EARTH DAMS WITH AN INTERNAL CORE

Mohamed Abd El-Razek M. Rezk
Irrigation and Hydraulics department, Faculty of Engineering,
Alexandria University, Alexandria, Egypt.

ABSTRACT

The problem of seepage through an earth dam with an internal core is investigated experimentally in this paper. The core has less permeability than that of the dam body. The change of the relative permeability between the core and the body of the dam is studied. Based on the experimental results, an empirical equation for calculation quantity of seepage passing through earth dam with internal core is recommended. A comparison between the recommended equation and that given by N.P. Rozanov [11] and N.N. Rozanov [12] is made for different values of the relative permeability of the core. Free water surface is recorded experimentally so that, drop due to the core can be measured. Another empirical equation is put to calculate the reduction in the quantity of seepage due constructing the core.

Keywords: Earth dams, Core, Seepage, Filter.

NOTATION

B	base width of the dam,
g	acceleration due to gravity,
h_1	height of the free water surface at the core end, measured vertically from the impervious base, Figure (3),
H	the upstream retained water head,
K	coefficient of permeability, Ref. [3],
K_c	permeability of the core material,
K_T	permeability of the dam body,
L	horizontal distance measured from the core end to the beginning of the filter,
Q_1	seepage discharge of earth dam with an internal core,
Q	seepage discharge of earth dam without internal core,
R	reduction in quantity of seepage discharge due to constructing the core,
S_1	horizontal distance denoted by equation (5),
t	the inner distance between the two prespex plates,
T	total height of the dam,
α	angle of inclination of the upstream face of the dam, equals 45°,
β	angle of inclination of the downstream face of the dam, equals 30°,
υ	kinematic viscosity of the oil used in experiments,
δ_c	width of the internal core, Figures (1,2,3), and
δ'_c	equivalent width of core, denoted by equation (4) and shown in Figure (1).

INTRODUCTION

The problem of seepage through an earth dam with internal core and based on an impervious base is investigated in this paper. The core of the dam can be constructed of impervious material [1,8,9] or of material has less permeability than that of the main body of the dam [5, 6, 7]. According to the shape of the core it can be constructed vertically or in sloping position [2,4]. In such case, the core function is to cut the seepage line or to minimize seepage discharge by making drop in the free water surface. In earth dams containing internal core, less base width of the dam can be achieved. The seepage discharge through the core is given by N.P. Rozanov [11] as follow:

$$Q_1 = q_1 + q_2 \text{ cm}^2/\text{sec} \qquad (1)$$

where q_1 and q_2 represent the quantity of seepage passing through the upper part and the lower part of the core respectively, Figure (1), and are given by the following equations:

$$q_1 = 1.35\ K_c\ [\sqrt{1.82(\delta'_c)^2 + (H-h_1)^2} - 1.35\ \delta'_c] \qquad (2)$$

$$q_2 = k_c\ [\frac{H-h_1}{\delta'c}].h_1 \qquad (3)$$

$$\delta'_c = (\frac{K_c}{K_T})\ S_1 + \delta_c \qquad (4)$$

$$S_1 = \lambda H + (T\text{-}H)\ m_1 \qquad (5)$$

$$\lambda = \frac{m_1}{1+2m_1}\ ,\ m_1 = \cot\alpha \qquad (6)$$

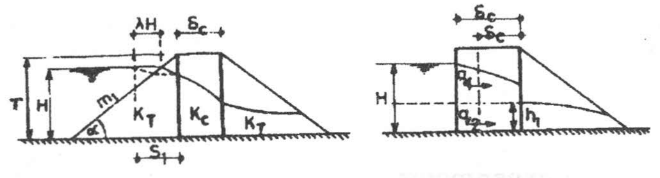


Figure 1. Geological section given by Rozanov [11].

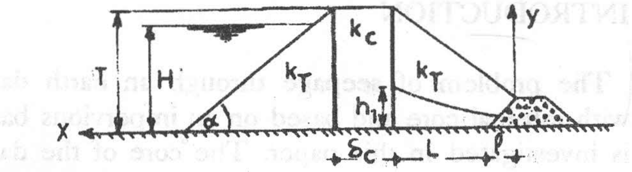


Figure 2. Geological section suggested by Rozanov [12].

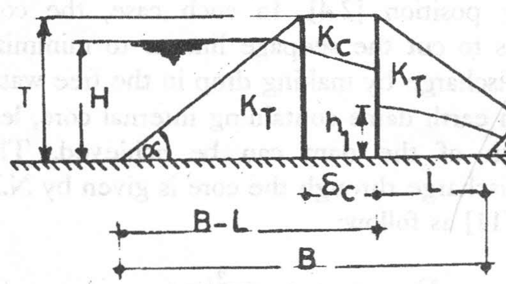


Figure 3. Geological section used in the experimental work.

The quantity of seepage discharge through dam with an internal core, Figure (2), was expressed by N.N. Rozanov [12] as follow:

$$Q_1 = K_T\ H^2/\ [2L\ (1 + \frac{K_T}{K_c} * \frac{\delta_c}{L})] \qquad (7)$$

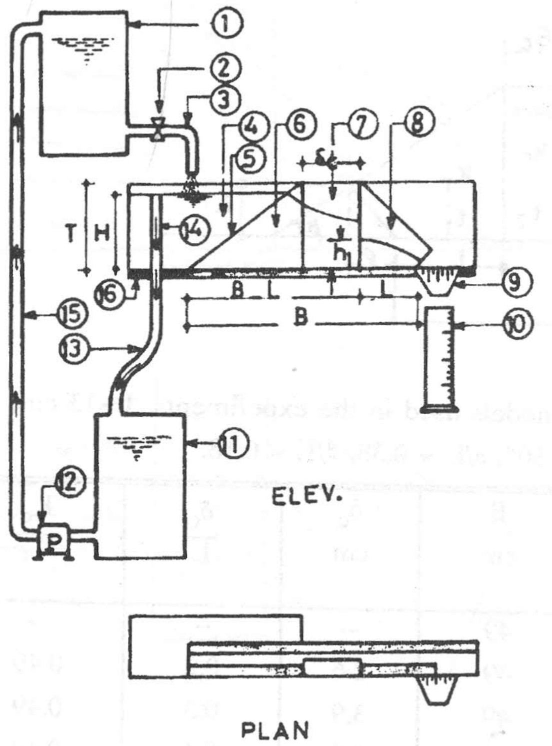
The objective of the present study is to find, the change effect of the relative permeability of the core on the drop of the free water surface. Also evaluation both of the quantity of seepage passing through dam with internal core and the reduction in the quantity of seepage due to constructing the core.

EXPERIMENTAL MODEL

The Hele-Shaw model of prespex material, is used for studying of nonhomogeneous condition, such as given herien of earth dam with an internal core, Figure (3). The model shown in Figure (4) represents the dam body of upstream part (6) and downstream part (8) of permeability K_T. In between these parts, the core (7) is represented by a width (δ_c) and has a coefficient of permeability K_c. The inner distance between the two prespex plates is controlled by a copper washers of a constant thickness (t). The coefficient of permeability depends upon the inner distance between the plates. The relation between the permeability of the core and that of the dam body is related by [10], and can be represented as follow:

$$\frac{K_c}{K_T} = \frac{(t/2)^2 \text{ of the core}}{(t/2)^2 \text{ of The dam body}} \qquad (8)$$

where K in general equals $[(t/2)^2 .g/3\upsilon]$ Ref. [3]. The core of the dam (7) has a width δ_c. The dam based on an impervious base (16). The upstream face of the dam (5) is feeded from feeder tank (4). An overflow tube (14) is used to keep a constant head upstream the dam. A flexible joint (13) carrys the excess oil to the collector tank (11). A centrifugal pump (12) is used to lift up the oil [7500 - 20w/50] to the main supply tank (1) through a pipe (15). A valve (2) is used to control the quantity of oil passing through the pipe (3) to the tank (4). An inclined channel (9) is fixed at the end of the model to collect the seepage oil, which is measured by a graduated tube (10).



1- Main supply tank.
2- Control valve.
3- Feeder tube.
4- Feeder tank.
5- The upstream face of the dam.
6- The upstream dam body of permeability K_T.
7- The core of the dam of permeability K_c
8- The downstream dam body of permeability K_T.
9- Inclined collector channel.
10- Graduated tube.
11- Collector tank.
12- Centrifugal pump.
13- Flexible joint.
14- Overflow tube.
15- Carrier tube.
16- Impervious base.

Figure 4. Experimental Hele-Shaw model.

Procedure of experimental study

About twenty experiments are carried out using different models with different dimensions as shown in Table (1). In each experiment recorded in the table, the upstream retained head "H" is changed five times; 13,10,8,6 and 4 cm. The seepage discharge in each run is measured and the corresponding free water surface is recorded.

For the same base width of earth dam with internal core, another dam without a core is studied, so that the reduction in quantity of seepage due to constructing the core can be estimated.

ANALYSIS OF RESULTS

The problem of seepage through an earth dam with an internal core is studied experimentally in this paper. About 20 experiments of 100 runs are carried out, Table (1). In Each run, free water surface is recorded so that the drop $(H-h_1)$, Figure (3), can be measured. A sample of the free water surface is shown in Figure (5). and is Photographed as shown in Photo (1) and (2). The relation between the relative permeability of both core and dam body (K_c/K_T) versus the relative height of the free water surface at the core end (h_1/H), is shown in Figure (6) and recorded in Table (I-Appendix), from the figure, it is clear that with increasing (K_c/K_T) to a limited value equals 0.6, (h_1/H) increases, after which (h_1/H) still almost constant and equal 0.65 till (K_c/K_T) reaches 1.0. It means that for the same dam without core and has the same dimensions of the dam with internal core, value of $(h_1/H) = 0.65$ at the same distance of the core end. It means also that, there is no effect on the value (h_1/H) if the value of (K_c/K_T) should be greater than 0.60, in this case core has no value. From the application point of view, the permeability of the core should be less than 0.6 the permeability of the dam body so that a smaller relative value (h_1/H) can be obtained. If the value $(H-h_1)$ is denoted by the drop of the free water surface at the core end then, its value equals 0.7 H and 0.35 H at $(K_c/K_T) = 0.1$ and 0.6 respectively, Figure (6). The drop $(H-h_1)$ remains constant and equals 0.35 H for $(K_c/K_T) > 0.6$. If the internal core theoretically impervious then, $(h_1/H) = 0.0$ and the drop $(H-h_1)$ should be equals "H".

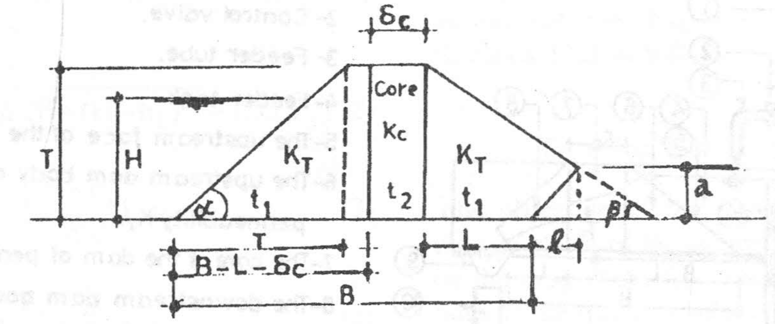


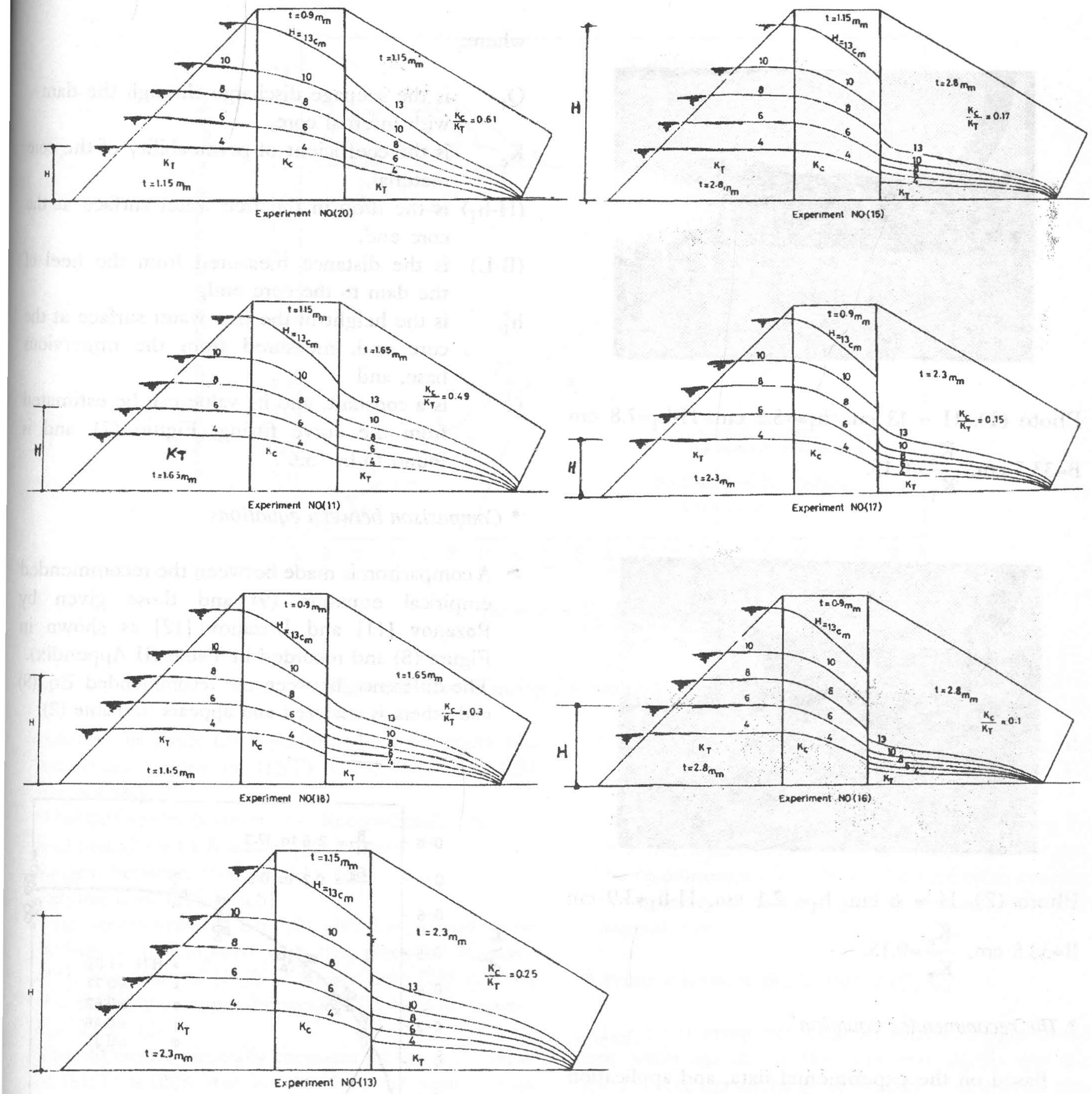
Table 1. Dimensions of the different models used in the experiments, L=13 cm, T= 14 cm, $\alpha = 45°$, $\beta = 30°$, $a/L = 0.38$, $\ell/L = 0.18$.

Experiment No.	t_1 mm	t_2 mm	B cm	δ_c cm	$\frac{\delta_c}{L}$	$\frac{K_c}{K_T}$
1	1.65	--	49	--	--	--
2	1.65	1.15	49	2.6	0.2	0.49
3	1.65	1.15	49	3.9	0.3	0.49
4	1.65	1.15	49	5.2	0.4	0.49
5	1.65	1.15	49	6.5	0.5	0.49
6	1.65	--	44	--	--	--
7	1.65	1.15	44	6.5	0.5	0.49
8	1.65	--	39	--	--	--
9	1.65	1.15	39	6.5	0.5	0.49
10	1.65	--	33.5	--	--	--
11	1.65	1.15	33.5	6.5	0.5	0.49
12	2.3	--	33.5	--	--	--
13	2.3	1.15	33.5	6.5	0.5	0.25
14	2.8	--	33.5	--	--	--
15	2.8	1.15	33.5	6.5	0.5	0.17
16	2.8	0.9	33.5	6.5	0.5	0.10
17	2.3	0.9	33.5	6.5	0.5	0.15
18	1.65	0.9	33.5	6.5	0.5	0.3
19	1.15	--	33.5	--	--	--
20	1.15	0.9	33.5	6.5	0.5	0.61

Experiments. No. 1,6,8,10,12,14 and 19 for a dam without internal core.

Experiments. No. 2,3,4,5,7,9,11,13,15,16,17,18 and 20 for a dam with internal core.

a/L is based on the experimental point of intersection the free water surface with the downstream slope of the dam in case of no core and filter, and for maximum retained water head.



Experiment NO(20)

Experiment NO(15)

Experiment NO(11)

Experiment NO(17)

Experiment NO(18)

Experiment NO(16)

Experiment NO(13)

Figure 5. Sample of the experimental free water surface in earth dam with an internal core.

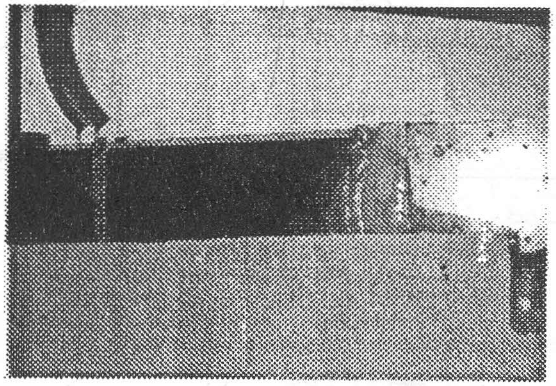


Photo (1). $H = 13$ cm, $h_1 = 5.2$ cm, $H-h_1=7.8$ cm $B=33.5$ cm, $\frac{K_c}{K_T}=0.15$.

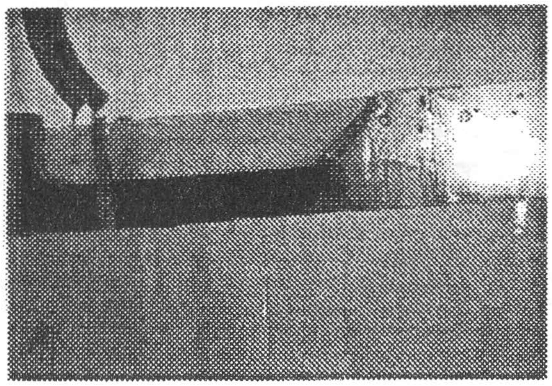


Photo (2). $H = 6$ cm, $h_1 = 2.1$ cm, $H-h_1=3.9$ cm $B=33.5$ cm, $\frac{K_c}{K_T}=0.15$.

* *The recommended equation*

Based on the experimental data, and application of Darcy's law at the core end: the recommended seepage discharge equation is put in the following form:

$$Q_1 = C.\ K_c.\ \frac{(H-h_1)}{(B-L)}.\ h_1 \text{ cm}^2/\text{sec} \qquad (9)$$

where:

Q_1	is the seepage discharge through the dam with internal core,
K_c	is the coefficient of permeability of the core material,
$(H-h_1)$	is the drop in the free water surface at the core end,
$(B-L)$	is the distance measured from the heel of the dam to the core end,
h_1	is the height of the free water surface at the core end, measured from the impervious base, and
C	is a constant, and its value can be estimated from the curve fitting, Figure (7), and is found to be "3.6".

* *Comparison between equations*

- A comparison is made between the recommended empirical equation (9) and those given by Rozanov [11] and Rozanov [12] as shown in Figure (8) and recorded in Table (II-Appendix).
- The difference between the recommended Eq. (9) and others is analyzed and appears in Table (2).

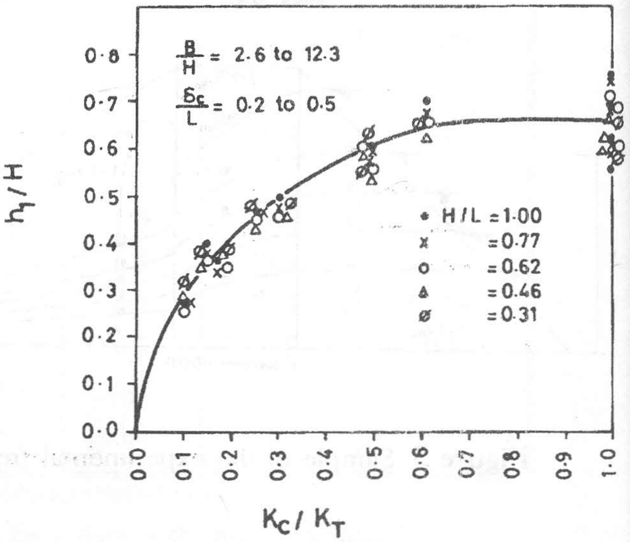


Figure 6. Values of (K_c/K_T) versus (h_1/H).

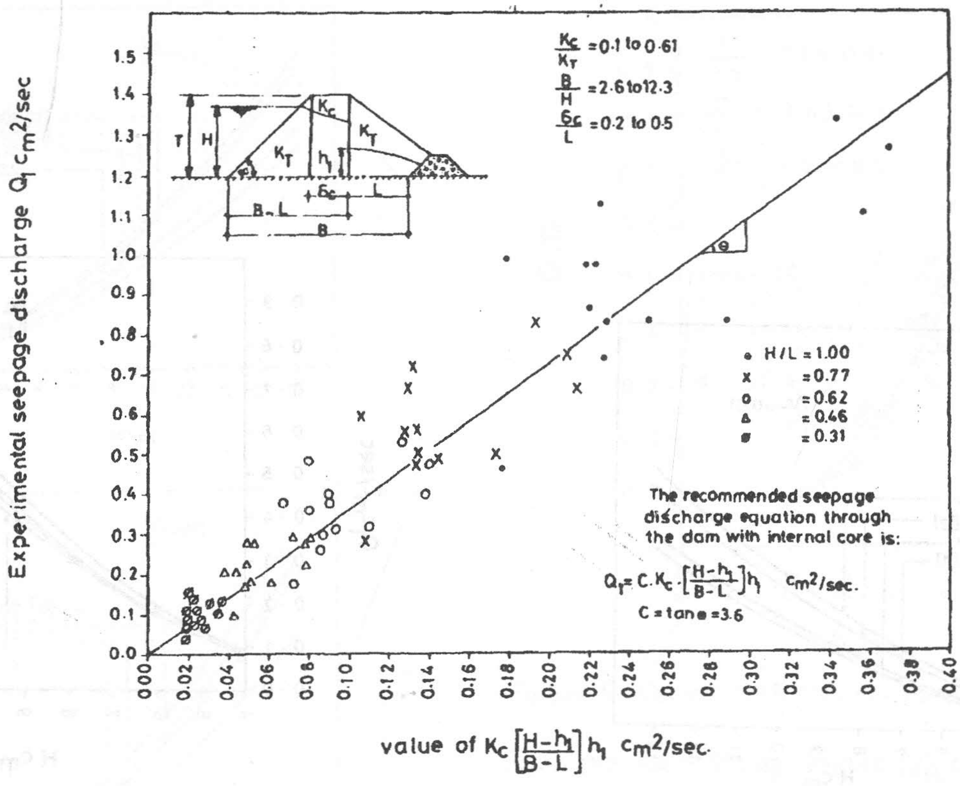


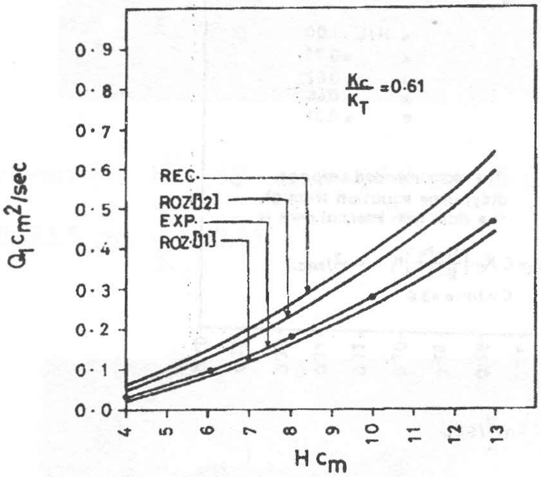
Figure 7. Curve fitting for the experimental data.

Analysis in Table (2) is performed for minimum and maximum values of (H/T) equal 0.29 and 0.93 respectively.

- The difference between the Recommended Eq. (9) and that given by Rozanov [12], column (2) Table (2), ranges between 0.06 to 0.15 for value of (K_c/K_T) ranging from 0.25 to 0.61.
- The recommended Eq. (9) also has a reasonable difference if compared with that given by Rozanov [11]. For value of (K_c/K_T) ranges from 0.25 to 0.30, the difference ranges between 0.04 to 0.13 column (1), Table (2).
- The difference generally increases for the small value of (H/T) = 0.29, this is related to the small values given by the equations as shown in Figure (8).
- The big difference also appears, for the small value of (H/T) = 0.29, in comparison between Eqs. given by Rozanov [12] and Rozanov [11]; column (4), Table (2).
- For the small value of $(K_c/K_T) < 0.17$, the average difference between equations is about 0.31.
- The difference between the recommended Eq. (9) and that given by Rozanov [11], column (1), Table (2), for value of $(K_c/K_T) = 0.61$, is similar to the difference between Rozanov [12] and Rozanov [11], column (4), Table (2).
- From the above analysis and comparison between the recommended Eq. (9) and Others, it can be said that, the recommended Eq. (9) can be applied to estimate the quantity of seepage passing through dams with internal core.

** Relation between (h_1/H) versus (Q_1/Q)*

The relationship between the relative height of the free water surface at the core end (h_1/H) and the relative seepage discharge of the dam with internal core (Q_1/Q), is shown in Figure (9) and data is recorded in Table (III-Appendix). Figure (9) shows that, (Q_1/Q) increases with increasing (h_1/H). The relative discharge (Q_1/Q) equals zero at $(h_1/H) = 0.0$, which means that core is of impervious material. For $(h_1/H) = 0.6$, the relative discharge $(Q_1/Q) = 0.75$. And for $0.6 < (h_1/H) = 0.65$ value of $(Q_1/Q) = 1.0$, it means that $K_c = K_T$ and $Q_1 = Q$. Also it is mentioned before from Figure (8) that, the value of $(h_1/H) = 0.65$ at $(K_c/K_T) = 1.0$,


$Q_1\ cm^2/sec$
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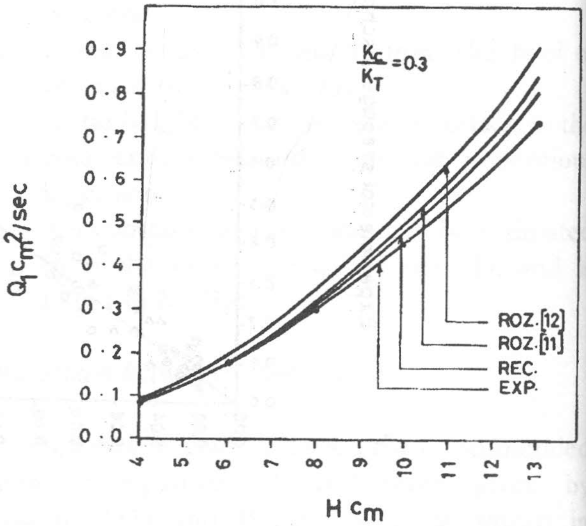
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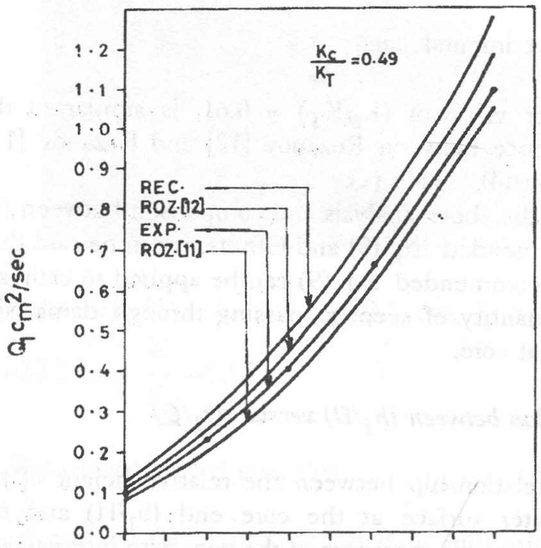
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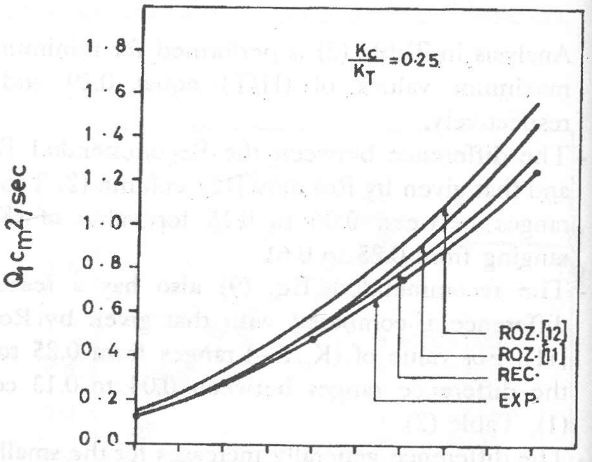
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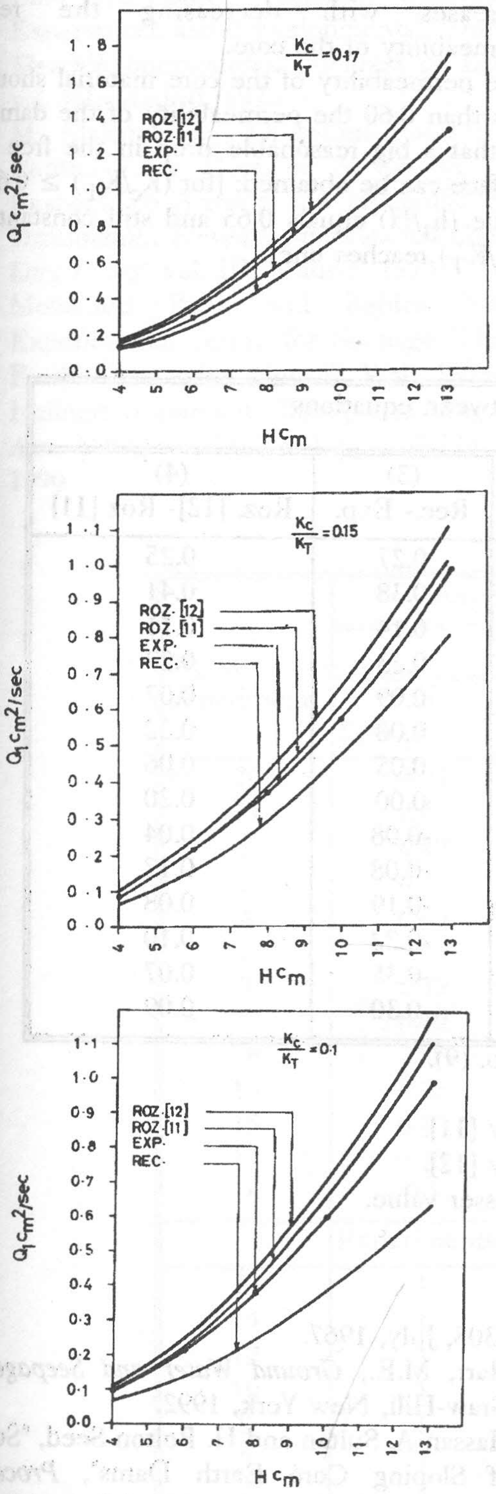

Figure 8. Comparison between the REC. Eq and the Eqs. Given by Roz. [22] and Roz. [12].

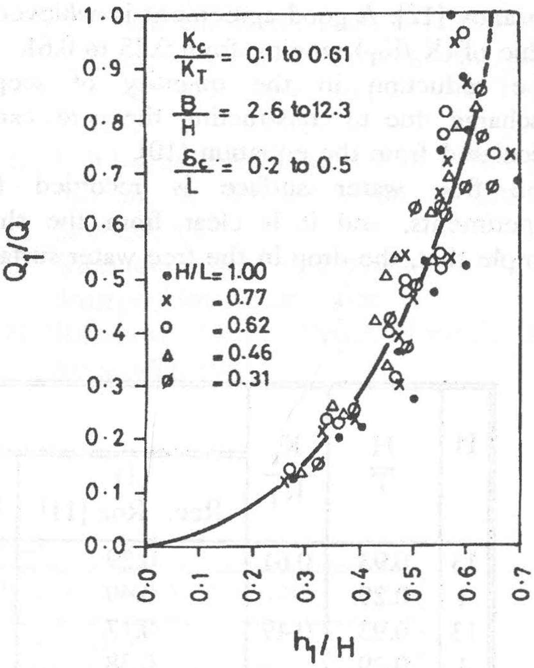

Figure 9. Values of (h_1/H) versus (Q_1/Q).

From the curve fitting, Figure (9), the reduction in the quantity of seepage due to constructing the core, can be calculated from the following empirical equation:

$$R = 1 - (Q_1/Q) \tag{10}$$

where:

$$(Q_1/Q) = 1.767\ (h_1/H)^{1.23}\ (K_c/K_T)^{0.41} \tag{11}$$

Substituting $(h_1/H) = 0.65$ and $(K_c/K_T) = 1.0$ in equation (11) to get $(Q_1/Q) \simeq 1.0$.

CONCLUSIONS

Seepage through an earth dam with internal core is studied experimentally in this paper and the following conclusions are made:

1- Based on the experimental results, a simple empirical equation (9) is recommended to calculate quantity of seepage discharge passing through earth dam with internal core.

2- A comparison is made between the recommended equation (9) and those given by Rozanov [11] and

Rozanov [12]. A good agreement is achieved for value of (K_c/K_T) ranging from 0.25 to 0.61.

3- The reduction in the quantity of seepage discharge due to constructing the core, can be calculated from the equation (10).

4- The free water surface is recorded from experiments, and it is clear from the shown sample that, the drop in the free water surface increases with decreasing the relative permeability of the core.

5- The permeability of the core material should be less than 0.60 the permeability of the dam body so that a big reasonable drop in the free water surface can be obtained; [for $(K_c/K_T) \geq 0.60$, the value (h_1/H) equals 0.65 and still constant until (K_c/K_T) reaches one].

Table 2.

H	$\frac{H}{T}$	$\frac{K_c}{K_T}$	Difference between equations			
			(1) Rec.- Roz [11]	(2) Rec.- Roz [12]	(3) Rec.- Exp.	(4) Roz. [12]- Roz [11]
13	0.93	0.61	0.29	0.06	0.27	0.25
4	0.29		0.49	0.14	0.38	0.41
13	0.93	0.49	0.17	0.07	0.14	0.11
4	0.29		0.38	0.15	0.23	0.27
13	0.93	0.3	-0.04	-0.10	0.09	0.07
4	0.29		0.13	-0.11	0.00	0.22
13	0.93	0.25	-0.10	-0.15	0.05	0.06
4	0.29		0.08	-0.13	0.00	0.20
13	0.93	0.17	-0.27	-0.30	-0.08	0.04
4	0.29		-0.20	-0.29	-0.08	0.12
13	0.93	0.15	-0.22	-0.28	-0.19	0.08
4	0.29		-0.30	-0.36	-0.22	0.10
13	0.93	0.1	-0.42	-0.46	-0.35	0.07
4	0.29		-0.30	-0.36	-0.30	0.09

Rec. means the recommended equation No. (9).
EXP. means the experimental results.
Roz. [11] means the equation given by Rozanov [11].
Roz. [12] means the equation given by Rozanov [12].
The negative sign means that Rec. Eq. has the lesser value.
(1), (2), (3) and (4) means Numbers of columns.

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Table (I-Appendix)

No of experiment	Experiments of earth dam with internal core					
	Values of (h_1/H)					
	H K_c/K_T	13 ●	10 x	8 o	6 Δ	4 φ
20	0.61	0.7	0.68	0.65	0.62	0.65
11	0.49	0.6	0.57	0.55	0.53	0.55
2	0.49	0.57	0.58	0.59	0.58	0.63
3	0.49	0.59	0.60	0.56	0.58	0.63
4	0.49	0.60	0.57	0.56	0.57	0.60
5	0.49	0.55	0.55	0.55	0.53	0.55
7	0.49	0.52	0.48	0.48	0.47	0.5
9	0.49	0.54	0.50	0.48	0.45	0.45
18	0.3	0.5	0.47	0.46	0.45	0.48
13	0.25	0.47	0.47	0.45	0.43	0.48
15	0.17	0.36	0.33	0.34	0.37	0.38
17	0.15	0.40	0.39	0.36	0.35	0.38
16	0.1	0.27	0.27	0.26	0.28	0.32
	Experiments of earth dam without internal core					
19	1	0.75	0.71	0.68	0.63	0.63
14	1	0.72	0.70	0.66	0.63	0.63
12	1	0.74	0.72	0.68	0.63	0.63
10	1	0.75	0.74	0.70	0.67	0.65
8	1	0.69	0.68	0.68	0.67	0.65
6	1	0.62	0.61	0.60	0.62	0.58
1	1	0.55	0.59	0.59	0.60	0.65

* The average value of (h_1/H), for earth dam without internal core, was found about 0.65.

* h_1 is measured at distance equals (B-L) in earth dam without core, this distance means the core end in earth dam with internal core.

Table (II-Appendix). Comparison between discharge of both experiments, Rozanov [11], Rozanov [12] and the recommended equation.

	Discharge values cm^2/sec					
	H cm $\frac{K_c}{K_T}$	13	10	8	6	4
experimental discharge.	0.61	0.46	0.28	0.18	0.10	0.04
Rozanov [11]		0.446	0.247	0.158	0.088	0.033
Rozanov [12]		0.595	0.352	0.225	0.127	0.056
the recommended equ.		0.63	0.39	0.26	0.15	0.065
Exp.	0.49	0.10	0.66	0.40	0.23	0.10
Rozanov [11]		1.06	0.60	0.37	0.20	0.08
Rozanov [12]		1.19	0.70	0.45	0.25	0.11
Rec.		1.28	0.78	0.50	0.28	0.13
Exp.	0.30	0.74	0.47	0.30	0.18	0.08
Rozanov [11]		0.84	0.49	0.30	0.17	0.07
Rozanov [12]		0.90	0.53	0.34	0.19	0.09
Rec.		0.81	0.48	0.31	0.17	0.08
Exp.	0.25	1.26	0.75	0.48	0.28	0.13
Rozanov [11]		1.47	0.83	0.52	0.29	0.12
Rozanov [12]		1.56	0.92	0.59	0.33	0.15
Rec.		1.33	0.79	0.50	0.28	0.13
Exp.	0.17	1.34	0.83	0.53	0.30	0.13
Rozanov [11]		1.68	0.99	0.62	0.34	0.15
Rozanov [12]		1.75	1.04	0.66	0.37	0.17
Rec.		1.23	0.70	0.45	0.26	0.12
Exp.	0.15	0.97	0.56	0.36	0.21	0.09
Rozanov [11]		1.01	0.59	0.38	0.21	0.09
Rozanov [12]		1.10	0.65	0.42	0.23	0.10
Rec.		0.79	0.46	0.29	0.16	0.07
Exp.	0.10	0.99	0.60	0.38	0.21	0.10
Rozanov [11]		1.11	0.66	0.42	0.24	0.10
Rozanov [12]		1.19	0.70	0.45	0.25	0.11
Rec.		0.64	0.38	0.24	0.14	0.07

Table (III-Appendix).

No of experiment	H	13 ●		10 x		8 o		6 Δ		4 ϕ	
	$\frac{K_c}{K_T}$	Q_1/Q	h_1/H	Q_1/Q	h_1/H	Q_1/Q	h_1/H	Q_1/Q	h_1/H	Q_1/Q	h_1/H
20/19	0.61	0.68	0.7	0.74	0.68	0.73	0.65	0.82	0.62	0.67	0.65
11/10	0.49	0.52	0.6	0.54	0.57	0.52	0.55	0.53	0.53	0.63	0.55
2/1	0.49	0.01	0.57	0.95	0.58	0.96	0.59	0.79	0.58	0.86	0.63
3/1	0.49	0.88	0.59	0.87	0.60	0.81	0.56	0.79	0.58	0.76	0.63
4/1	0.49	0.78	0.60	0.72	0.57	0.77	0.56	0.69	0.57	0.67	0.60
5/1	0.49	0.74	0.55	0.66	0.55	0.53	0.55	0.62	0.53	0.62	0.55
7/6	0.49	0.53	0.52	0.54	0.48	0.49	0.48	0.54	0.47	0.63	0.50
9/8	0.49	0.47	0.54	0.46	0.50	0.47	0.48	0.50	0.45	0.42	0.45
18/10	0.30	0.27	0.50	0.3	0.47	0.31	0.46	0.33	0.45	0.37	0.48
13/12	0.25	0.36	0.47	0.39	0.47	0.40	0.45	0.42	0.43	0.48	0.48
15/14	0.17	0.20	0.36	0.21	0.33	0.23	0.34	0.24	0.37	0.24	0.38
17/12	0.15	0.22	0.40	0.23	0.39	0.23	0.36	0.25	0.35	0.26	0.38
16/14	0.1	0.12	0.27	0.12	0.27	0.13	0.26	0.13	0.28	0.15	0.32