Analysis and Estimation of Seepage Through Earth Dams with Internal Cut Off

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Research Article

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Abstract

The study of seepage through earth-fill dams is very important for the constructed dams to ensure that the control of seepage is sufficient for the safe and sustainable operation of the dam. It is also important in the design and construction of new dams to ensure that the seepage through and under the dam will be well controlled. Construction horizontal, inclined, trapezoidal or pipe filters one of the dam protection methods. Cut off also can be constructed to minimize seepage discharge directed to the downstream face of the dam. Seepage through an earth dam with internal cut off is experimentally studied in the laboratory of Irrigation Engineering and Hydraulics Department, Faculty of Engineering, Alexandria University, Egypt on a Hele-Shaw model. Also, using computer program SEEP/W (which is a sub-program of Geo-Studio). The experimental and numerical analyses of seepage through earth-fill dam with internal cut off is conducted. Results from solutions are compared with each other.

1. Introduction

Earth dams are widely used across rivers to retain and store its water, also used as embankment in irrigation canals. It is important to reduce dam width at base with respect to its safety against seepage which considers the main dangerous factor, therefore, many causions be taken and constructed to prevent failure against seepage. El Molla (2019), presented the Seepage through homogeneous earth dams provided with a vertical sheet pile and formed on impervious foundation. She found that the sheet pile height decreases the total seepage discharge by a ratio up to 34.4% of its value without sheet pile. Javanmard, Mottaghi and Hosseini (2018), Investigated the Influence of Penetration Length of Cut-off Wall on its Dynamic Interaction with Core and Foundation of Earth Dam. They found that the horizontal displacement of the cut-off wall just after penetrating into core, considerably increases, which is due to smaller stiffness of core material to that of foundation. Aghajani and Anzabi (2018), Selected Optimum Cutoff Wall Position for Rehabilitation of an Inclined Core Earth fill Dam. They found that if the cut off wall is not connected to a lower impervious layer of foundation, the effects of the cut off walls position variations on the seepage value are significant also if the cut off wall is constructed at the dam heel, minimum seepage occurs. Sazzad and Islam (2019), presented the Effect of Width, Length and Position of Cutoff Wall on the Seepage Characteristics of Earth Dam. They found that the numerical results depict that the best possible position of the cut off walls is at the downstream toe of the dam. This is because in this position, most number of flowlines gets encountered by cut off wall. They are also observed that the effect of the width of cut off wall on the total head and pore water pressure (PWP) is negligible but it affects the velocity of seepage and total discharge. Cato and Rogers (2018), presented the Failure of the Alexander Dam Embankment and Reconstruction Using Drainage Mitigation on Kauai, Hawaii, 1930–1932. They found important lessons which are: The necessity of effective internal drainage in the sloping shells of a hydraulic fill embankments. They used volcanic residuum which is problematic because of disaggregation and breakdown of clods, creating a semi-impervious and low-strength fill. Attia, Abdel Razek and Abdel Salam (2021), studied experimentally the seepage through earth dams with internal cut off using Hele-Shaw model. They found that the minimum discharge entering the filter occurs when the cut off locates in the middle length of the dam base. Also, the maximum drop in phreatic surface, which produces minimum dam width, occurs at the same distance. Therefore, it can be said that the optimum position of cut off is the position which gives minimum discharge directed to the filter and maximum drop in phreatic surface.

2. Experimental Set-up

Hele-Shaw model is a laboratory research device that can be used to analyze steady groundwater flow problems. The model shown in Fig.1 and consists of two Perspex plates. A constant spacing between Perspex plates is kept constant by using Klingerit washers, 1.27 mm thickness. The slope of the upstream and downstream face of the dam has a constant inclination 1:1. An impervious strip of the Klingerit material (14) is used to fix depth of the pervious base of the dam. The dam model is fed from a tank (1) having an overflow tube (17) to control the upstream retained head of the dam. A tank (16) is used to collect the excess oil (SUPER 7500 -20W/50) passing through the overflow tube (17) and the flexible joint. The seepage discharge through the soil and filter are collected using a graduated tube (13). The collected oil in tank (14) is lifted to the main supply tank (1) by a centrifugal pump (18) through a tube (19). The flowing oil from the main supply tank is controlled by a valve (2). Seepage discharge and drop in phreatic surface due to cut-off are experimentally measured, so that comparison with SEEP/W can be achieved.

3. Seep/w

3.1. Numerical Model

A homogenous earth dam with dimensions shown in Fig. 2 is taken similar to the experimental set-up. In boundary condition, water level (total head) in upstream is 30 cm, water level in downstream is assumed zero meters. Also, the foundation’s floor and its right and left walls and the downstream slope of dam shell are impermeable (zero flow). Nodes around the horizontal drain have atmospheric pressure (zero pressure). The upstream and downstream slope shell of dam have inclination 1V:1H. Seep/w software can automatically generate a well-behaved unstructured pattern of quadrilateral and triangular elements. In this study, unstructured pattern of quadrilateral elements used in simulation. Two-dimensional simulation of homogenous earth dam has 200 cm length foundation. A 2-cm thick remedial cutoff wall is constructed inside the dam body, and extended to the foundation to improve the current earth fill dam performance, and decrease seepage in the dam body and foundation.

3.2. Material Properties

For the numerical analysis of the models of the earthen dam with cutoff wall using SEEP/W, the material for the body of dam and the foundation is considered to be Coarse Sand for all cases. Here, the cutoff wall is considered to be of completely impermeable material. The coefficient of permeability used for the numerical analysis is calculated from Darcy low as shown below.

$$Q = -K.i.A$$

$$= -K.\frac{dy}{dx}.(y*1)$$

$$Q\int_{x}^{D_w} dx = -K\int_{D}^{y_2} y\,dy$$

$$Q(D_w - x) = -K\left[\frac{y^2}{2}\right]_D^{y_2}$$

$$Q = -\frac{K}{2(D_w - x)}\left[(H + D - \Delta h_1 - \Delta h_2 - \Delta h_3)^2 - D^2\right]$$

$$\boldsymbol{K = \frac{2Q(D_w - x)}{(H+D-\Delta h_1-\Delta h_2-\Delta h_3)^2-D^2}} \text{.......................................} \textbf{ eq.1}$$

From Fig.3 and by applying eq.1 using experimental data to find the used range of (K) which shown in Table.1.

4. Analysis Of Results

Fig. 4(a) and Table. 3 show that, the average ratio between experimental discharge and that resulted from SEEP/W equals 0.86, for D/H=0.5 and X/Dw=0.5.

Fig. 4(b, c) and Table. 3 show that average experimental discharge equals 0.94 and 1.18 of that resulted from SEEP/W, for and 1.0 respectively.

For , experimental discharge exceeds than that resulted from SEEP/W by 0.23. In addition, for experimental discharge reaches to be 0.93 of that given from SEEP/W as shown in Fig. 4(d, e).

From Table. 2 and Fig. 5, it is clear that experimental results are almost very near to that obtained from SEEP/W.

Phreatic surface due to SEEP/W and experimental work is drawn as shown in Fig.6. It is clear that a good agreement between the two methods.

5. Conclusions

Earth dam with an internal cut off is experimentally and numerically studied and the following conclusions are made: -

1. A comparison between experimental and numerical results deduced from SEEP/W, is made and a good agreement has been shown for to 2.0.
2. An average ratio between experimental discharge and that obtained from SEEP/W equals 1.028.
3. A good agreement between phreatic surface drawn from SEEP/W and that measured experimentally.

6. References

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Tables

Table. 1 The Coefficient of Permeability used for the Numerical Analysis

Type of the material	Coefficient of Permeability, k_{sat} (m/s)
Shell and Foundation	0.021~ 0.0811
Cutoff	(1/100) $K_{\text{Shell and Foundation}}$

Table. 2 Average values of experimental discharge related to that obtained from SEEP/W

D/H	0.5	0.75	1.0	1.5	2.0
	0.86	0.94	1.18	1.23	0.93

Table. 3 The average ratio between experimental discharge and that resulted from SEEP/W

D=15 cm, X=50 cm, H=30 cm			
X/Dw=0.5, D/H=0.5			
q_t $cm^3/sec/cm$` EXPERIMENTAL	K cm/sec DARCY	q_t $cm^3/sec/cm$` SEEP/W	qexp/qseep
16.27	2.52	17.4	0.94
16.8	2.56	19	0.88
17.59	2.47	20.2	0.87
18.37	2.6	22.6	0.81
18.64	2.55	23.3	0.8
		average Value	0.86

D=45 cm, X=50 cm, H=30 cm				
X/Dw=0.5, D/H=1.5				
d/D	q_t $cm^3/sec/cm$` EXPERIMENTAL	K cm/sec DARCY	q_t $cm^3/sec/cm$` SEEP/W	qexp/qseep
0.2	56.17	3.37	46.9	1.2
0.4	56.17	3.33	47.6	1.18
0.6	60.63	3.47	49.9	1.22
0.7	62.47	3.3	49.8	1.25
1	65.62	3.29	51.1	1.28
			average Value	1.23

D=22.5 cm, X=50 cm, H=30 cm			
X/Dw=0.5, D/H=0.75			
q_t $cm^3/sec/cm$` EXPERIMENTAL	K cm/sec DARCY	q_t $cm^3/sec/cm$` SEEP/W	qexp/qseep
22.31	2.49	23	0.97
22.83	2.47	24.1	0.95
23.36	2.42	24.7	0.95
23.62	2.38	25.4	0.93
23.88	2.28	25.9	0.92
		average Value	0.94

D=60 cm, X=50 cm, H=30 cm				
X/Dw=0.5, D/H=2.0				
d/D	q_t $cm^3/sec/cm$` EXPERIMENTAL	K cm/sec DARCY	q_t $cm^3/sec/cm$` SEEP/W	qexp/qseep
0.2	102.36	7.58	120.6	0.85
0.4	115.49	8.11	132	0.87
0.6	123.36	7.97	132.8	0.93
0.7	125.98	7.76	132.2	0.95
1	128.61	7.15	124.5	1.03
			average Value	0.93

D=30 cm, X=50 cm, H=30 cm			
X/Dw=0.5, D/H=1.0			
q_t $cm^3/sec/cm$`	K cm/sec	q_t $cm^3/sec/cm$`	qexp/qseep

EXPERIMENTAL	DARCY	SEEP/W	
27.56	2.1	23.3	1.18
29.13	2.12	24.4	1.19
30.45	2.16	25.8	1.18
31.5	2.16	26.7	1.18
32.02	2.12	27.1	1.18
		average Value	1.18

Figures

1. The Main Supply Tank
2. Control Valve
3. Feeder Tube
4. Oil (SUPER 7500-20W/50)
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
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13. Graduated Vessels
14. Impervious Layers
15. Drained Valve and Tube
16. Collecting Tank
17. Overflow Drained Tube
18. Centrifugal Pump
19. Delivery Pipe

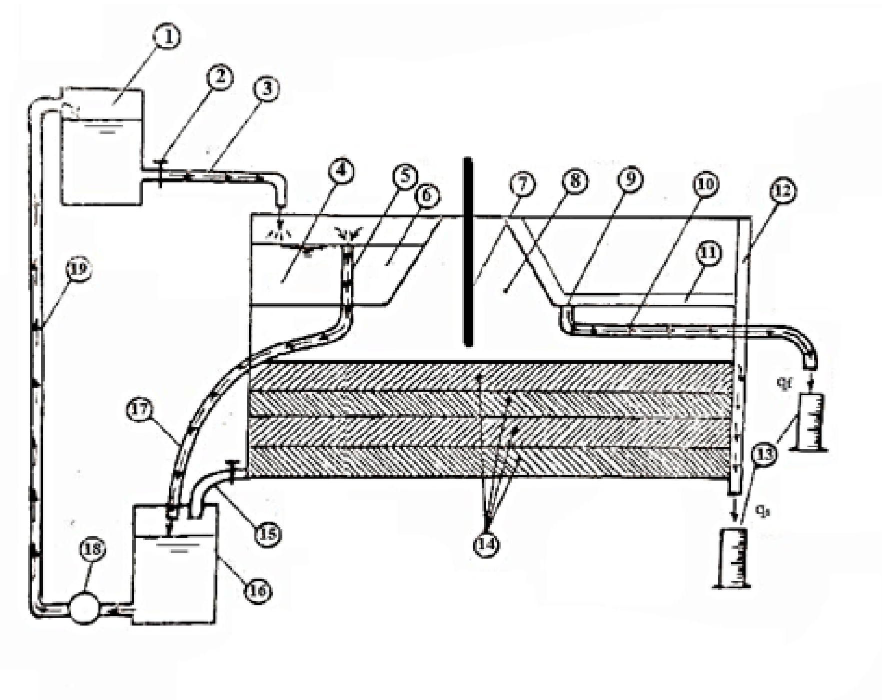

Figure 1

Experimental Set-Up

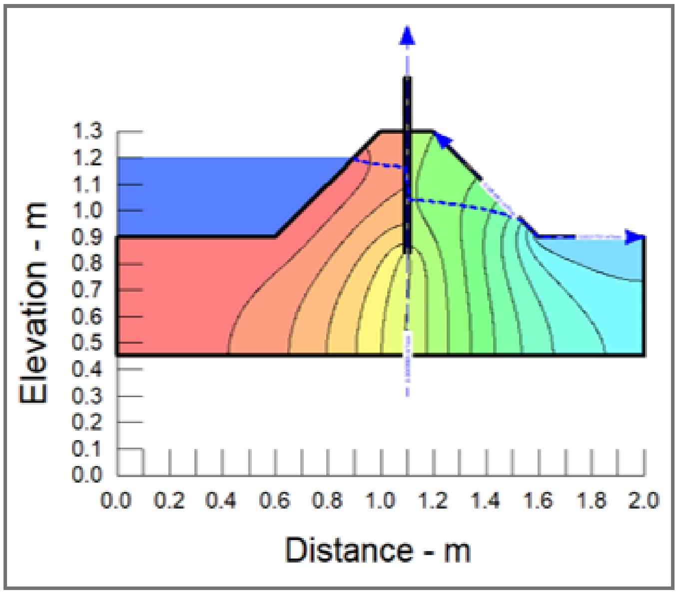

Figure 2

Cross section of homogenous earth dam used in SEEP/W

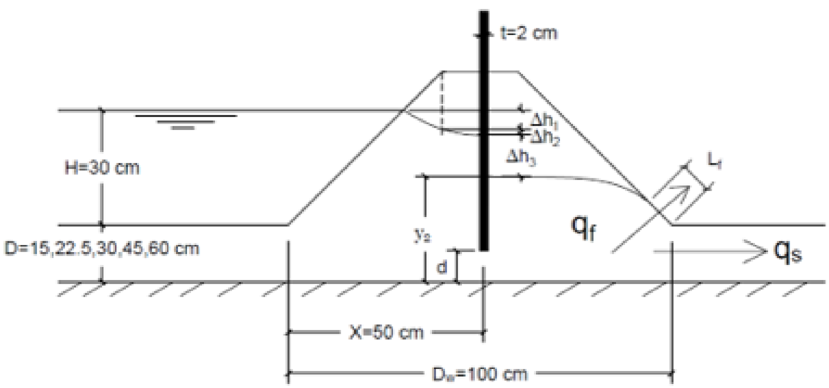

Figure 3

Dimensions of earth dam

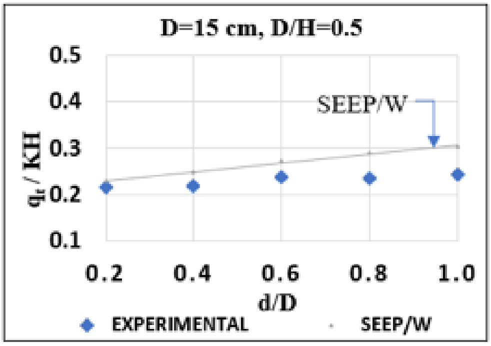

Fig. 4(a)

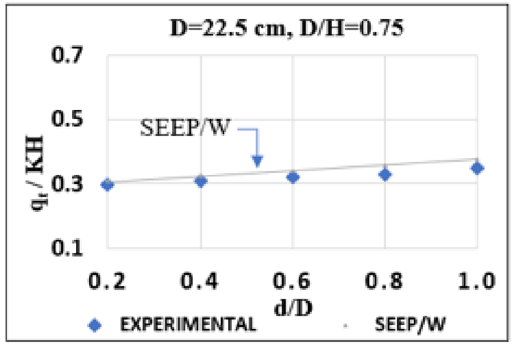

Fig. 4(b)

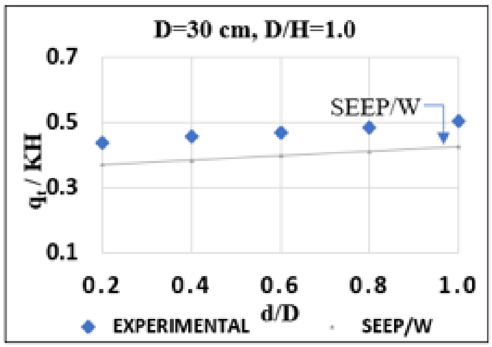

Fig. 4(c)

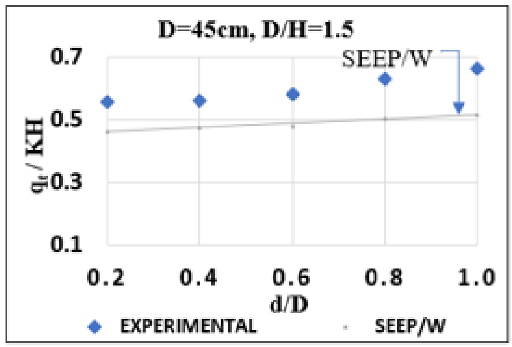

Fig. 4(d)

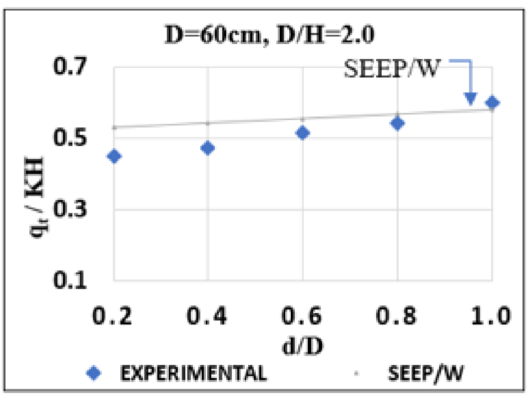

Fig. 4(e)

Figure 4

(a) The relation between the relative total discharge (qt/KH) and the relative cut off penetration depth (d/D) for D=15cm. (b) The relation between the relative total discharge (qt/KH) and the relative cut off penetration depth (d/D) for D=22.5cm (c) The relation between the relative total discharge (qt/KH) and the relative cut off penetration depth (d/D) for D=30cm (d) The relation between the relative total discharge (qt/KH) and the relative cut off penetration depth (d/D) for D=45cm. (e) The relation between the relative total discharge (qt/KH) and the relative cut off penetration depth (d/D) for D=60cm.

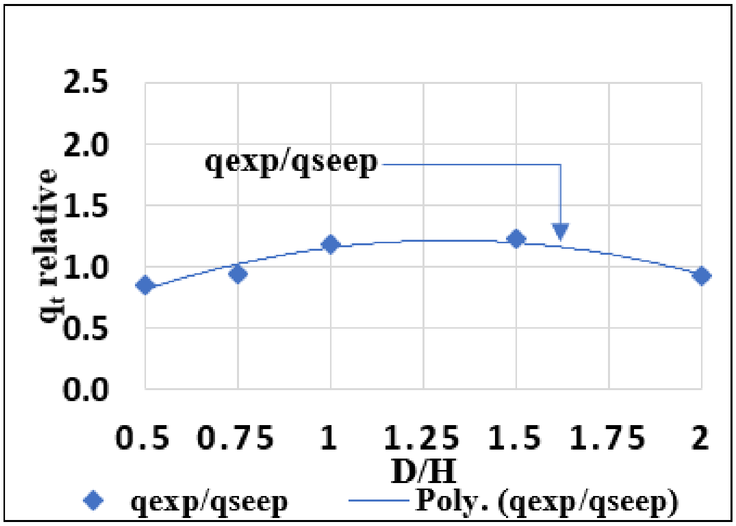

Figure 5

The relation between the relative total discharge (qt) and the relative pervious layer depth (D/H).

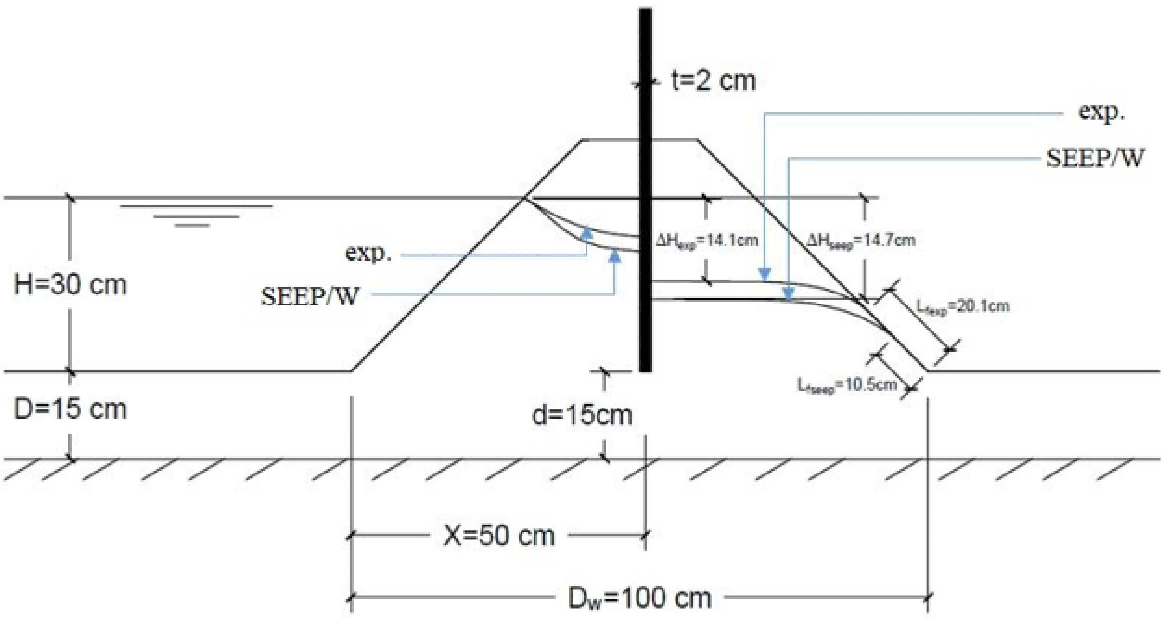

Figure 6

Phreatic surface due to SEEP/W and experimental work