EFFECT OF INCLINED CUTOFF ON SEEPAGE BENEATH HYDRAULIC STRUCTURES

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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 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 this research work, a laboratory study was achieved using electrophoresis. In order to achieve the research objectives, an experimental work was executed where the different contributing parameters were varied and investigated (i.e. Twenty five (25) models were investigated in order to cover the various aspects of the problem under consideration). 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; Sheet pile; creep length.

1. INTRODUCTION

Seepage under the aprons of irrigation structures, founded on permeable soil, governs their design. The hydraulic gradient of the percolating water causes uplift pressure underneath the apron of the irrigation structures in terms of piezo metric head. This hydraulic gradient is affected by the length of the seeping water which by its turn is affected by the length of the seepage path (percolation length) under the apron of the irrigation structures.

Seepage water imparts energy to individual soil grains by viscous shear and by buoyancy. The resultant of these two forces is known as the "seepage force". This force, according to the fundamentals of hydrodynamics (Euler's equations of motion) is proportional to the hydraulic gradient. This leads the coarser particles to leave via soil cavities below the apron. This phenomenon is known as undermining. Also, at the section just at the apron toe, if the upward pressure of water exceeds the submerged weight of soil, measures should be implemented to ensure the apron safety against the destructive vertical piping.

This is achieved by providing aprons with cutoffs at the sections to ensure the safety of these structures against uplift pressures, undermining and horizontal piping.

As for the vertical piping downstream the apron toe, safety could partly be achieved by eliminating undermining and by loading the apron downstream at the toe (i.e. By perforated covers of concrete blocks, cutoffs which undoubtedly have a very good effect in retarding the piping process, as they originally maintain mild hydraulic gradient by increasing length of creep line.

In terms of the importance of hydraulic structures, this research was initiated with the objective of introducing an untraditional measure to ensure the safety of aprons by implementing vertical cutouts placed at its bottom in order to profit of its depth in dissipating the energy and reducing the potential energy in the water. In order to achieve the research objectives, a methodology was planned, according to which an experimental work was executed where the different contributing parameters were varied and investigated. Measurements were undertaken and documented. These measurements were analyzed, plotted on graphs, presented and discussed. Finally, an optimum configuration was reached; conclusions were deduced and recommendations, for future research were provided.

This paper presents the above under the following headlines:

- Reviewing the literature
- Executing a theoretical study
- Undertaking experimental investigations
- Analyzing and discussing the results
- Conclusions and recommendations

2. 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 (Lw) of water. The value of the weighted creep length is calculated as

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

Where:

L_{hz} : Sum of horizontal creep lengths

L_V : Sum of vertical creep lengths

CB : Bligh's coefficient

H : Piezometer head

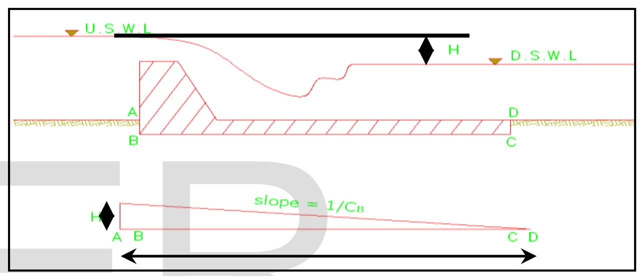


Figure (1) Creep line and Hydraulic Gradient Diagram

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 Lhz (sum of horizontal contacts and all sloping contacts whose angle with the horizontal is less than 45) to LV (sum of vertical contacts and all sloping contacts whose angle with the horizontal is more than 45) by the following equation:

Lw* (weighted creep length) is equal to:

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

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

$$L_W^{\ *} \lhd C_L . H$$

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) investigated flow patterns for 25 models representing aprons of hydraulic structures provided with cutoffs at various positions. All investigated models were founded on isotropic soil where the coefficient of permeability was considered the same for all flow directions. The SEEP-2D program was used to construct the flow pattern (flow net) for the investigated models. The percolation length for each model was thoroughly investigated. A new trend for precise, easy and quick estimation of both percolation length and uplift pressure under aprons of hydraulic structures were provided with. Also, the apron safe thickness could be easily and quickly designed or checked for the cases similar to the investigated models.

3. EXECUTING A THEORETICAL STUDY

In this research, a theoretical study was executed. Models representing apron of horizontal length (Lhz) 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). 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). 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 t 1.00.

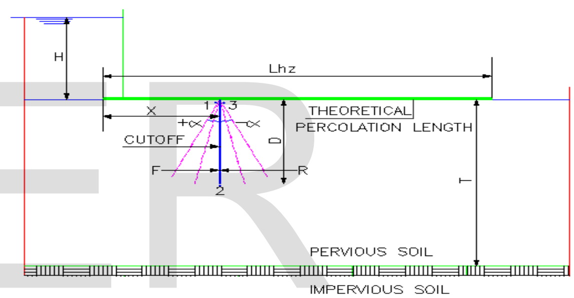


Figure (2) Definition Sketch

3. a. DIMENSIONAL ANALYSIS

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

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

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) provided with a single cutoff in a homogeneous stratum of soil with (K) permeability and (T) thickness.

3. b. DIMENSIONLESS RELATIONSHIP

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

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

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

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

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

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

So, any variable has a function as follows:

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

4. UNDERTAKING EXPERIMENTAL INVESTIGATION

An experimental study was carried out. This section presents the experimental apparatus, experimental program and undertaken measurements, as follows:

4. a. EXPERIMENTAL APPARATUS

The experimental apparatus consists mainly of a shallow glass tank of 600 x300x50 mm dimensions. In addition, there are two copper strips thoroughly prepared to work as electrodes (cathode and anode), variable resistor (rheostat) and plastic strips which are also prepared to be used for simulating the cutoffs beneath the floor of the model. An accurate DC power supply is also used to feed the system with the required potential. A digital ammeter of very high sensitivity is used to measure the different potentials at various points within the field. The experimental set-up is presented on figure (3).

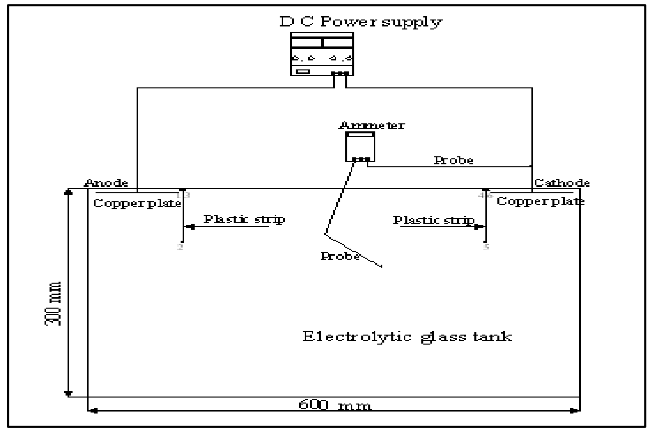


Figure (3) Experimental Model

Tap water is put in the glass tank to a depth of 5 mm. The DC power supply provides the experimental system with a voltage ranging between (1) and (15) volts. The equipotential lines resulting from the voltage drop occurring through the flow field between the electrodes of the system are measured for each experimental run by the aid of two electric probes which are connected to the digital ammeter.

4. b. PLANNING AN EXPERIMENTAL PROGRAM

An experimental program was planned to investigate a depth (D) =5.00cm. A 30 cm deep heterogeneous soil with a depth ratio (D/T) =0.167 was selected. The length of the apron (Lhz) was 30 cm. The position of the cutter was varied according to the length of the apron (i.e. X / Lhz = 0.00, 0.25, 0.50, 0.75 and 1.00). The angle of inclination (α) was varied (i.e. 0, 5 and 10 degrees). The chosen head (H) was 3.0 volts that was supplied by a DC Power Supply.

Twenty five (25) models were investigated in order to cover the various aspects of the problem under consideration. A thoroughly designed experiment was carried out to investigate these models. Three different potentials were used to cause the potential difference between the electrodes through the field of investigation. The used potentials are 3.0 volts. Different flow patterns were investigated for each model.

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)

- 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 – 1.00).

α= 0°	α= +5°	α= +10°	α= - 5°	α= - 10°

- The cutoff inclined with angle (α).

4. c. UNDERTAKING MEASUREMENTS

The digital ammeter facilitates the measuring process as well as minimizes the time required for each experimental run and consequently helps to avoid the effect of polarization process, which may happen between the electrodes and the electrolyte in the experimental apparatus during the testing time of each model.

4. d. EXPERIMENTAL PROCEDURE

The experimental replications proceeded following the steps:

- The tank was filled with tap water to a depth of 500 mm.
- The two copper plates were situated upstream and downstream the model and connected to the electric circuit.
- Potential = (3.00) was used to cause the potential difference between the electrodes through the field of investigation.
- The probe was moved along the tank in order to measure the potential at the key points 1, 2 and 3, figure (4).
- At the end of each test, the total potential drop was measured to insure that it was kept constant during the test. If the total potential drop changed, the water must be changed and the run should be repeated.

A total number of 25 models were carried out during the experimental program of the present work.

These steps were replicated to each model.

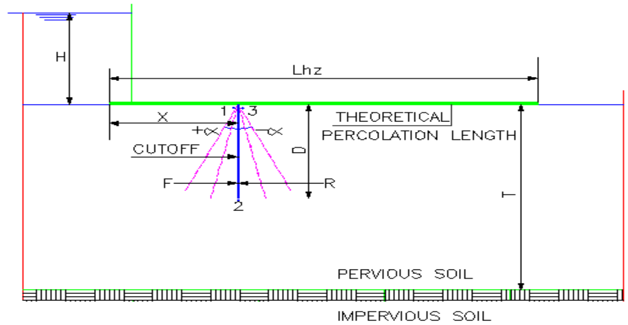


Figure (4) Flat Apron Provided with Cutoff

5. ANALYZING AND DISCUSSING THE EXPERIMENTAL RESULTS

Twenty five (25) experiments were executed to five (5) different angles (i.e. 0o, +5o, +10o,

-5o and -10o) using five (5) relative positions of the apron. Measurements were undertaken. Observations were recognized.

These measurements, observations were documented and archived. They were analyzed, comprehended and plotted on graphs. These graphs are presented here. They are discussed from the point of view of energy dissipation ability and creep length as follows:

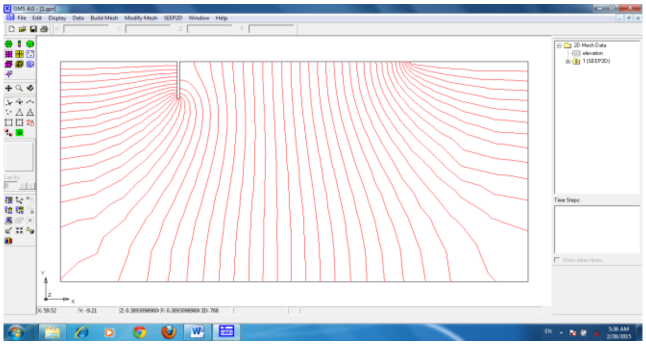
- Figure (5) is provided for comparison purposes. It presents the relation between F/R and X/L_{hz} of cutoff with all the inclinations.

From the above figures, it was clear that:

- The rear face dissipation is an increase than the front face dissipation when α = +5 and +10 for all positions.
- The front face dissipation is a decrease than the rear face dissipation when α = -5 and -10 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 example run (!) the equipotential lines for cutoff

α= 0°, X/Lhz =0



The Equipotential lines for run (1)

H/Lhz = 0.1			D/T = 0.167		
Angles	**α= 0°**	**α= +5°**	**α= +10°**	**α= -5°**	**α= - 10°**
X/Lhz	**F/R**	**F/R**	**F/R**	**F/R**	**F/R**
0	1.43	1.24	1.15	1.57	1.76
0.25	1.31	1.16	1.05	1.37	1.62
0.5	1.00	0.86	0.68	1.17	1.38
0.75	0.76	0.69	0.57	0.86	0.95
1	0.69	0.63	0.54	0.82	0.89

Table (1) a summary to the effect of the inclination of cutoff

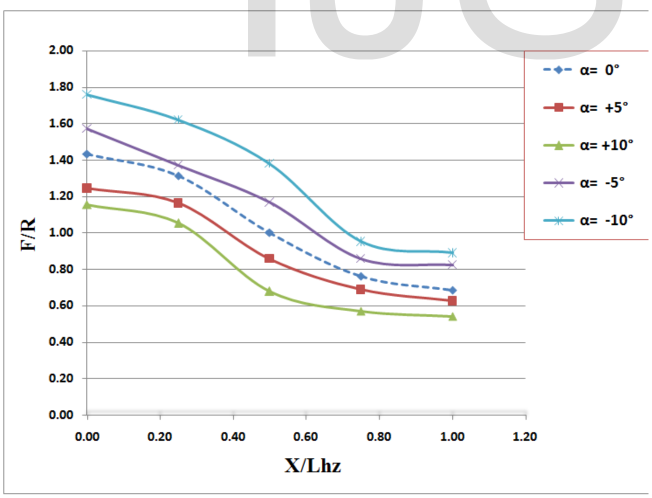


Figure (5) is provided for comparison purposes. It presents the relation between F/R and X/L_{hz} of cutoff with all the inclinations.

6. CONCLUSIONS AND RECOMMENDATIONS

Based on the above investigation phases, the concluded aspects were listed as follows:

- For positive values of α, there is an increase in the efficiency of the cutoff for X/Lhz (i.e. ranged between 0 to before midpoint of apron) and vice versa.
- For negative values of α, there is an increase in the efficiency of the cutoff for X/Lhz (i.e. ranged between after midpoint of apron to 1.00) and vice versa.
- For positive and negative values of α, there is a decrease in the efficiency of the cutoff for X/Lhz=0.50.
- Based on the results, the best position of the cutoff with inclination angle could be estimated from charts at (F/R) = 1.
- The presented charts could be used as a design charts for aprons for the cases similar to the investigated models.

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