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The Effect of Cutoffs on the Uplift Pressure Beneath the Hydraulic Structures Floor

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Abstract: The use of cutoffs underneath the hydraulic structures is considered a safe solution to ensure the stability of hydraulic structure against uplift pressure and piping phenomenon in addition to the sliding and overturning forces of the water.
These cutoffs are used at critical sections underneath the floor of hydraulic structure to substitute with their depths the horizontal lengths of the creep line of the hydraulic structure base. In this paper, the experimental method- by using electrical analogue model- was carried out to plot the flow net and study the efficiency of the front and rear faces of the cutoffs for dissipating the potential energy of the percolating water underneath the floor of hydraulic structure. An electrical analogue model which was used in this study consists of twenty five models with different depths of upstream and downstream cutoffs. After plotting the flow net for all models, it is concluded that the efficiency of the inner sides are less than that of the outer sides which were investigated before in this topic of this work that both faces reduction values in the uplift pressure are considered the same, where the efficiency of the outer face of upstream cutoff is (70.35) % and for the inner face is (29.64)%, while for the downstream cutoff the efficiency for the outer face is (76.21)% and for the inner face is (23.79)% .

Keywords: *Seepage, Uplift pressure, Flow net, Efficiency of cutoffs, Electrical analogue model.*

تأثير الحواجب القاطعة على ضغط الاصعاد تحت أرضية المنشآت الهيدروليكية

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الخلاصة: إن استخدام الحواجب القاطعة تحت المنشآت الهيدروليكية يعتبر الحل السليم لضمان استقرارية المنشأ الهيدروليكي تجاه ظاهرة ضغط الاصعاد وحدوث ظاهرة الجريان الانبوبي بالإضافة الى قوى الانزلاق والانقلاب للمياه.ان هذه الحواجب تستخدم في المقاطع الحرجة تحت أرضية المنشأ الهيدروليكي وذلك بتأثير عمقها للتعويض عن النقص الحاصل في تأثير خط الزحف تحت قاعدة المنشأ الهيدروليكي. في هذا البحث استخدمت نمذجة التشابه الكهربائي لرسم شبكة الجريان ودراسة كفاءة وجهي هذه الحواجب في مقدم ومؤخر المنشأ في تشتيت طاقة المياه الكامنة عند تسربه تحت المنشآت الهيدروليكية. لقد تم استخدام نموذج التشابه الكهربائي في هذه الدراسة وقد تضمنت (25) لأعماق مختلفة من الحواجب في المقدم المؤخر. وبعد رسم شبكة الجريان لجميع النماذج فقد تم استنتاج ان كفاءة الأوجه الداخلية للحواجب أقل من الأوجه الخارجية وليس كما ورد التوصل اليه سابقاً في هذا المجال من ان قيم اختزال ضغط الاصعاد تعتبر متساوية على كلا الوجهين, حيث ان كفاءة الوجه الخارجي للحاجب في مقدم المنشأ هي (70.35)% وللوجه الداخلي (29.64)% . أما للحاجب في مؤخر المنشأ فكفاءة الوجه الخارجي (76.21) %, وللوجه الداخلي (23.79) % .

1- INTRODUCTION:

When the hydraulic structures are constructed on permeable foundations and there is a difference in water level between the upstream and downstream of these structures, the seepage of water will occur underneath the floor of these structures. [1]

The seeping water will exerts an uplift pressure on the apron of hydraulic structure and it will generate an erosive forces pull the particles of soil with the flow leading to format irregular passage such as pipes which move underneath the floor reaching to the end causing failure in the hydraulic structure. This process is called piping phenomenon. [2]

Also, at any point underneath the floor of hydraulic structures, if the pressure of the water which seeping under the structure exceeds the submerged weight of the soil mass above it, the process of boiling or heaving of the soil particles will occur especially in the exit gradient of the hydraulic structure which represents the serious case of the problem under consideration. [3] The most important aspects that must be taken into account when the hydraulic structures are designed, according to the failure it could happen due to piping phenomenon and the uplift pressure.

Providing the aprons with cutoffs at different sections is one of the most solutions which is used by engineers to ensure safety of the hydraulic structures apron against both piping phenomenon and uplift pressure. These cutoffs are used to elongate the seepage path (creep line) which is the contact line between the soil foundation and the apron of hydraulic structures. [4]

In order to investigate the safety of the hydraulic structures against the uplift pressure and piping phenomenon, Bligh (1910) introduced the theory of the creep length. Subsequently, Lane (1932) relied on his investigations of about (200) damaged hydraulic structures and presented his theory which is called the weighted creep length. Bligh assumed that there is no distinguishing in vertical and horizontal creeps in evaluating their effectiveness against piping. He presented a formula to obtain the weighted creep length value (L_w). as:

$$L_w = L_h + L_v \quad (1)$$

$$L_w = C_B * H \quad (2)$$

Where:

L_w: Weighted creep length (m).

L_h, L_v: The summation of horizontal and vertical creep lengths (m).

He suggested that the ratio of (L_w/H) should not exceed the specific value of (C_B) which is known as a Bligh's coefficient and depends on the soil type.

H: Head difference between the upstream and downstream of hydraulic structure(m). [5]

Later on, Lane 1932 represented the concept of the line that have least resistance and the flow of water may be followed this concept. In calculation of the length of creep, Lane suggested a distinguishing between the vertical and horizontal surfaces, where finally, he concluded that the vertical surface should be given greater weight than the horizontal surface, therefore he obtained formula to calculate the value of the weighted creep length as:

$$L_w = L_v + \frac{L_h}{3} \quad (3)$$

Also he suggested that the ratio (L_w/H) should not exceed the value of (C_L) which is called Lane's coefficient of percolation and depends on the type of soil. [6]

This means that the weighted creep length could be expressed as:

$$L_w = C_L * H \quad (4)$$

For the purpose of designing a hydraulic structure which provided with cutoffs, and when calculating the required horizontal length of the seepage path (creep line) underneath the apron of hydraulic structures, for this purpose, the theories of Bligh or Lane are usually used.

The efficiency of the outer face of the vertical cutoff is considered equal to the efficiency of the inner face for the same cutoff and the horizontal length of the floor in dissipating the energy of the seeping water, according to Bligh's theory. While according to Lane's theory, the efficiency of the two faces of vertical cutoffs is equal to three times that of equivalent horizontal length.

The experimental work of the present paper is carried out to investigate models of hydraulic structures provided with two cutoffs of different depths at the upstream and downstream of the structure. The electrical analogue model is used in this investigation.

2- AIMS OF THE STUDY:

The main objectives of this study could be summarized by the following points:

1- Plot the equipotential lines for the water which seeping underneath the hydraulic structure which is provided with two cutoffs, by electrical model then draw the flow lines by means of circle method (Forchimer method).

2- study the efficiency of the outer and inner faces of the cutoffs in dissipating the potential of the water seepage underneath the floor of hydraulic structure.

3- THE EXPERIMENTAL WORK:

The results were obtained by the electrical model using the electrolytic tank which is shown in figures (1) and (2), that carried out in electrical circuit and measurement laboratory of the electrical department at the Middle Technical University, Kut, Technical Institute. The electrical analogue is based on the analogy between the flow of water through porous media and flow of electrical current through the conductor media, [7] and this analogue is based on the similarity between Darcy's law and Ohm's law.

Where the flow of water through permeable soil is governed by Darcy's law as follows:

$$v = -ki = -k\left(\frac{d_h}{d_s}\right) \quad (5)$$

Where:

v: the discharge velocity (m/s).

k: the hydraulic conductivity (m/s).

i: the hydraulic gradient in the flow direction.

While the flow electric current is governed by Ohm's la

$$I = \frac{1}{R}\left(\frac{d_E}{d_s}\right) \quad (6)$$

Where:

I: the intensity of current per unit area $(Amp./m^2)$.

R: the specific resistance $(Ohm.m)$.

$\frac{1}{R}$: the electric conductivity.

E: the electric potential ($Volt$)
$\frac{d_E}{d_s}$: the voltage gradient in the direction of current.
The head at any point inside the electrolytic tank can be represented by the voltage which measured at that point, and by identifying points with equal voltages, equipotential lines can be plotted and the stream lines are plotted perpendicular to them later. [8]

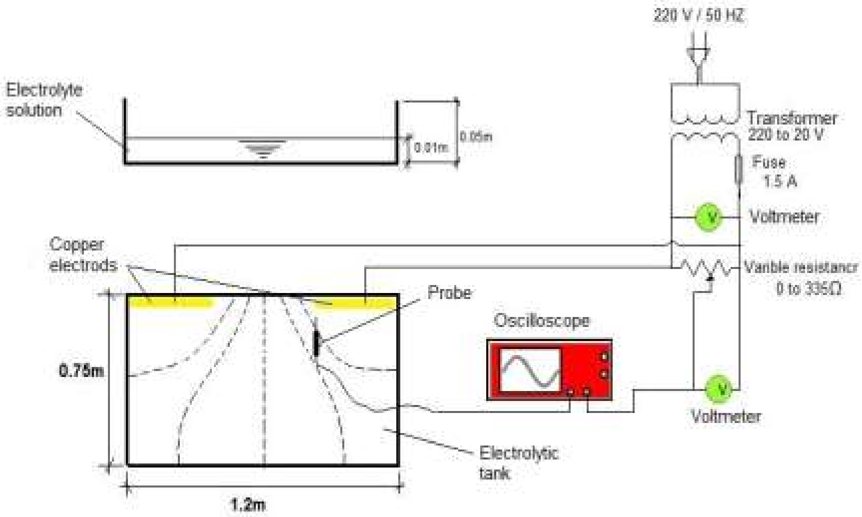

Fig (1) plane of the electrical model

Fig (2) photo of the electrical model

4- THE EXPERIMENTAL SETUP:
The experiments were conducted for twenty five models with different depths of the cutoff at the upstream and downstream of structure with constant length of the floor of hydraulic structure**,** also the head which applied on the upstream was (20 volte) for all models. The experimental setup which is used in this work consists of two parts, the first part is a glass tank of a dimensions (1.2 m long, 0.75 m wide, 0.05 m depth) and the thickness of glass is (0.006 m). An electrolyte solution was used with depth of (0.01 m) to represent the conductive medium, which consists of (0.15 Kg) of hydro Copper Sulphate diluted in (10 liters) of distilled water.
The solution should be kept always at the same level in the glass tank to make sure that the conductivity at the same level during all the experiments. In case any change happen in the depth of the solution leads to series of errors in the flow net shape. While the second part of the experimental work is an electrical circuit which consists of: A.C power source, Rheostat to change the voltage from (0 %) to (100 %), Oscilloscope with probe to show the points with zero

voltage in the solution, variak transformer to reduce the A.C supply voltage from (220 volts) to (20 volts), Voltmeter for checking the output voltage from variak, and copper electrodes of dimensions (0.36 m long, 0.02 m wide, 0.002 m thick) which represents the water boundary (heads of water) at the upstream and downstream of the structure. While the part of glass tank which was not covered by electrodes, represents the floor of structure in the electrical model. Therefore the flow of electric current moving through the electrolyte solution is from the electrode which represents (20 volte) to other electrode which represents (0 volte).

In addition to the above two main parts, there are other tools to complete the requirements of the model and get the required results, such as the pantograph which is used to determine the zero voltage point, by forwarding the probe in the solution according to the Oscilloscope wave in one side of the pantograph. In the other side of the pantograph, there is a pencil used to plot the reflection of that movement on the drawing paper on the board.

Plastic parts were also used with different lengths and fixed by plastic clay for representing the cutoffs in the model.

5- Analysis of data:

The measurements which are obtained from the experimental work have been analyzed to determine the efficiency of both outer and inner faces of the upstream and downstream cutoff. Efficiency can be expressed as the dissipated head through the two faces of cutoff depth. Initially, the flow net of (25) models were plotted in five cases. At each case the depth of the upstream cutoff (d_1) is constant, and the depth of downstream cutoff (d_2) is changed for five depths as (0.05, 0.1, 0.15, 0.20 and 0.25) m. After plotting the flow nets for all models, the number of equipotential lines was determined for both the outer and inner faces of both the upstream and downstream cutoffs, also the number of equipotential lines for the horizontal surface (the floor of structure) was determined as shown in table (1).Then, the ratio between the number of equipotential lines of the outer face of upstream cutoff and the total number of equipotential lines which drawn at both faces of the upstream cutoff was calculated as a percentage $(\frac{N_e\ outer\ of\ d_1}{total\ N_e\ of\ d_1})$, therefore the average of this ratio for each of the five cases was found as $(A.v_1)_{d_1}$. While $(A.v_2)_{d_1}$, which is the average of percentage of equipotential lines drawn on the inner face relative to the total number of equipotential lines which drawn on both the outer and inner faces of the upstream cutoff was calculated as: $[100 - (A.v_1)_{d_1}]$ for each of the five cases. The previous steps are followed for the downstream cutoff , where $(A.v_1)_{d_2}$ and $(A.v_2)_{d_2}$ were also calculated, as shown in table (2), which mean the average of equipotential lines which drawn at both the outer and inner faces of downstream cutoff separately relative to the total number of equipotential line of downstream cutoff.

The ratio of the number of equipotential lines for the horizontal and vertical surfaces to the total number of equipotential lines, which is (20) lines was also found as a percentage $(\frac{N_e\ for\ L_v}{total\ of\ N_e})$ and $(\frac{N_e\ for\ L_h}{total\ of\ N_e})$, then the average of these ratios was found for each of the five cases as $(A.v_3)_{L_v}$ and $(A.v_4)_{L_h}$ as shown in table (3).

6- Discussion of results:

After scheduling the results obtained, it is found that the number of equipotential lines of the outer face is more than the number of the inner face for both the upstream and downstream cutoffs, and this mean that the efficiency of the outer faces in dissipating the head of the percolating water is more than that in the inner faces for both the upstream and downstream cutoffs, and this can be seen in figure (3) and figure (4). Hence, the outer faces of both upstream and downstream cutoffs should have more weight than that in the inner faces. It is also possible to note that the efficiency of the outer face for the upstream cutoff is less than that of the same face for the downstream cutoff as shown in figure (5).

This point of view in the opinion of the researcher is happened according to the phreatic surface pressure in the outer sides of the cutoffs which are expressed both in the upstream and downstream. In the meantime, the inner sides of the both cutoffs are subjected to a closed pressure underneath the structure floor. Also in the electrical analogue which represents a free movement of voltage electricity in the outer sides, and restricted movement in the inner sides, underneath the structure. Figure (6) shows that the percentage of equipotential lines of the vertical surface is higher than that in the horizontal surface.

7- Conclusions:

The efficiency of both the outer and inner faces of the upstream and downstream cutoffs in dissipating the head of percolating the water is investigated using the data obtained from the laboratory work.

The following conclusions were obtained:

1- The outer and inner face of the upstream and downstream cutoff do not have the same efficiency for dissipating the potential of percolating water.

2- The efficiency of the outer face for both upstream and downstream cutoff is greater than that of the inner face, where the average efficiency of the outer face of the upstream cutoff for all models is (70.35)% and (29.64)% for the inner face. As well as for the downstream cutoffs, the efficiency of the outer face is (76.21)% , while for the inner face is (23.79)% .

3- According to the results obtained from this work, the vertical surface which represents the cutoff underneath the apron of hydraulic structure has a weight greater than the horizontal surface which represents the floor of hydraulic structure, where the efficiency of the vertical surface which consists of two cutoffs at the upstream and downstream of the structure ($2d_1+2d_2$), is (74.88)% and the efficiency of the horizontal surface is (25.12)% .

TABLE (1) CALCULATIONS AND MEASUREMENTS

d1 (cm)	Ne for the outer face	Ne for the inner face	d2 (cm)	Ne for the outer face	Ne for the inner face	Ne for 2d1+2d2 (Lv)	Ne for Lh
5	3	1.5	5	5	2.1	11.6	8.4
	3.4	2.1	10	6.2	2.1	13.8	6.2
	4	1.3	15	6.4	3.1	14.8	5.2
	3.4	1.3	20	8	2.3	15	5
	3	1.3	25	8	2.4	14.7	5.3
10	5	2.3	5	4.2	1.3	12.8	7.2
	4.1	2.3	10	6.3	2.1	14.8	5.2
	4	2.4	15	7	1.3	14.7	5.3
	4.1	2.5	20	7	2.3	15.9	4.1
	4	1.6	25	7.3	2.6	15.5	4.5
15	5	2.4	5	4.2	2.1	13.7	6.3
	4.3	2.2	10	6.2	2.2	14.9	5.1
	4.4	2.3	15	6.1	2.2	15	5
	5	2.3	20	6.4	2.3	16	4
	5	1.4	25	8	2.3	16.7	3.3
20	6.1	2.3	5	4	1.4	13.8	6.2
	6	2.2	10	5.1	2.3	15.6	4.4
	6	1.7	15	6	1.3	15	5
	5	2.3	20	7	2.3	16.6	3.4
	5	1.7	25	7	2.2	15.9	4.1
25	6	2.5	5	4.1	1.1	13.7	6.3
	6	2.4	10	6	1.3	15.7	4.3
	6.1	2.4	15	6	1.4	15.9	4.1
	6	1.8	20	7	1.2	16	4
	5.5	1.3	25	8	1.5	16.3	3.7

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VOLUME: (6), NO. : (3) 2018

TABLE (2) PERCENTAGE OF EQUIPOTENTIAL LINES FOR (D1)AND(D2)

d1 (cm)	d2 (cm)	$\left(\frac{N_e \text{ outer of } d_1}{\text{total } N_e \text{ of } d_1}\right)\%$	$(Av._1)_{d_1}$	$(Av._2)_{d_1}$	$\left(\frac{N_e \text{ outer of } d_2}{\text{total } N_e \text{ of } d_2}\right)\%$	$(Av._1)_{d_2}$	$(Av._2)_{d_2}$
5	5	66.67	69.21	30.79	70.42	73.42	26.58
	10	61.82			74.7		
	15	75.47			67.37		
	20	72.34			77.67		
	25	69.77			76.92		
10	5	68.49	65.72	34.28	76.36	76.94	23.06
	10	64.06			75		
	15	62.5			84.34		
	20	62.12			75.27		
	25	71.43			73.74		
15	5	67.57	69.2	30.8	66.67	73.04	26.96
	10	66.15			73.81		
	15	65.67			73.49		
	20	68.49			73.56		
	25	78.13			77.67		
20	5	72.62	73.37	26.63	74.07	75.3 1	24.69
	10	73.13			68.92		
	15	77.92			82.19		
	20	68.49			75.27		
	25	74.63			76.09		
25	5	70.59	74.32	25.68	78.85	82.34	17.66
	10	71.43			82.19		
	15	71.76			81.08		
	20	76.92			85.37		
	25	80.88			84.21		

TABLE (3) PERCENTAGE OF EQUIPOTENTIAL LINES FOR (LV)AND(LH)

d1 (cm)	d2 (cm)	$\left(\frac{N_e \text{ for } L_v}{20}\right)\%$	$A_{v.3}$	$\left(\frac{N_e \text{ for } L_h}{20}\right)\%$	$A_{v.4}$
5	5	58	69.9	42	30.1
	10	69		31	
	15	74		26	
	20	75		25	
	25	73.5		26.5	
10	5	64	73.7	36	26.3
	10	74		26	
	15	73.5		26.5	
	20	79.5		20.5	
	25	77.5		22.5	
15	5	68.5	76.3	31.5	23.7
	10	74.5		25.5	
	15	75		25	
	20	80		20	
	25	83.5		16.5	
20	5	69	76.9	31	23.1
	10	78		22	
	15	75		25	
	20	83		17	
	25	79.5		20.5	
25	5	68.5	77.6	31.5	22.4
	10	78.5		21.5	
	15	79.5		20.5	
	20	80		20	
	25	81.5		18.5	

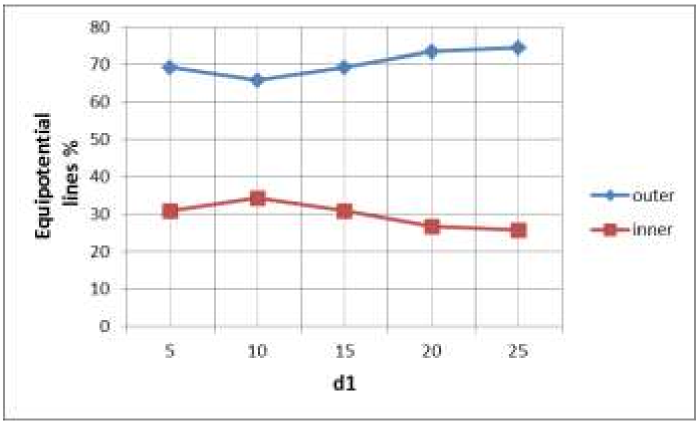

Fig (3) the percentage of equipotential lines for both outer and inner sides of upstream cutoff

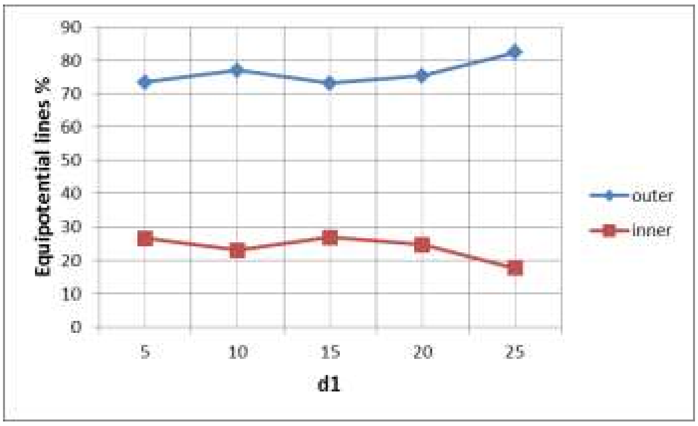

Figure (4) the percentage of equipotential lines for both outer and inner sides of downstream cutoff

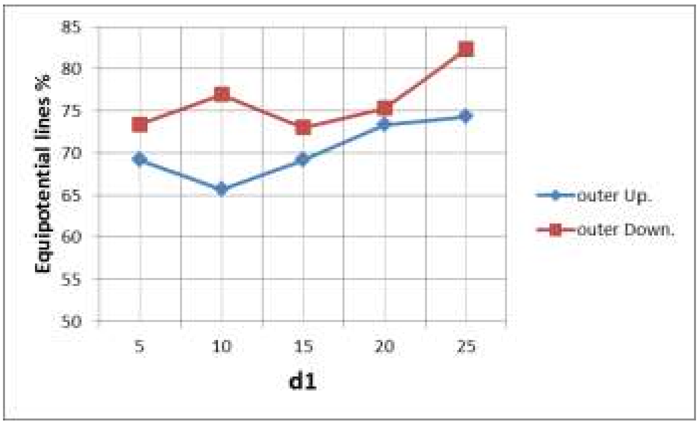

Figure (5) the percentage of equipotential lines for the outer side of both the upstream and downstream cutoff

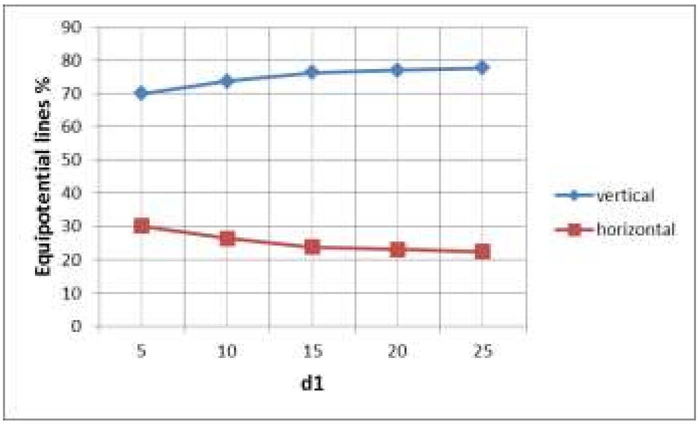

Figure (6) the percentage of equipotential lines for both vertical and horizontal surface

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