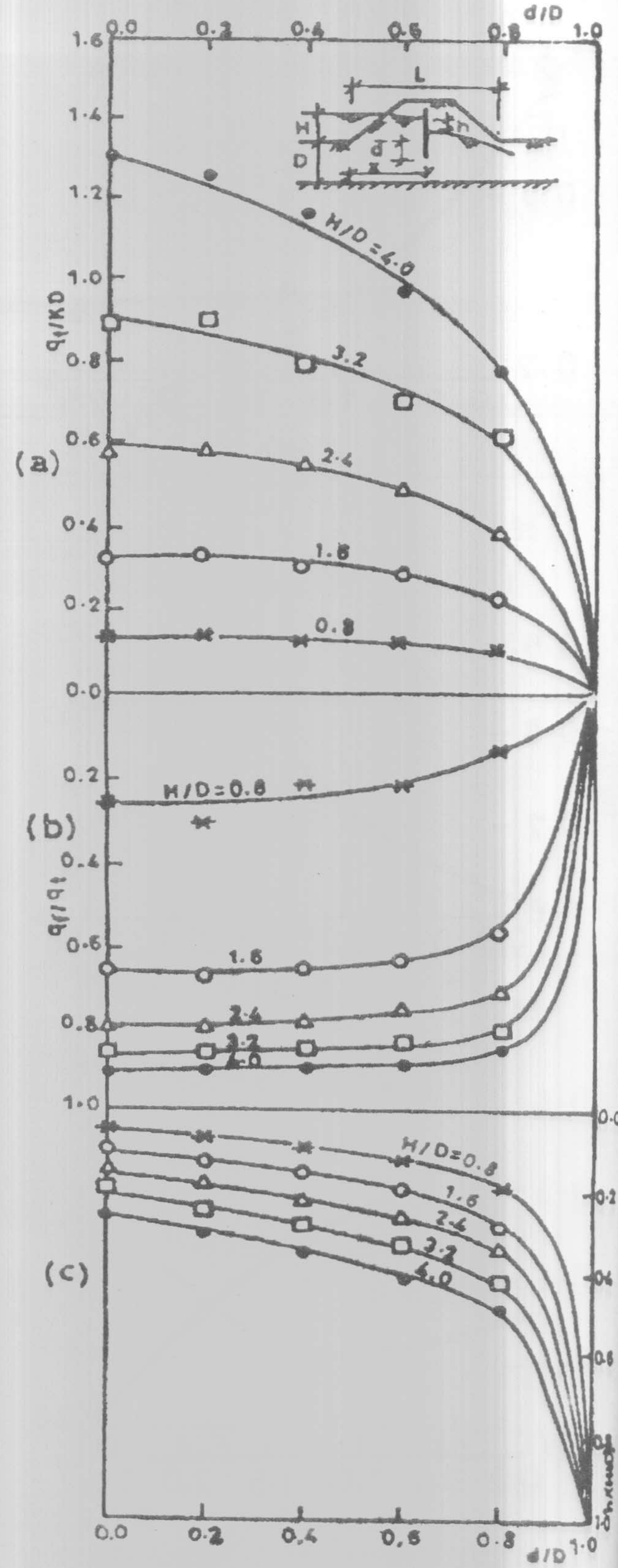


Figure 8. Group II (D/L = 0.092) X/D = 6.0.

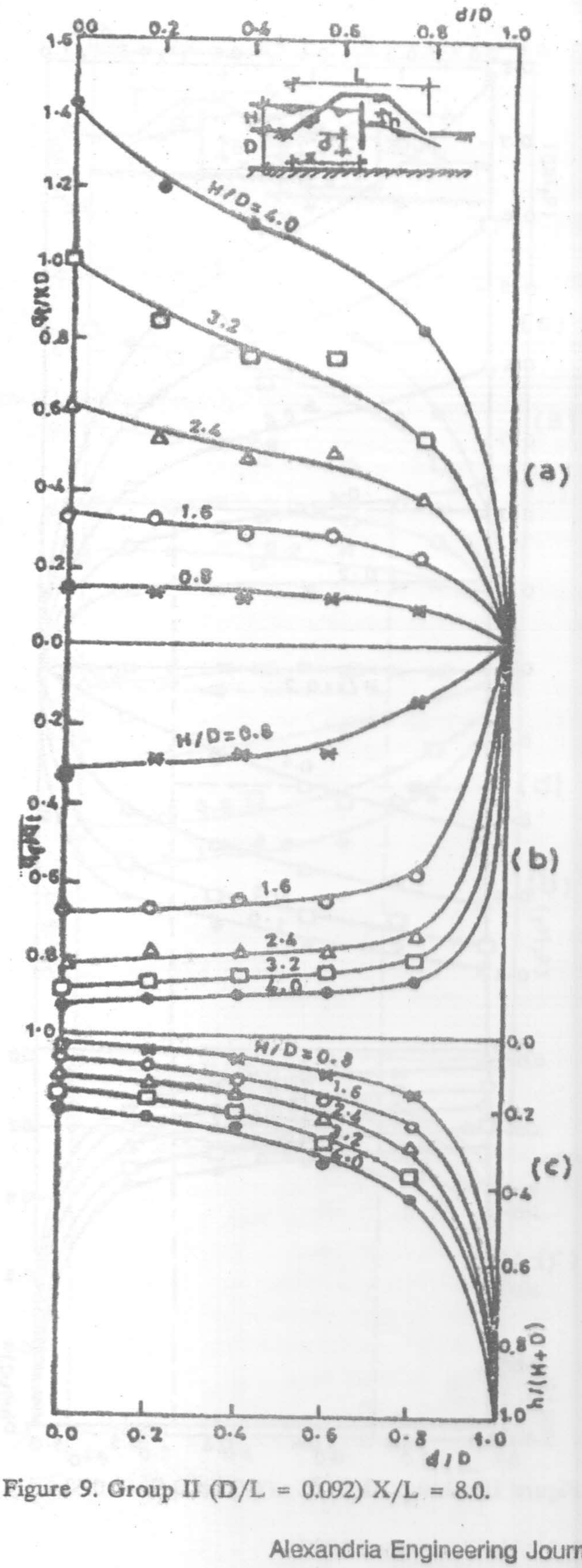


Figure 9. Group II (D/L = 0.092) X/L = 8.0.

Effect of the Cut-off Penetration Depth (d)

The effect of the cut-off penetration depth is studied herein in a wide range with all other variables as shown in Figures. (6-a & b) through (13-a & b). It is assumed always as a relative depth by the pervious layer thickness (d/D) and taken the values 0.0, 0.2, 0.4, 0.6, and 0.8 for all experiments. The figures indicate that, the total discharge (q_t) and the ratio (q_f/q_t) have appreciable effect by the variation of (d/D). The values of (q_t) and (q_f/q_t) are decreased when the ratio (d/D) is increased. They will be zero when the value of (d/D) = 1.0 because the flow domain is closed. Referring to Figures (6-c) through (13-c), it is found that, the relative loss of head due to the cut-off, h/(H+D), is increased as the ratio (d/D) increases. When the ratio (d/D) = 1.0, the relative loss of head, h/(H+D), will be equal 1.

Effect of the Retained Water Head (H)

The effect of the retained water head upstream the dam (H) can be analysed from Figures (3) and (6) through (13). Section (a) of the Figures show that, for constant values of (D), (X), and (d/D), the total quantity of seepage discharge through the dam (q_t) is increased when the retained water head (H) is increased. The relative quantity of seepage which is drained through the filter (q_f/q_t) is also increased for the same increase in head (H). The rate of increasing in (q_f/q_t) is also decreased for the same increase in (H). Figures (10-b) through (13-b) indicate that, the filter does not work for a small value of (H). For the value X/L = 0.366, D/X = 0.5 and for all values of (d/D) the filter is dry for $H/X \leq 0.20$, while it will always be dry for $H/X < 0.60$ for D/X = 1.5. The loss of head due to the cut-off, which is presented in section. (c) of the figures, is also affected by the variation of the retained water head (H). For constant values of (X), (D), and (d/D), the loss of head (h) is increased when the value of (H) is increased. Increasing the value of (H) by equal increments causes an equal excess in head due to cut-off. On other words, the rate of increasing in (h) is constant.

Figure (3) and Figures (6) through (13) can be also used as design charts for available dimensions of earth dams with inclination angles equal 60° at upstream and downstream. As mentioned before, the cut-off should be located at the upstream direction as it possible. The values of (q_t), (q_f/q_t) and (h) can be calculated for known values of (L), (D), (d), and (H) by helping of the design charts. Consequently, the quantity of seepage discharge which is drained through the filter $q_f = q_t \cdot (q_f/q_t)$ and the remained value is the quantity of seepage discharge through the pervious layer, $q_s = q_t - q_f$. The filter should be designed for maximum value of (q_f). The loss of head due to the cut-off can be also obtained from the charts. To illustrate the procedure of calculation, a solved example is prepared.

SOLVED EXAMPLE

Figure (14) shows the cross section and dimensions of an earth dam with a cut-off founded on a finite depth of a pervious layer. It is required to calculate the quantity of seepage discharge which is drained through the filter and the loss of head due to the cut-off. Recalculate the same requirements for the case without cut-off.

Solution

From the figure, D = 6.0 m, X = 10 m, d = 4.2 m, H = 5.0 m, K = 0.01 cm/sec, and L = 30 m (D/L = 0.2, X/L = 0.33, d/D = 0.7, and H/L = 0.166).

a- Case with a cut-off

For D/L = 0.2, Figures (10) and (11) are used. As mentioned before, the values of (q_t) and (q_f/q_t) are constant for any value of (X/L).

For D/L = 0.138, Figure (10), $q_t/KD = 0.125$, $q_f/q_t = 0.30$ and $h/(H+D) = 0.20$

For D/L = 0.275, Figure (11), $q_t/KD = 0.220$, $q_f/q_t = 0.05$ and $h/(H+D) = 0.18$

For the present case D/L = 0.20, and by interpolation, the following results are obtained :

$q_t/KD = 0.216$, $q_f/q_t = 0.2538$, and $h/(H+D) = 0.1963$

$$q_t = 0.216 \times \frac{0.01}{100} \times 6.0 \times 24 \times 60 \times 60 = 11.197 \text{ m}^3/\text{day/m}$$

$q_f = 11.197 \times 0.2538 = 2.842$ m /day/m, and

$h = 0.1963\ (5+6) = 2.16$ m

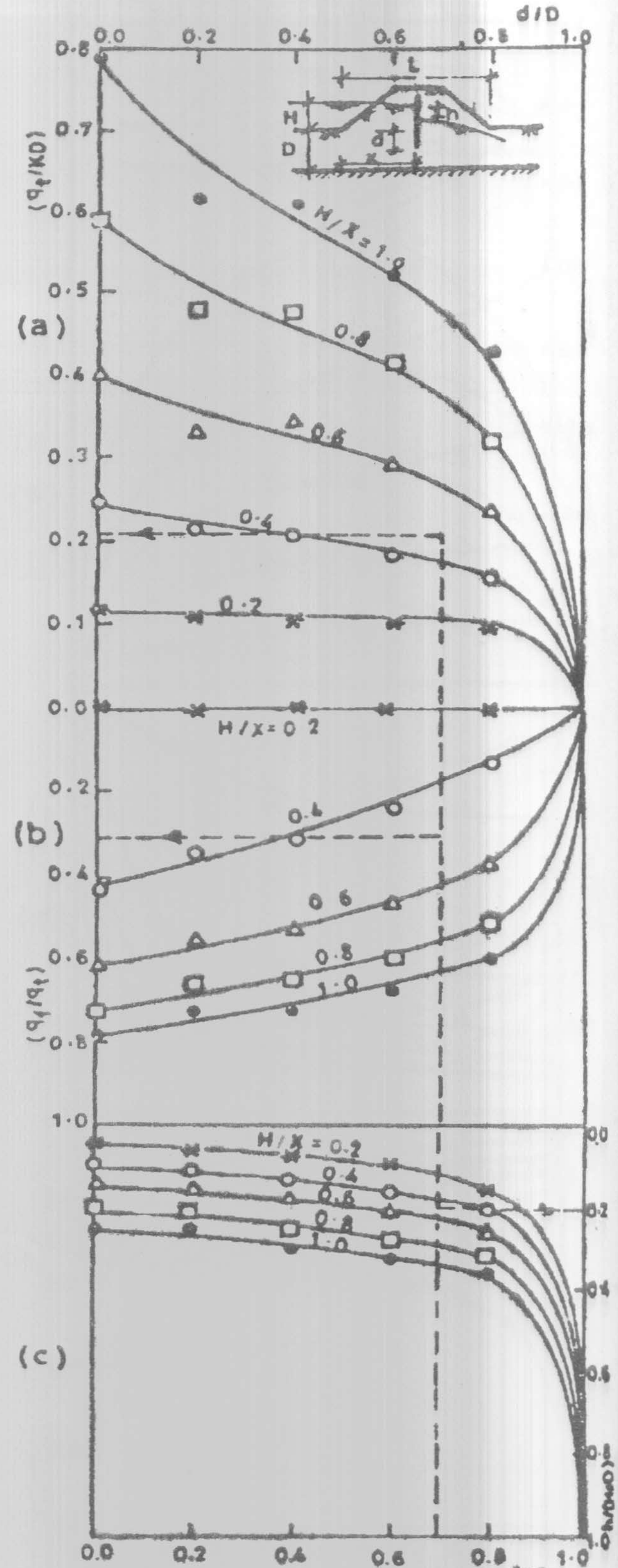


Figure 10. Group III (X/L = 0.366) D/X = 0.50.

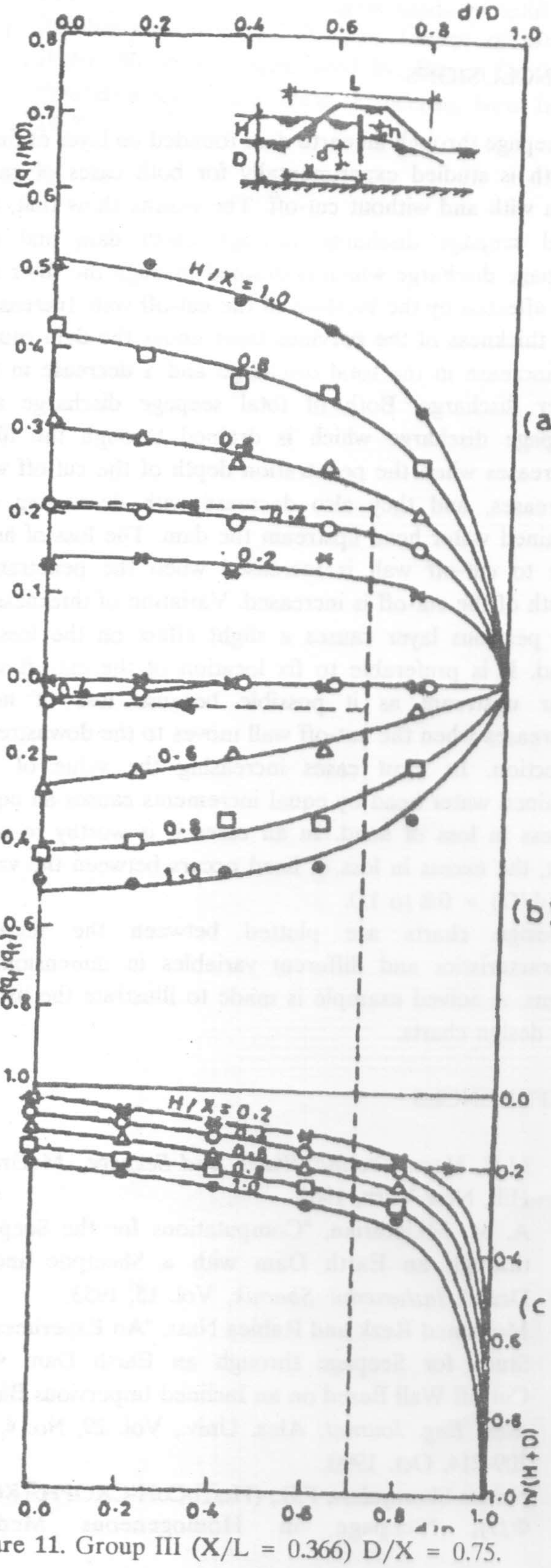


Figure 11. Group III (X/L = 0.366) D/X = 0.75.

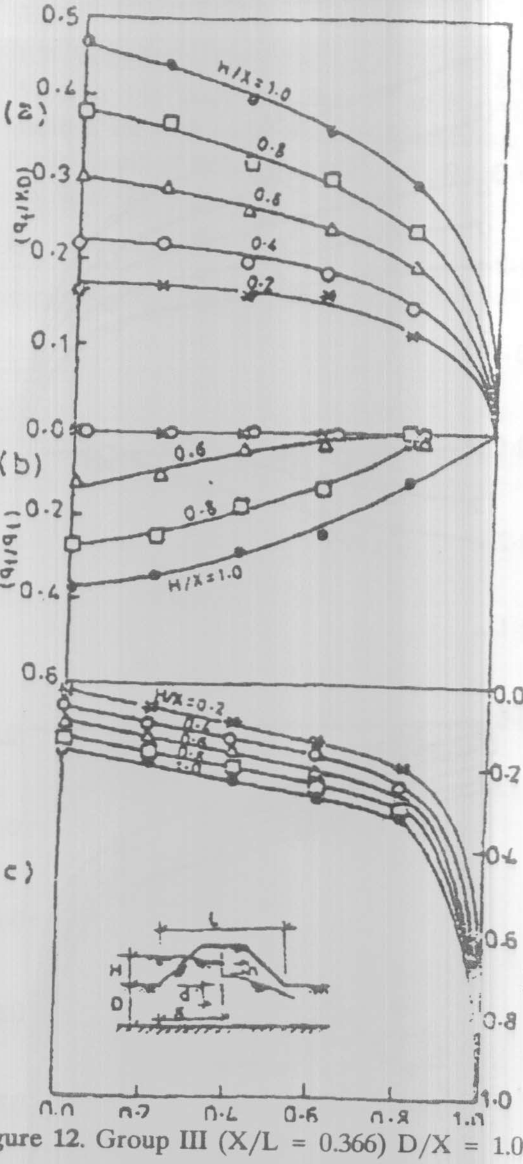


Figure 12. Group III (X/L = 0.366) D/X = 1.0.

b- case without a cut-off

By using Figure (3), the following results are obtained :

$q_t/KL = 0.050, \ q_f/q_t = 0.36$

$$q_t = 0.05 \times \frac{0.01}{100} \times 30 \times 24 \times 60 \times 60 = 12.96 \ m^3/day/m$$

$q_f = 12.96 \times 0.36 = 4.666$ m /day/m, and

h = 0.0

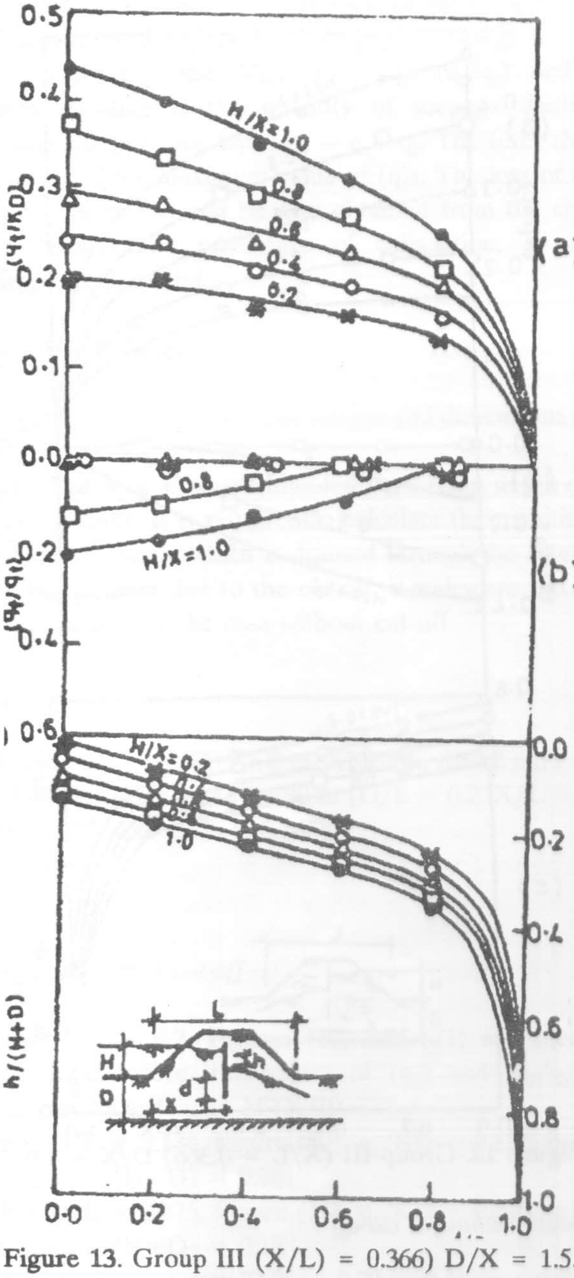


Figure 13. Group III (X/L) = 0.366) D/X = 1.5.

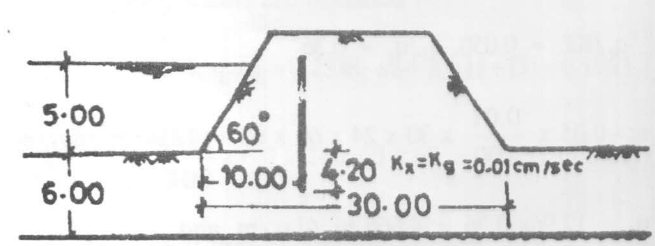


Figure 14.

In the solved example, the results indicate that the cut-off reduces the quantity of seepage drained through the filter by about 40%.

CONCLUSIONS

Seepage through an earth dam founded on layer of finite depth is studied experimentally for both cases of earth dam with and without cut-off. The results show that, the total seepage discharge through earth dam and the seepage discharge which is drained through the filter are not affected by the location of the cut-off wall. Increasing the thickness of the pervious layer under the dam causes an increase in the total discharge and a decrease in the filter discharge. Both of total seepage discharge and seepage discharge which is drained through the filter decreases when the penetration depth of the cut-off wall increases, and they also decrease with decreasing the retained water head upstream the dam. The loss of head due to cut-off wall is increased when the penetration depth of the cut-off is increased. Variation of thickness of the pervious layer causes a slight effect on the loss of head. It is preferable to fix location of the cut-off wall near upstream as it possible because loss of head decreases when the cut-off wall moves to the downstream direction. In most cases increasing the value of the retained water head by equal increments causes an equal excess in loss of head. In all cases it is worthy to note that, the excess in loss of head occurs between the value of (d/D) = 0.8 to 1.0.

Design charts are plotted between the seepage characteristics and different variables in dimensionless forms. A solved example is made to illustrate the use of the design charts.

REFERENCES

[1] M.E. Harr, *Ground Water and Seepage*, McGraw-Hill, New York, 1962.

[2] A. M. Mkhitarian, "Computations for the Seepage through an Earth Dam with a Sheetpile and a Drain", *Inzhenernii Sbornik*, Vol. 15, 1953.

[3] Mohamed Rezk and Rabiea Nasr, "An Experimental Study for Seepage through an Earth Dam with Cut-off Wall Based on an Inclined Impervious Base", *Alex. Eng. Journal*, Alex. Univ., Vol. 29, No. 4, pp 209-214, Oct. 1990.

[4] Nelson-Skornyakov, F.B., (HeДbCoH-CKOPHЯKOB, Ф,Б), "Seepage in Homogeneous Media",

Gosudarctvennoe Izd., Sovetskaya Nauka, Moscow, 1949.

[5] Polubarinova-Kochina, P. Ya., *Theory of Ground Water Movement*, translated by, Roger De Wiest, Princeton University Press, Princeton, New Jersey, 1962.

[6] N.N. Rozanov, *Earth Dams*, Moscow, Strouizdat, 1983.

[7] A.P. Voshchinin, (ВОЩНИН,А.Л), "Flow Ground Water in the Body and Base of an Homogeneous Earth Dam with an Horizontal Underdrain with a Finite Depth of Permeable Material", *DAN*, Vol. 25, No. 9, 1939.