Studying Effect Inclination of cutoff on the percolation Length under Aprons of Hydraulic Structures Founded on Isotropic soil

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ABSTRACT - In terms of the importance of hydraulic structures, this research was started with the impartial of avoiding traditional solutions by implementing vertical or inclined cutoffs for the purpose of profiting of its depth and keeping it away of the phreatic line in order to dissipate the energy in the water below the apron and to reduce the potential energy in the water. In the present paper flow pattern for 105 models representing apron of hydraulic structures provided with different cutoffs and different angles of cutoff at various position are investigated models are founded on isotropic soil where the coefficient of permeability considered the same for all directions. SEEP-2D program is used to construct the flow net for the investigated models. Measurements were undertaken and documented. These measurements were analyzed, plotted on graphs, presented and discussed. Finally, an optimum configuration was reached and recommended.

KEY WORDS - Cutoff, Apron, Energy Dissipation, Sheet pile and creep length.

1. INTRODUCTION

Hydraulic structures are used to control the flow of water in rivers and canals. These structures must be secured against the uplift pressure and piping in order to ensure their structural stability. Hydraulic structures built on permeable soils are often provided with Cutoffs as a protection measure against uplift forces and piping.

Designers used to use either Bligh's or lane's formula in cases of estimating the required length of the percolation under aprons of hydraulic structures. This mean that, in case of using cutoffs, the two faces of these cutoffs are employed to have the same effect in dissipating the energy of the percolating water under aprons according to Bligh's formula, or having an effect equal to three times of the equivalent horizontal length according to Lane's formula.

In the present paper, flow patterns 105 models representing aprons for hydraulic structures provided with cutoff underneath and founded on isotropic soil are investigated. The flow net is constructed to represent the flow patterns for the investigated models. A SEEP-2D computer program is used to draw the flow net for the investigated models. The percolation coefficients for both horizontal and vertical directions of the percolation are thoroughly measured and investigated for various models. New trend to deal with the percolation length for both horizontal and vertical seepage path for condition similar to the investigated models is represented.

In order to achieve the research objectives, a methodology is planned, according to which a numerical model is executed where the different contributing parameters are varied and investigated. Measurements are undertaken and documented. These measurements are analyzed, plotted on graphs, presented and discussed. Finally, an optimum configuration is reached; conclusions were deduced and recommendations, for future research were provided.

This paper presents the above under the following headlines:

- Objective of the study
- Reviewing the literature
- Executing a theoretical study
- Undertaking numerical investigations
- Analyzing and discussing the results

2. OBJECTIVE OF THE STUDY

The objective of the present study is to obtain a precise and easy form for evaluating the proper percolation length for aprons that founded on isotropic soil and provided with one cutoff underneath. This trend is mainly based on investigating the flow net that thoroughly constructed for the investigated models. A computer program based on finite element technique and called SEEP-2D is used to draw the flow net for the chosen models. Models represent simple case for aprons provided with one cutoff of different depths, different angels and located at various position with respect to their horizontal length.

3. REVIEWING THE LITERATURE

Many researchers are occupied in investigating the required length to ensure the safety of hydraulic structures apron. For example:

Bligh (1910) and Soliman, M.N. (1979) assumed that the hydraulic slope, (or gradient), is constant throughout the length ABCD, figure (1). The hydraulic gradient diagram is represented by a triangle with base length (L) which is equal to the length of ABCD. This is called "Length of Creep", which is supposed to be the path of percolation (L_w) of water. The value of the weighted creep length is calculated as:

$$L_W = L_{hz} + L_V = C_B \times H \qquad \textbf{(1)}$$

Where:

L_{hz} Sum of horizontal creep lengths

L_V : Sum of vertical creep lengths

C_B **:** Bligh's coefficient

H : Piezometic head

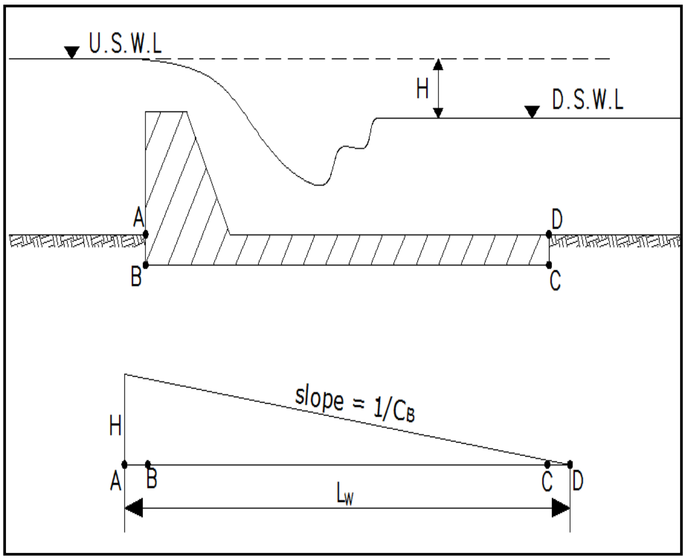

Figure (1) Creep line and Hydraulic Gradient Diagram

Lane (1932) and Soliman (1979) introduced the concept of the line of the least resistance, which the water flow may follow. Lane considered "more weight" for creep along vertical and steeply sloping surfaces, for the following reasons:

- Intimate contact between flat surfaces and soil is not always secured, thus accumulation of streamlines along line of creep is more likely to occur resulting in high velocity, and probable failure.
- Underneath flat aprons, soil may settle locally forming voids, a phenomenon often described as (roofing action). This is dangerous with respect to piping.
- Safety against piping depends mainly on vertical elements of foundation.

Lane developed the a theory where he related L_{hz} (sum of horizontal contacts and all sloping contacts whose angle with the horizontal is less than 45) to L_V (sum of vertical contacts and all sloping contacts whose angle with the horizontal is more than 45) by the following equation:

L_w* (weighted creep length) is equal to:

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$$L_W{}^* = \frac{L_{hz}}{3} + L_V \qquad (2)$$

To ensure safety against undermining, L_w* should be as follows:

$$L_W{}^* = C_L.H \qquad (3)$$

Where:

CL : An empirical coefficient depending on type of soil

El-Salawy, El-Molla and Bakry (1997) used an electrolytic tank to investigate the effect of both the front and rear faces (upstream and downstream) of the cutoffs on the hydraulic gradient of the creep line in contact with them. Their investigation assisted in the estimation of the actual length of the creep beneath the floor of the hydraulic structures. They concluded that the total effect of cutoff under aprons of hydraulic structures on the creep line depends on its position. As a result, weighted value of the cutoff faces should be used to estimate the whole length of the creep line in case of using either Bligh's or Lane's formulae.

EL- Salawy and El-Molla (2000) used an electrolyte tank to investigate models of aprons of hydraulic structures provided with cutoffs beneath them. The efficiencies of faces, front and/or rear, of these cutoffs on affecting the hydraulic gradient beneath the models of aprons are investigated at various positions for each individual model.

El-Molla (2001) used a computer program called SEEP-2D to investigate 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 the horizontal length of the apron.

Mobasher (2005) 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.

El Tahan, El-Molla (2013) an electrical analogue model was used to investigate the effect of the depth of the upstream and downstream cutoff D_1 and D_2 respectively when the upstream cutoff is at the start of the apron and the downstream cut off is at the end of the apron on the uplift forces along the hydraulic structure and the rear and front faces head drop of both upstream and downstream cutoff.

Adel Elsheemy (2015) used an electric analogue to study the effect of inclination of cutoffs on the total net potential and horizontal creep length. 225 models were investigated in order to cover the various aspects of the problem under consideration.

4. EXECUTING A THEORETICAL STUDY

In this research, a theoretical study was executed. Models representing apron of horizontal length (L_{hz}) were founded on pervious isotropic soil of thickness (T). The actual percolation length for every model was investigated under the effect of the applied net potential head (H_0). The apron provided with cutoff of different depths (D) located at various positions (X) with respect to the required horizontal length with various angles (α) in front and rear direction, figure (2).

The actual percolation length for every model is investigated under the effect of the applied net potential head (H_0). Five relative positions of the cutoff with respect to total horizontal length of apron (X/L_{hz}) are chosen to cover the range from 0.00 to 1.00.

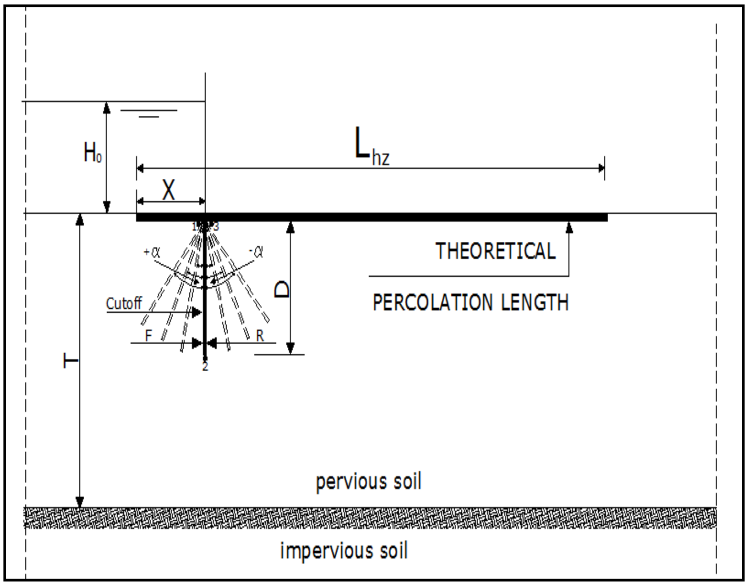

Figure (2) Definition Sketch

3.a. DIMENSIONAL ANALYSIS

During the theoretical study, a dimensional analysis was achieved, as follows:

$$\Phi = \left(F,\ R,\ D,\ T, H_0, \alpha\ ,\ K,\ L_{hz},\ X,\ g,\ \rho\right) = 0 \qquad \textbf{(4)}$$

Where:

g = gravitational Acceleration

ρ = density of seeping water

K = permeability coefficient through the homogeneous stratum of thickness (T)

Equation (4) is supposed include the entire variable involved in the problem of seepage under an apron under a given head (H_0) provided with a single cutoff in a homogeneous stratum of soil with (K) permeability and (T) thickness.

4. b. DIMENSIONLESS RELATIONSHIP

By applying Buckingham Π- theorem, taking X, g and ρ as repeated variables, the relation could be written as:

$$\Phi' = \left(X/F,\ X/R,\ X/D,\ X/T\ ,\ H_0/L_{hz},\ \alpha,\ Xg/K^2,\ X/L_{hz}\right)=0 \qquad \textbf{(5)}$$

The eight dimensionless terms in (5) were reduced to six terms. By combining both the first and second terms, the third and fourth terms:

$$\Phi'' = \left(F/R,\ D/T\ ,H_0/L_{hz}\ ,\alpha\ ,\ Xg/K^2,\ X/L_{hz}\right)=0 \qquad \textbf{(6)}$$

For the homogeneous soil with known permeability (K) and if (X) is constant, the fifth term reduces to a constant, equation (6):

$$\Phi''' = \left(F/R,\ D/T,\ H_0/L_{hz},\ \alpha\ ,X/L_{hz}\right)=0 \qquad \textbf{(7)}$$

So, any variable has a function as follows:

$$X/L_{hz} = \Psi\left(F/R,\ D/T,\ \ H_0/L_{hz},\ \alpha\right) \qquad \textbf{(8)}$$

5. UNDERTAKING NUMERICAL INVESTIGATION

A numerical study is carried out. This section presents the numerical apparatus, as follows:

5. a. NUMERICAL APPARATUS

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 analog 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

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

$$I' = -\frac{1}{R}\left(\frac{\mathrm{dE}}{\mathrm{ds}}\right) \qquad \textbf{(9)}$$

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:

$$v = k\mathrm{i} = -k\left(\frac{\mathrm{dh}}{\mathrm{ds}}\right) \qquad \textbf{(10)}$$

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 this point and the equipotential lines are determined by points of equal voltage and stream lines are those perpendicular to them.

5. b. DESCRIPTION OF THE SEEP2D MODEL

SEEP2D is a 2D finite element (steady state) flow model. The two dimensions are the horizontal and vertical dimension (i.e., vertical profile). The SEEP2D software was developed by the United States Army Engineer Waterways Experiment Station to model a variety of problems involving seepage. The governing equation used in the SEEP2D models is the Laplace equation. Transient or time varying problems cannot be modeled using it. SEEP2D allows for different hydraulic conductivities along the major and minor axes (anisotropic conditions) to be defined [SEEP2D Primer, 1998].

Post-processing includes contouring of the total head (equipotential lines), drawing flow vectors, and computing flow potential values at the nodes. These values can be used to plot flow lines together with the equipotential lines (i.e., flow nets). The phreatic surface can also be displayed [SEEP2D Primer, 1998 and El Molla, 2014].

5. c. NUMERICAL SIMULATION METHOD

A Numerical program was planned to investigate a depth (D) = 6.00 cm, 8.00 and 10 cm. A 40 cm deep heterogeneous soil with a depth ratio (D/T) =0.16, 0.20 and 0.25 are selected. The length of the apron (L_{hz}) was 50 cm. The position of the cutter is varied according to the length of the apron (i.e. X / L_{hz} = 0.00, 0.25, 0.50, 0.75, and 1.00). The chosen head (H_0) is 5.0 volts.

One hundred and five (105) models are investigated in order to cover the various aspects of the problem under consideration. The used potentials are 5.0 volts.

The parameters are written in dimensionless form together with their considered range as follows:

- The ratio of cutoff depth to the thickness of the pervious layer (D/T) equals (0.16), (0.20) and (0.25)
- The relative positions of cutoff to the total horizontal length of the apron (X/L_{hz}), equals (0.00. 0.25, 0.50, 0.75, and1.00).

6. RESULTS AND DISCUSSING

For every investigated model, the values of potential drops for both the front and rear faces of the cutoff are measured from the flow net pattern for various postions of cutoff. These vlues represent the dissipated potential along either the front or rear face of cutoff and are denoted as (F) and (R) respectively. So, the total dissipated potential along the two faces of the cutoff is estimated and expresswd as (H_V) ; (= F+R). Also, the values of relative dissipated potentitial along either the vertical length of percolation with to the total net acting potential difference (H_0) is individually computed and expressed as (H_V/H_0). the effective vertical length (L_V) is estimated as:

1)For α = 0.0 °
L_V = (1+R/F) × D. For case of (X/L_{hz}) < 0.50,

L_V = (1+F/R) × D. For case (X/L_{hz}) > 0.50, and

L_V = 2 × D. For case (X/L_{hz}) = 0.50.

2)For α = + °
L_V = (1+R/F) × D. For case of (X/L_{hz}) =0.0, and

L_V = (1+F/R) × D. For case (X/L_{hz}) > 0.00.

3) For α = - °
L_V = (1+R/F) × D. For case of (X/L_{hz}) < 1.00, and

L_V = (1+F/R) × D. For case (X/L_{hz}) = 1.00.

This trend is followed to consider the unequal effect for both the front and rear faces of the cutoff on potential dissipation along the vertical path of percolation length.

All results of reading and calculation for various item of investigated models are shown in table (1), (2) and (3) for D/T = 0.16, 0.20 and 0.25 respectively and all angels.

The relationship between X/L_{hz} against the relative effect for both front and rear face of cutoff on the dissipated potential along the cutoff (F/R) is plotted for all models shown in fig.(3), (4) and (5) for all value of D/T =0.15, 0.20 and 0.25 respectively and all angels.

From the above figures, it was clear that:

- The rear face dissipation is an increase than the front face dissipation when α = +15o, +30o and +45o for all positions.
- The front face dissipation is a decrease than the rear face dissipation when α = -15o, -30o and -45o for all positions.
- The front face dissipation is bigger than the rear face dissipation when α = 0 for X/L_{hz} (i.e. ranged between 0 to before midpoint of apron).
- The front face dissipation is smaller than the rear face dissipation when α = 0 for X/L_{hz} (i.e. ranged between after midpoint of apron to 1.00).
- The front face dissipation equals the rear face dissipation when α = 0 for X/L_{hz} = 0.50.

For all investigated models, the relationship between the relative position of cutoff (X/L_{hz}) against the relative vertical dissipated potential (H_V/H_o) is plotted and shown fig. (6), (7) and (8) for all value of D/T =0.15, 0.20 and 0.25 respectively and all angels. The relationships between X/L_{hz} against H_V/H_o are symmetrical about certain minimum values. The maximum values occur at the relative positions of cutoff under apron where X/L_{hz} = 0.00 or 1.00. this means that the maximum effect of cutoff on dissipating energy along the percolation length will occur if it will be located at one of these two mentioned positions. While the minimum value occurs if the cutoff is located at the midpoint of the apron horizontal length (i.e. at X/L_{hz} = 0.50).

Flow net is thoroughly constructed for every model under the effect of variation of various parameters that represent the important items that are mainly used for evaluating the efficiency of the cutoff under aprons. Samples of these flow nets are shown in figers (9)

7. CONCLUSIONS AND RECOMMENDATIONS

Based on the above investigation phases, the concluded aspects were listed and are represented on table (1), (2) and (3).
In general, the conclusions are as follows:

- For α = 0.0°, was observed there is an increase in the efficiency of the cutoff for X/L_{hz} = 0.0 and 1.00.
- For α = 0.0°, was observed there is a decrease in the efficiency of the cutoff for X/L_{hz} = 0.50.
- For positive values of α, was observed there is an increase in the efficiency of the cutoff for X/L_{hz} (i.e. ranged between 0 to before midpoint of apron) and vice versa.
- For negative values of α, was observed there is an increase in the efficiency of the cutoff for X/L_{hz} (i.e. ranged between after midpoint of apron to 1.00) and vice versa.
- For positive and negative values of α, was observed there is a decrease in the efficiency of the cutoff for X/L_{hz} = 0.50.
- When increasing the depth of the cutoff increases its efficiency.
- The presented charts could be used as a design charts for aprons for the cases similar to the investigated models.

Based on the above, the following recommendations were foreseen and are given, as follows:

- More investigations for the interaction between cutoffs and creep length for various cases of seepage under apron are still required to cover the different conditions in order to obtain reasonable forms that could help in achieving proper design of the aprons of hydraulic structures.
- A wider range of angles are to be tested.
- More studies are required for the efficiency of cutoffs under aprons of hydraulic structures for different types of soils.

Table (1) Measurements and Calculations for D/T = 0.15

D/T = 0.15							
Model NO.	angle α	X/L_{hz}	F	R	F/R	H_V	H_V/H_0
1	0°	0.00	1.223	0.491	2.491	1.714	0.343
2		0.25	0.468	0.397	1.179	0.864	0.173
3		0.50	0.374	0.376	0.995	0.750	0.150
4		0.75	0.397	0.473	0.839	0.869	0.174
5		1.00	0.492	1.221	0.403	1.712	0.342
6	+15°	0.00	1.127	0.598	1.883	1.725	0.345
7		0.25	0.407	0.474	0.859	0.880	0.176
8		0.50	0.309	0.436	0.709	0.745	0.149
9		0.75	0.317	0.525	0.604	0.842	0.168
10		1.00	0.390	1.301	0.300	1.691	0.338
11	-15°	0.00	1.301	0.392	3.322	1.692	0.338
12		0.25	0.520	0.317	1.640	0.837	0.167
13		0.50	0.434	0.311	1.395	0.745	0.149
14		0.75	0.476	0.412	1.156	0.887	0.177
15		1.00	0.597	1.126	0.530	1.723	0.345
16	+30°	0.00	1.011	0.706	1.432	1.716	0.343
17		0.25	0.335	0.545	0.615	0.880	0.176
18		0.50	0.242	0.482	0.502	0.724	0.145
19		0.75	0.242	0.561	0.431	0.802	0.160
20		1.00	0.301	1.355	0.222	1.655	0.331
21	-30°	0.00	1.353	0.301	4.495	1.654	0.331
22		0.25	0.556	0.243	2.288	0.799	0.160
23		0.50	0.482	0.243	1.986	0.724	0.145
24		0.75	0.549	0.340	1.616	0.888	0.178
25		1.00	0.708	1.007	0.703	1.715	0.343
26	+45°	0.00	0.867	0.820	1.057	1.686	0.337
27		0.25	0.253	0.608	0.416	0.860	0.172
28		0.50	0.175	0.513	0.340	0.687	0.137
29		0.75	0.172	0.581	0.295	0.752	0.150
30		1.00	0.214	1.386	0.154	1.600	0.320
31	-45°	0.00	1.388	0.213	6.529	1.600	0.320
32		0.25	0.576	0.171	3.368	0.747	0.149
33		0.50	0.514	0.175	2.937	0.689	0.138
34		0.75	0.615	0.260	2.368	0.874	0.175
35		1.00	0.822	0.866	0.949	1.687	0.337

Table (2) Measurements and Calculations for D/T = 0.20

D/T = 0.20							
Model NO.	angle α	X/L_{hz}	F	R	F/R	H_V	H_V/H_0
36	0°	0.00	1.414	0.562	2.517	1.975	0.395
37		0.25	0.616	0.501	1.230	1.117	0.223
38		0.50	0.491	0.491	1.000	0.981	0.196
39		0.75	0.502	0.621	0.808	1.123	0.225
40		1.00	0.561	1.414	0.397	1.974	0.395
41	+15°	0.00	1.318	0.680	1.939	1.997	0.399
42		0.25	0.547	0.599	0.913	1.145	0.229
43		0.50	0.406	0.567	0.716	0.973	0.195
44		0.75	0.402	0.683	0.589	1.085	0.217
45		1.00	0.451	1.495	0.301	1.945	0.389
46	-15°	0.00	1.496	0.450	3.324	1.946	0.389
47		0.25	0.678	0.401	1.692	1.078	0.216
48		0.50	0.565	0.409	1.381	0.974	0.195
49		0.75	0.602	0.551	1.093	1.153	0.231
50		1.00	0.679	1.318	0.515	1.997	0.399
51	+30°	0.00	1.198	0.803	1.492	2.000	0.400
52		0.25	0.463	0.694	0.667	1.156	0.231
53		0.50	0.323	0.626	0.516	0.948	0.190
54		0.75	0.311	0.722	0.431	1.033	0.207
55		1.00	0.346	1.555	0.222	1.900	0.380
56	-30°	0.00	1.553	0.348	4.468	1.900	0.380
57		0.25	0.718	0.309	2.324	1.027	0.205
58		0.50	0.625	0.323	1.935	0.948	0.190
59		0.75	0.695	0.468	1.486	1.162	0.232
60		1.00	0.802	1.198	0.669	2.000	0.400
61	+45°	0.00	1.043	0.939	1.111	1.982	0.396
62		0.25	0.367	0.781	0.470	1.147	0.229
63		0.50	0.233	0.669	0.348	0.902	0.180
64		0.75	0.219	0.745	0.294	0.964	0.193
65		1.00	0.249	1.588	0.157	1.837	0.367
66	-45°	0.00	1.588	0.248	6.403	1.836	0.367
67		0.25	0.740	0.219	3.389	0.959	0.192
68		0.50	0.670	0.233	2.880	0.902	0.180
69		0.75	0.789	0.374	2.111	1.162	0.232
70		1.00	0.939	1.044	0.899	1.982	0.396

Table (3) Measurements and Calculations for D/T = 0.25

D/T = 0.25							
Model NO.	angle α	X/L_{hz}	F	R	F/R	H_V	H_V/H_0
71	0°	0.00	1.583	0.618	2.563	2.200	0.440
72		0.25	0.767	0.595	1.289	1.362	0.272
73		0.50	0.599	0.602	0.995	1.201	0.240
74		0.75	0.595	0.766	0.777	1.360	0.272
75		1.00	0.619	1.582	0.391	2.201	0.440
76	+15°	0.00	1.492	0.744	2.005	2.236	0.447
77		0.25	0.683	0.711	0.961	1.393	0.279
78		0.50	0.504	0.690	0.730	1.193	0.239
79		0.75	0.482	0.829	0.581	1.311	0.262
80		1.00	0.492	1.664	0.296	2.156	0.431
81	-15°	0.00	1.663	0.501	3.319	2.164	0.433
82		0.25	0.825	0.481	1.715	1.306	0.261
83		0.50	0.689	0.505	1.364	1.194	0.239
84		0.75	0.711	0.691	1.029	1.401	0.280
85		1.00	0.745	1.491	0.499	2.235	0.447
86	+30°	0.00	1.378	0.879	1.568	2.256	0.451
87		0.25	0.594	0.821	0.723	1.414	0.283
88		0.50	0.402	0.762	0.528	1.164	0.233
89		0.75	0.372	0.877	0.424	1.248	0.250
90		1.00	0.388	1.726	0.225	2.114	0.423
91	-30°	0.00	1.725	0.389	4.439	2.113	0.423
92		0.25	0.870	0.374	2.328	1.243	0.249
93		0.50	0.764	0.402	1.900	1.166	0.233
94		0.75	0.824	0.604	1.365	1.427	0.285
95		1.00	0.876	1.378	0.636	2.254	0.451
96	+45°	0.00	1.232	1.028	1.199	2.259	0.452
97		0.25	0.490	0.931	0.526	1.421	0.284
98		0.50	0.294	0.819	0.359	1.112	0.222
99		0.75	0.266	0.901	0.295	1.167	0.233
100		1.00	0.281	1.764	0.159	2.044	0.409
101	-45°	0.00	1.764	0.281	6.278	2.045	0.409
102		0.25	0.895	0.266	3.365	1.161	0.232
103		0.50	0.817	0.298	2.742	1.115	0.223
104		0.75	0.936	0.504	1.857	1.440	0.288
105		1.00	1.030	1.230	0.837	2.260	0.452

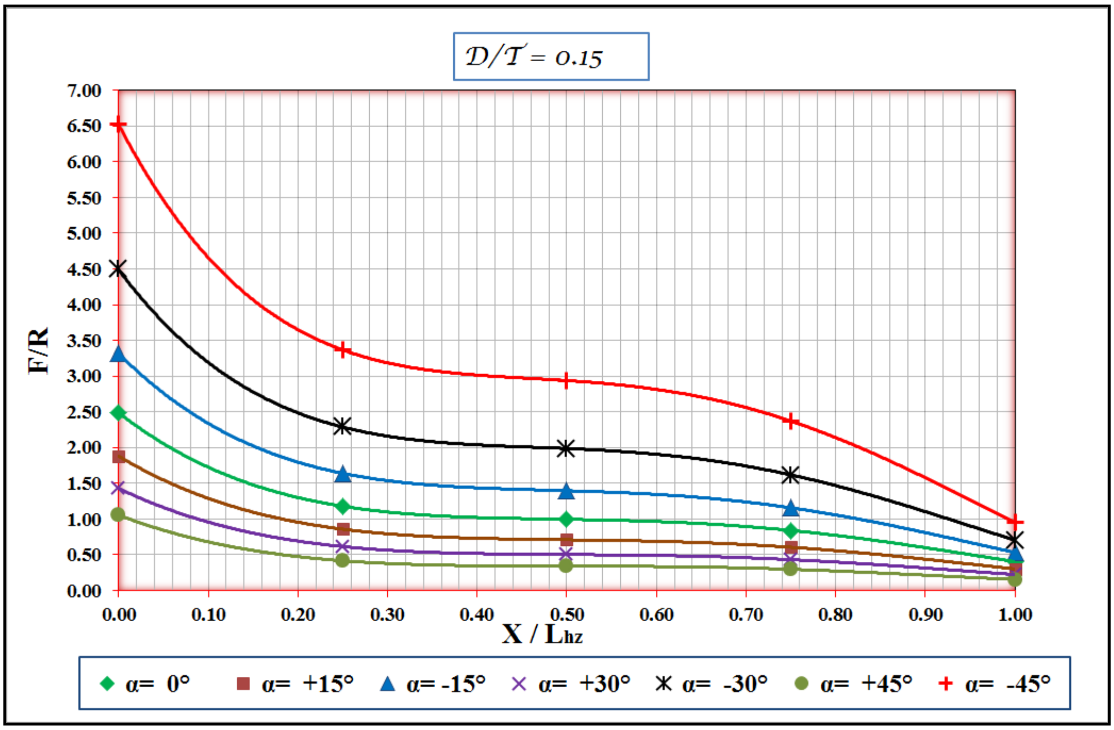

Fig. (3) Presents the relation between F/R and X/L_{hz} for D/T = 0.15.

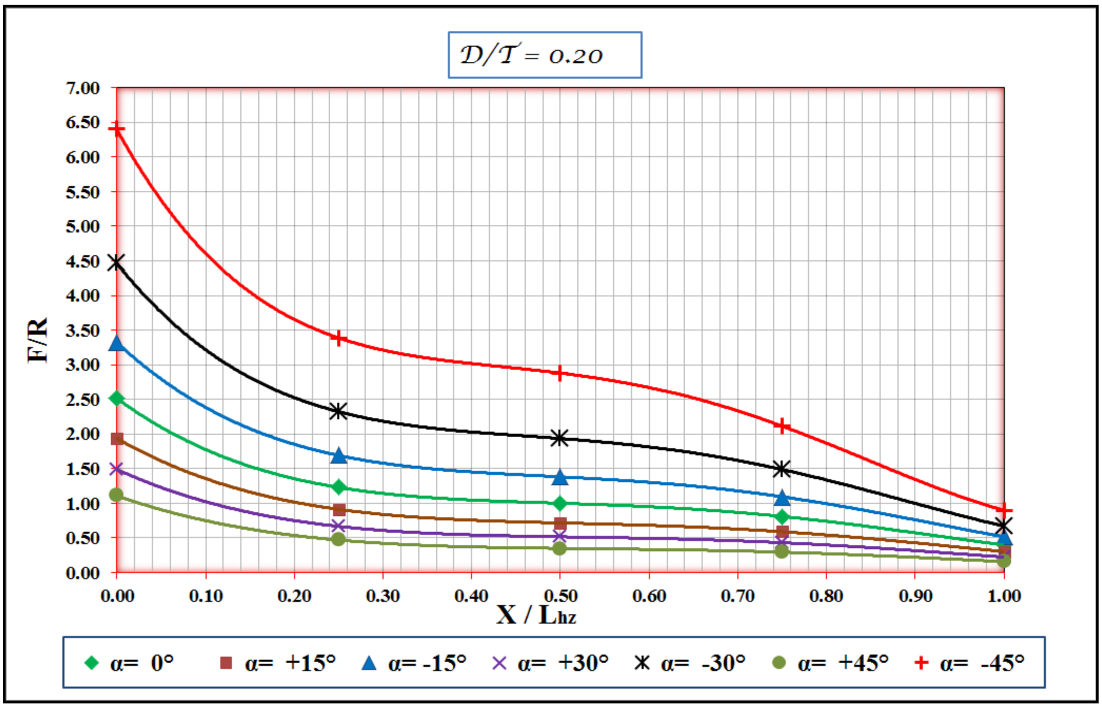

Fig. (4) Presents the relation between F/R and X/L_{hz} for D/T = 0.20.

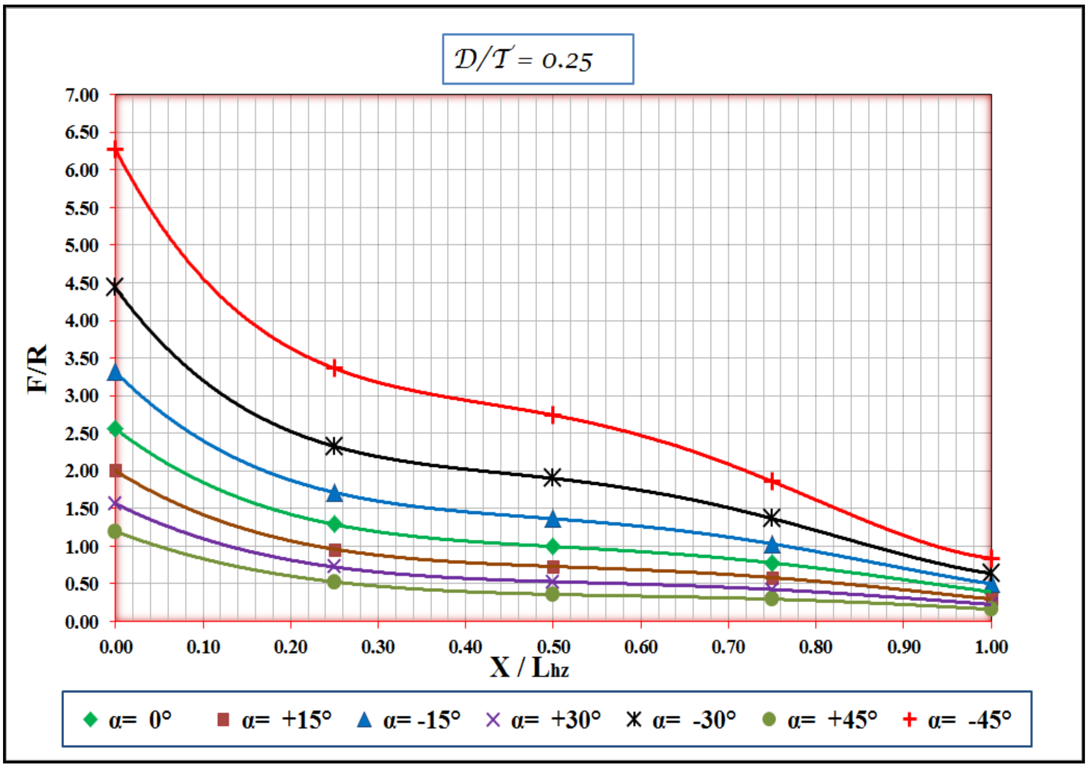

Fig.(5) Presents the relation between F/R and X/L_{hz} for D/T = 0.25.

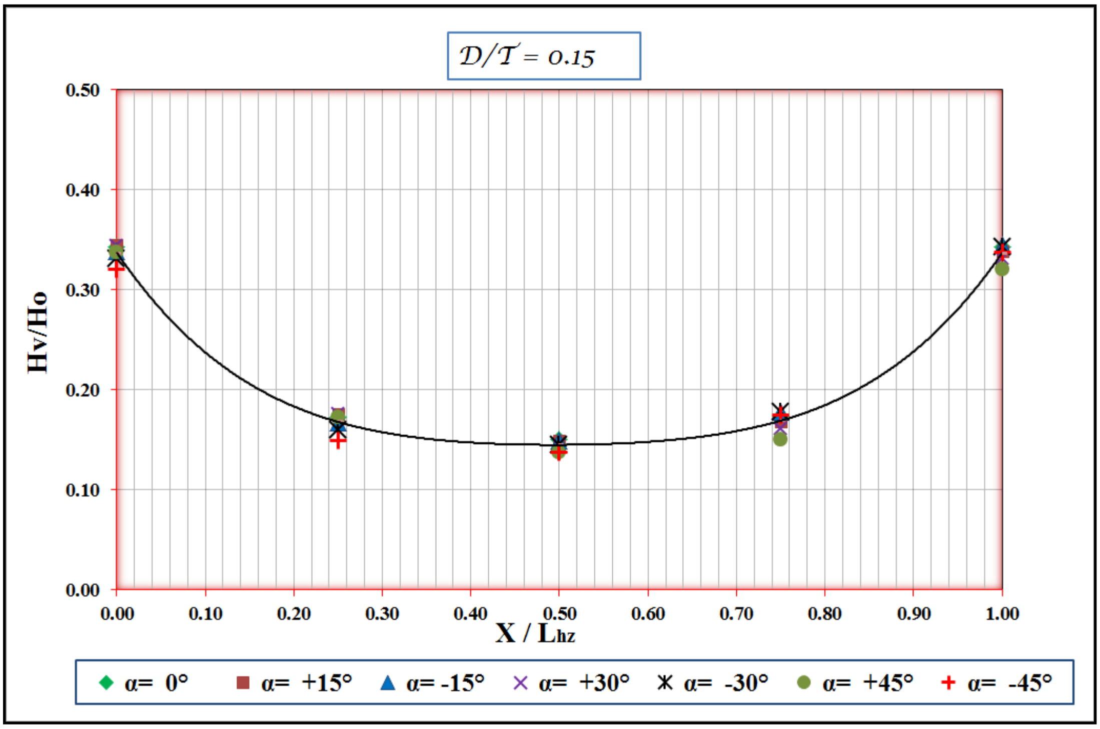

Fig. (6) Presents the relation between H_V/H_o and X/L_{hz} for D/T = 0.15.

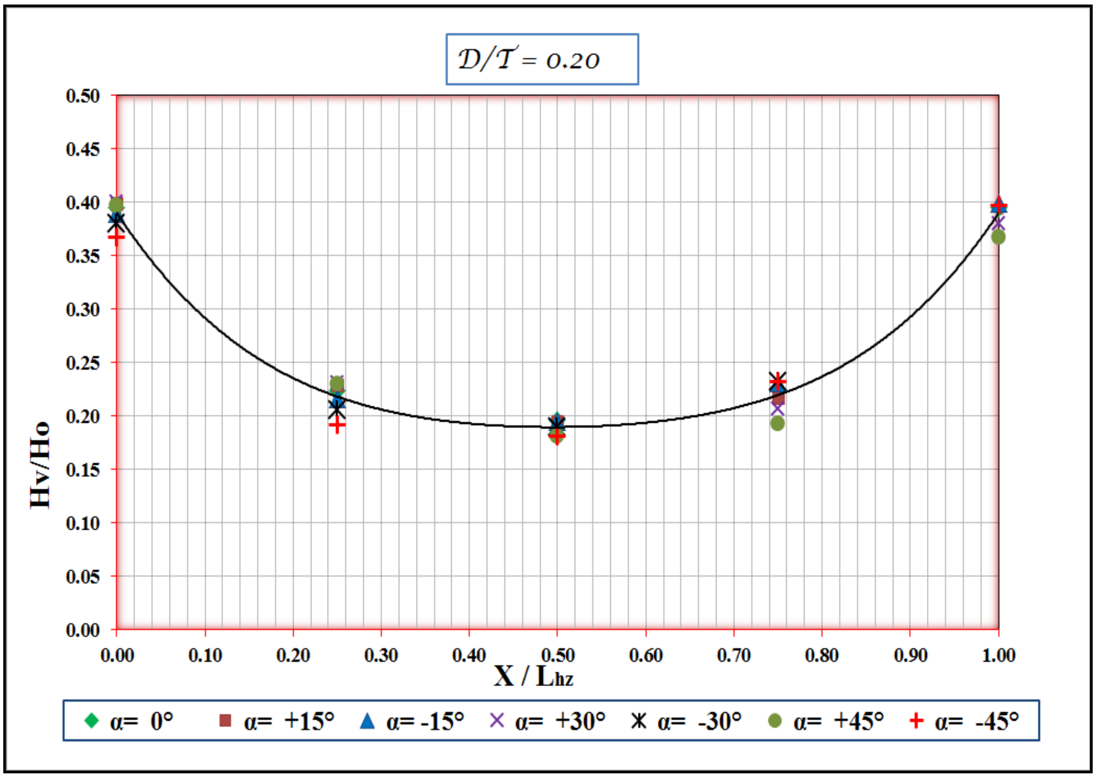

Fig. (7) Presents the relation between H_V/H_o and X/L_{hz} for D/T = 0.20.

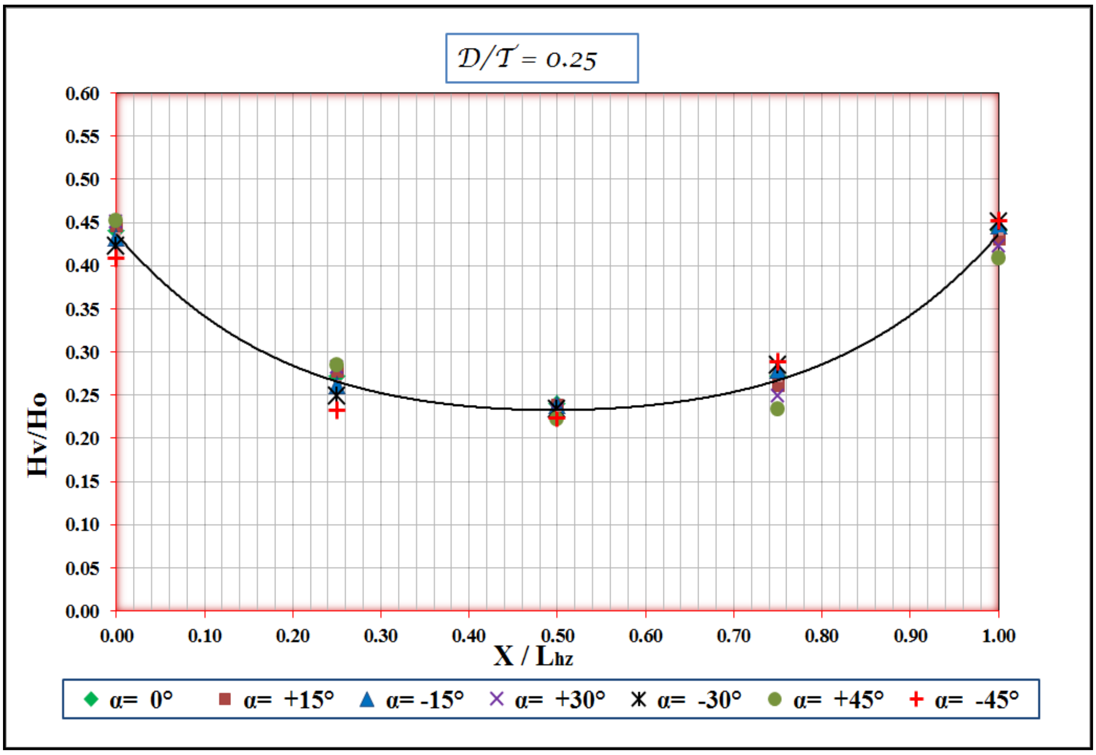

Fig. (8) Presents the relation between H_V/H_o and X/L_{hz} for D/T = 0.25.

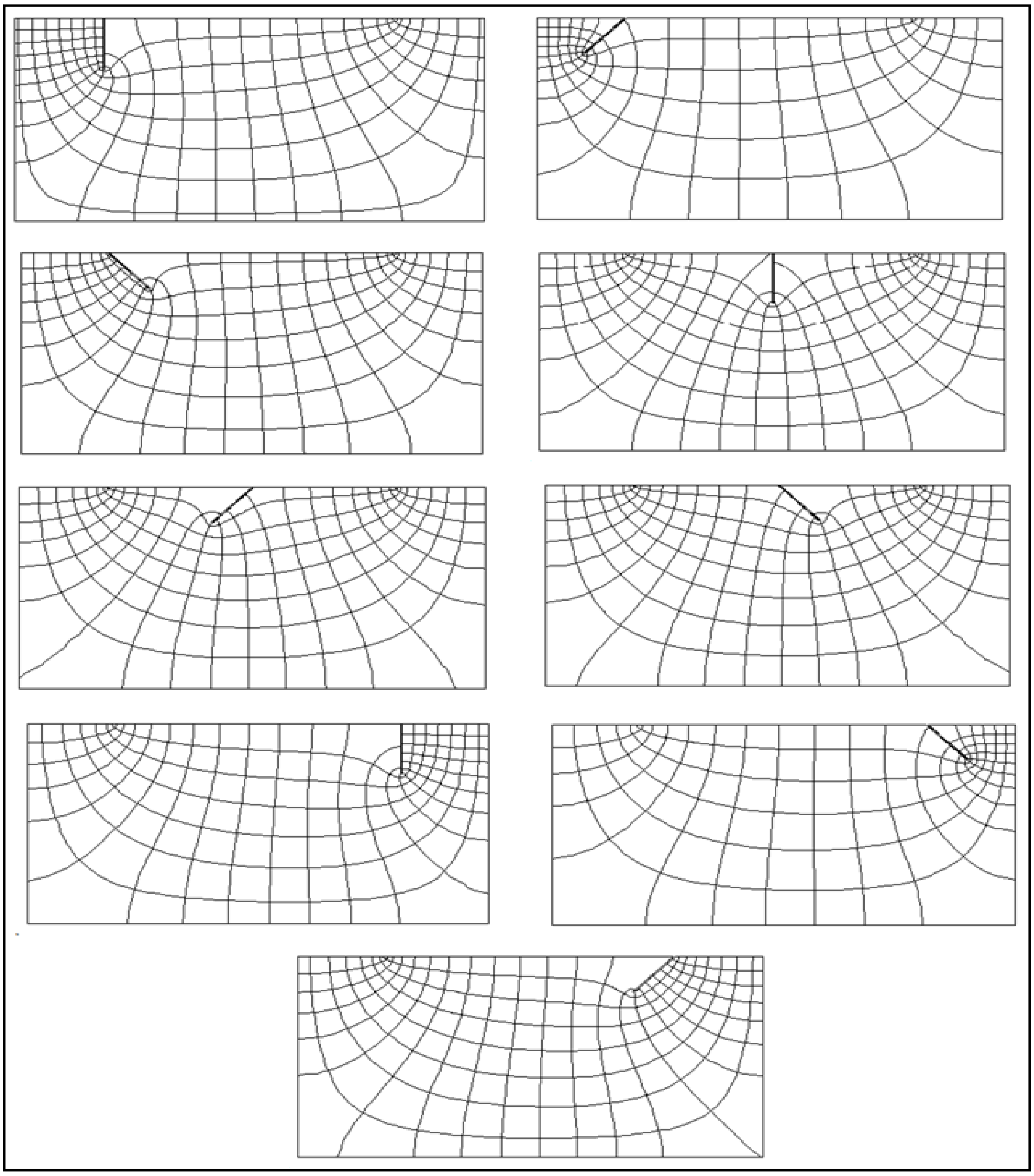

Fig. (9) Samples for flow net

For the shown figure (10) cross sectional elevation of a regulator with a single cutoff under apron:

D = 8.00 m, X = 7.50 m, H_o = 5.00 m and Total L_{hz} = 40.00 m.

If the given dimensions are supposed to secure safety against undermining and piping according to Bligh s criterion, suggest amendments required to render it conforming with the (F/R) concept according to present work if the cutoff with inclination angle (0º, +30º,-30º).

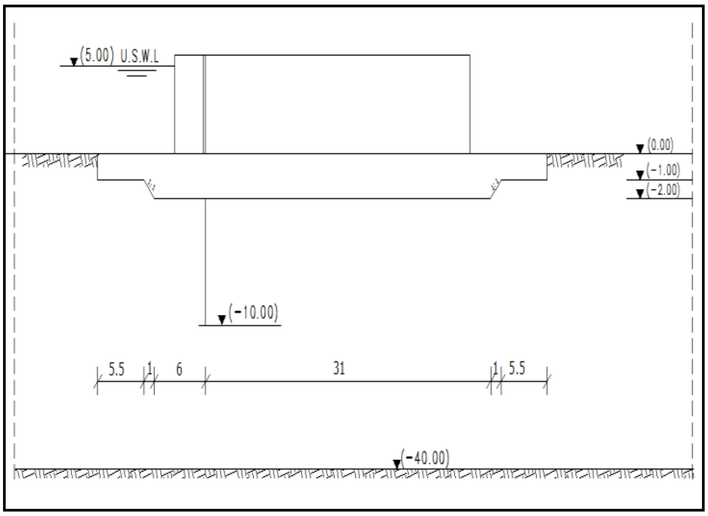

Fig. (10) Practical example

SOLUTION:

The creep length according to Bligh = $\Sigma L_V + \Sigma L_H$

ΣL_V = 1+1.414+ (2 × 8) + 1.414+1= 20.828m

ΣL_H = 5.5+1+31+1+5.5= 44.00 m

The creep length according to Bligh (L_W) = 64.828 m

$1/C_B$ = 5/64.828 = 1/ 12.966 (Hydraulic gradient)

From the chart fig. (4):

X/ L_{hz} = 12.5/50 = 0.25, and D/T = 8/40 = 0.20 For α = 0.0o

Get F/R = 1.23 ∴R/F = 0.813

The creep length according to present work= $\Sigma L_V^* + \Sigma L_H$

ΣL_V^*= 1+1.414+ (1+R/F) × D + 1.414+1= 4.828 + (1+0.813) ×8 = 19.332 m

ΣL_H = 5.5+1+31+1+5.5= 44.00 m

The creep length according to present work= 63.332 m $1/C_B^*$ = 5/63.332= 1/ 12.666 (Hydraulic gradient)
$1/C_B^* > 1/C_B$ (steeper)

Again, to guarantee a safe hydraulic gradient on the apron the creep length should be increase with increase in the cutoff depth. From the chart of fig. (7):

X/ L_{hz} = 0.25 and D/T = 0.20 f or α = 0.0o

Get H_V/H_0 = 0.225 but H_o =5.00m ∴H_V = (F+R) = 1.125

But F = 1.23 R ∴ 2.23 R = 1.125 ∴R = 1.125/2.23 = 0.504 m

∴F = 1.23 × 0.504= 0.620 m

F/D *= 0.620/ D * = 1/C_B = 1/ 12.966 ∴D * = 0.620×12.966 = 8.04m ≈8.00m (Okay)

From the chart of fig. (4):

X/ L_{hz} = 12.5/50 = 0.25 > 0.00, and D/T = 8/40 = 0.20 For α = +30.0o

Get F/R = 0.667

The creep length according to present work= ΣL_V*+ ΣL_H

ΣL_V *= 1+1.414+ (1+F/R) × D + 1.414+1= 4.828 + (1+0.667) ×8 = 18.164 m

ΣL_H = 5.5+1+31+1+5.5= 44.00 m

The creep length according to present work= 62.164 m 1/C_B* = 5/62.164= 1/ 12.433 (Hydraulic gradient)
1/C_B* > 1/C_B (steeper)

Again, to guarantee a safe hydraulic gradient on the apron the creep length should be increase with increase in the cutoff depth. From the chart of fig. (7):

X/ L_{hz} = 0.25 and D/T = 0.20 for α = +30.0o

Get H_V/H_0 = 0.225 but H_o =5.00m ∴H_V = (F+R) = 1.125

But F = 0.667 R ∴ 1.667 R = 1.125 ∴R = 1.125/1.667 = 0.675 m

∴F = 0.667 × 0.675= 0.45 m

R/D *= 0.45/ D * = 1/C_B = 1/ 12.966 ∴D * = 0.675×12.966 = 8.75m

Now, the modified creep length = 64.828 - (2×0.75) = 63.328m

1/C_B (modified) = 5/63.328 = 1/12.666 instead of 1/ 12.966,

On the safe side with respect to undermining and piping.

Percent decrease in cutoff depth = ((8.75-8.00)/8.00) ×100 = 9.375%

From the chart of fig. (4):

X/ L_{hz} = 12.5/50 = 0.25 > 0.00, and D/T = 8/40 = 0.20 For α = -30.0o

Get F/R = 2.324 ∴R/F = 0.43

The creep length according to present work= ΣL_V*+ ΣL_H

ΣL_V *= 1+1.414+ (1+R/F) × D + 1.414+1= 4.828 + (1+0.43) ×8 = 16.268 m

ΣL_H = 5.5+1+31+1+5.5= 44.00 m

The creep length according to present work= 60.268 m 1/C_B* = 5/60.268= 1/ 12.054 (Hydraulic gradient)
1/C_B* > 1/C_B (steeper)

Again, to guarantee a safe hydraulic gradient on the apron the creep length should be increase with increase in the cutoff depth. From the chart of fig. (7):

$X/L_{hz} = 0.25$ and $D/T = 0.20$ for $\alpha = -30.0o$

Get $H_V/H_0 = 0.225$ but $H_o = 5.00m$ $\therefore H_V = (F+R) = 1.125$

But $F = 2.324\ R$ $\therefore 3.324R = 1.125$ $\therefore R = 1.125/3.324 = 0.338m$

$\therefore F = 2.324 \times 0.338 = 0.785$ m

$F/D^* = 0.785/D^* = 1/C_B = 1/12.966$ $\therefore D^* = 0.785 \times 12.966 = 10.18m$

Now, the modified creep length = 64.828 - (2×2.18) = 60.458m

$1/C_B$ (modified) = 5/60.468 = 1/12.094 instead of 1/ 12.966,

On the safe side with respect to undermining and piping.

Percent decrease in cutoff depth = ((10.18-8.00)/8.00) ×100 = 27.25%

8. LIST OF REFERENCES

1. The Optimum Depth of Toe cutoff for Hydraulic Structures," Civil Engineering Research Magazine (CERM), Faculty of Eng., Al-Azhar University., Cairo, Egypt, pp.(1082-1090), Volume (16) – No. (11), November 1994.
2. Adel A. S., Yousry G., "Stability of Two Consecutive floors with Intermediate Filters," Journal of Hydraulic Research, Volume (39) - No. (5), November 2001.
3. Adel Elsheemy Effect of inclined cutoff on seepage under apron of Hydraulic Structure M.SC. . thesis, faculty of engineering, Al Azhar University, Cairo; 2015.
4. El-Molla, A. M., Akram K.S., Mohamed Abdellateef M., "Efficiency of Sheet piles under Apron of Hydraulic Structures," Civil Engineering Research Magazine (CERM), Faculty of Eng., Al-Azhar University, Cairo, Egypt, pp. (59-72), Volume (16) - No. (1), January 1994.
5. El-Molla, A. M., "New Trend for Evaluating the Percolation Length under Aprons of Hydraulic Structures Provided with Cutoff and Founded on Isotropic Soil," Civil Engineering Research Magazine (CERM), Faculty of Eng., Al-Azhar University, Cairo, Egypt, (183-198), Volume (23) - No. (1), January 2001.
6. El Molla, D. A., "Modeling Seepage Effects in Heterogeneous Soil Under Heading-Up Structures Using an Experimental and Numerical Methodology", Ph. D. Thesis, Faculty of Engineering, Ain Shams University, Cairo, 2014.
7. El-Morshedy, K. R., "Effect of Cutoff and Location on the Piezometric Head Distribution below Hydraulic Structures," Al-Azhar Eng. 7th Int. Conf., 2003.
8. El-Niazy, Hammad, El-Molla, A. M., Mohamed Abdellateef M., Ghada Samy "A computer-aided Model for seepage underneath Hydraulic Drops Structures," Al-Azhar Eng. 7th Int. Conf., 2003.
9. El-Salawy, M. A., "Reduction of Piping Liabilities by Use of End Cutoffs for Aprons of Control Structures," Doctor of Philosophy Thesis, Al- Azhar University, Cairo, 1988.
10. El-Salawy, M. A., EL-Molla, A. M., "Efficiency of Cutoffs under Apron of Hydraulic Structures," Civil Engineering Research Magazine (CERM), Faculty of Eng., Al-Azhar University, Cairo, Egypt, pp. (1790-1808), Volume (22) - No. (4), October, 2000.
11. El-Tahan, A. M. H., El-Molla, A.M., Effect of Cutoffs Depth Ratio on Uplift and Efficiency of Front and Back Faces of Upstream Cutoff, 21st Canadian Hydrotechnical Conference, 2013.
12. Mobasher AM. Efficiency of cutoffs under aprons of irrigation structures. M.SC. thesis, faculty of engineering, Al Azhar University, Cairo; 2005.
13. Salim, A. S., Yousry Ghazaw, "Stability of two consecutive floors with intermediate filters," Journal of Hydraulic Research, Volume (39) - No. (5), November 2000.