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The Effect of Impervious Layer Depth on the Uplift Water pressure beneath the Gate Location in the Hydraulic Structures

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Abstract:
Because of the maximum uplift water pressure usually became under the gate of the hydraulic structures, so in this research a determination of the uplift pressureunder the gate location was investigated by using a finite element method with the Geo- studio 2016 software together with experimental work by using electrical analogue model to compare the results obtained from the two methods and to show the accuracy of the electrical analogue model to simplify solving the seepage problems under the hydraulic structures.
The experiments were carried out in the electrical laboratory, Kut Technical Institute, for four cases of impervious layer at different depths of (75, 60, 45, 30) cm respectively, and each case consisted of (25) models, the flow net was plotted for each case and the total was (100) cases to determine the uplift pressure beneath the gate location.

The experimental flownets and results were compared with the results of Geo-studio software program, both results shown a good agreement between them approach to (92.561)%.

Keywords: impervious layer, uplift pressure, SEEP/W software, electrical analogue model.

پوختە:
بەهۆی بەرزی پەستان لەسەر بنکەی دەرگای دامەزراوە هایدرۆلیکیەکان، ئەم توێژینەوەیە هەوڵدەدات بری ئەو پەستانە لەو جێگانەدا دەستنیشان بکات لەرێی میتۆدی رەگەزی بێکۆتاوە (Geo- Studio 2016 SEEP/W) وە هاوتاکردنی دەرئەنجامی دەستکەوتوو بە دەرئەنجامەکانی کاری تاقیگەیی کە لە رێگەی بەکارهێنانی مۆدێلی ئەنەلۆگی کارەبایی یەوە دەست کەوتوون بە مەبەستی ئاسانکاری لە چارەسەرکردنی لێچوون لە دامەزراوە هایدرۆلیکییەکاندا.
تاقیکردنەوەکان لە تاقیگە کارەبایی یەکانی بەشی کارەبا لە پەیمانگای تەکنیکی کوت ئەنجامدراوە. کە تیایدا چوار جۆری جیاواز لە چینی نەبر لە قوڵی (75,60,45,30)سم تاقیکراوەتەوە. هەر یەکێك لەم حاڵەتانە (25) نموونە لە خۆ دەگرێت و بۆ هەریەکەیان تۆری ئاوەڕۆ کێشراوە و بەم شێوەیەش (100) نموونە دەست کەوتووە. لە کۆتادا، دەرئەنجامەکان بە شێوەیەکی بەرچاو بە رێژەی (92.561٪) هاوتابوون.

الخلاصة:
بسبب وجود أكبر ضغط اصعاد تحت موقع البوابة في المنشآت الهيدروليكية، فقد كرس هذا البحث لإيجاد ضغط الاصعاد في هذا الموقع باستخدام برنامج يعتمد على طريقة العناصر المحددة (Geo- Studio 2016 SEEP/W)، إضافة الى العمل المختبري باستخدام نموذج التماثل الكهربائي، وقد تمت مقارنة النتائج المستحصلة من الطريقتين لإظهار دقة نموذج التماثل الكهربائي وذلك لتبسيط حل مشاكل التسرب تحت المنشآت الهيدروليكية.
أجريت التجارب المختبرية على الموديل الكهربائي في مختبر الدوائر والقياسات- قسم الكهرباء- المعهد التقني في الكوت. لقد تم فحص أربع حالات لأعماق مختلفة من الطبقة العديمة النفاذية وهي على التوالي (75، 60، 45، 30) سم وكل حالة تتضمن (25) نموذج وقد رسمت شبكة الجريان لكل حالة حيث أصبح المجموع الكلي للحالات (100) حالة، وذلك لإيجاد ضغط الاصعاد تحت المنشأ الهيدروليكي في موقع البوابة، ان المقارنة بين نتائج العمل المختبري والبرنامج النظري قد أعطت توافق جيد يصل معدله الى (92.561)%.

1- Introduction:

The foundation in the hydraulic structures must be given a good attention than the other parts of the structure in the analysis and design of these structures because the failure of foundation will lead to series of failures in the whole structure.[1]

One of these problems which confronts engineers in the design of hydraulic structures is problem of seepage through the porous media where the structure is based occurring as a result to the difference of water level between upstream and downstream of the structure. [2]

As a result of this problem, seeping water will exert pressure onbase of the hydraulic structure knownas a net water pressure due to uplift and downward pressure obtained in the gate location, as well as the seepage force which try to erode the soil particlescausing the piping phenomenon. [3]

When designing the floor of hydraulic structure, the seepage problems should be minimized to lower values, and the most important work in this case is the reduction of the exerted uplift pressure. One of the mostengineering solutions followed in this respect to reduce the uplift pressure is using of cutoffs at the upstream and downstream of the structure. [4]

There are different methods used to analyze and solve the seepage problems such as an empirical formulas, conformal mapping analysis techniques, electrical analogue models, the flownet technique, experimental works by using physical model as well as numerical model. [5]

In this study, experimental work by using electrical analogue models and numerical model by using SEEP/W to plot the flownet and determine the values of uplift pressure, is adopted.

2-Objective:

The objective of the present study is to:

1- Study the effect of the impervious layer depth on the uplift pressure values underneath the hydraulic structures ata distance (b/7) to (b/5) from the beginning of the floor where the critical value of net pressure is occurred.

2- Compare the results which are obtained from the experimental tests by using the electrical analogue model with those which obtained from the numerical model by using Geo-studio 2016 SEEP/W software program.

3- The experimental method:

The electrical model has been used for performing experiments by using electrical analogue model techniques. This analogue was based upon the similarity between the percolating of water through porous media and the electrical current flow through an electrical conductor, where in the first condition the velocity of seeping water through porous media is proportional to the hydraulic gradient, while in the second condition the electric current movement is proportional to the drop of voltage through the electrical conductor. [6]

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

$v = ki = -k(\frac{d_h}{d_s})$ (1)

Where:

v: Discharge velocity (m/s).

k: Hydraulic conductivity (m/s).

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i: Hydraulic gradient in the direction of flow.
s: Distance (m).

While the flow of electric current is governed by Ohm′s law as:

$$I = \frac{1}{R}\left(\frac{d_E}{d_s}\right) \quad (2)$$

Where:
I: Intensity of the electric current per unit area (Amp/m^2).
R: Specific resistance (Ohm.m).
$\frac{1}{R}$: Electric conductivity.
E: is the electric potential (Volte).
$\frac{d_E}{d_s}$: is the voltage gradient in the direction of electric current. [7]

The conductive part of the electrical model can be represent by a solution and any change in the depth of the solution will be caused a change in the hydraulic conductivity. [8]

The head at any point inside the solution can represent by the voltage which measured at that point, after determine all the points having the same voltages values, the equipotential lines can be plotted and the stream lines are plotted perpendicular to them later by hand sketch.

5- The experimental set up:

The laboratory work has been conducted for four cases with different depth of impervious layer (75, 60, 45, 30) cm respectively. In each of the four cases, the depth of cutoffs at the upstream and downstream of the structure will change and the length of the floor of hydraulic structure will remain constant, also the head which applied on the upstream was (20) volts for all models.

The experimental model which is used in this study consists of two separate parts, the first part is a glass tank of a dimension (120cm long, 75 cm wide, and 5 cm high), with thickness of glass is (0.6) cm, as shown in figure (1).

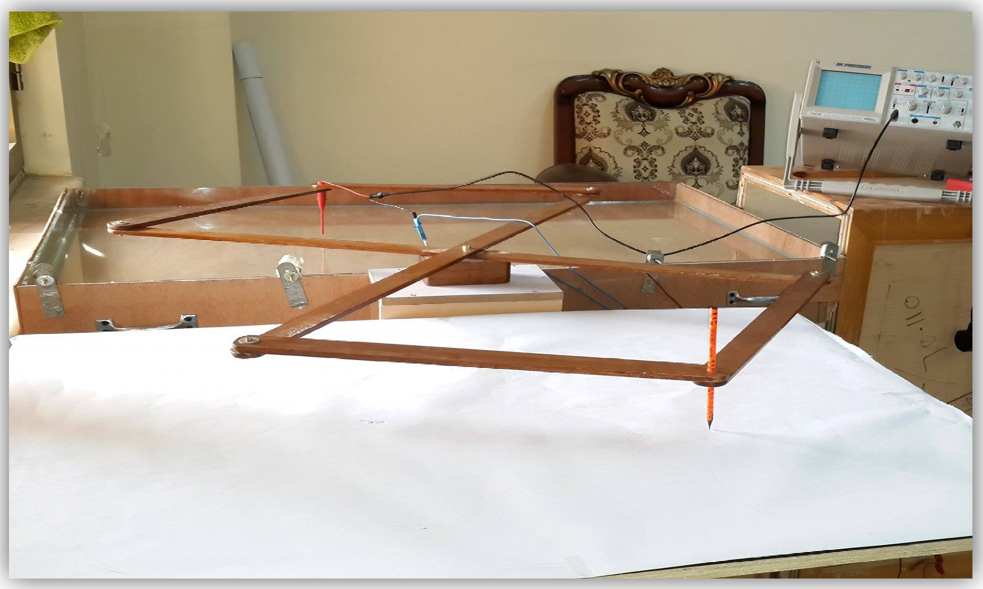

Figure (1) photo of the electrical model

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The depth of the solution in the glass tank must be reserved at the same level during all the experiments, it was (1) cm, to make sure that the conductivity always remain at the same value.

While the second part of the experimental work is an electrical circuit as shown in figure (2), which consist of: A.C power source, Rheostat, Oscilloscope with probe, Variak transformer, Voltmeter, and copper electrodes.

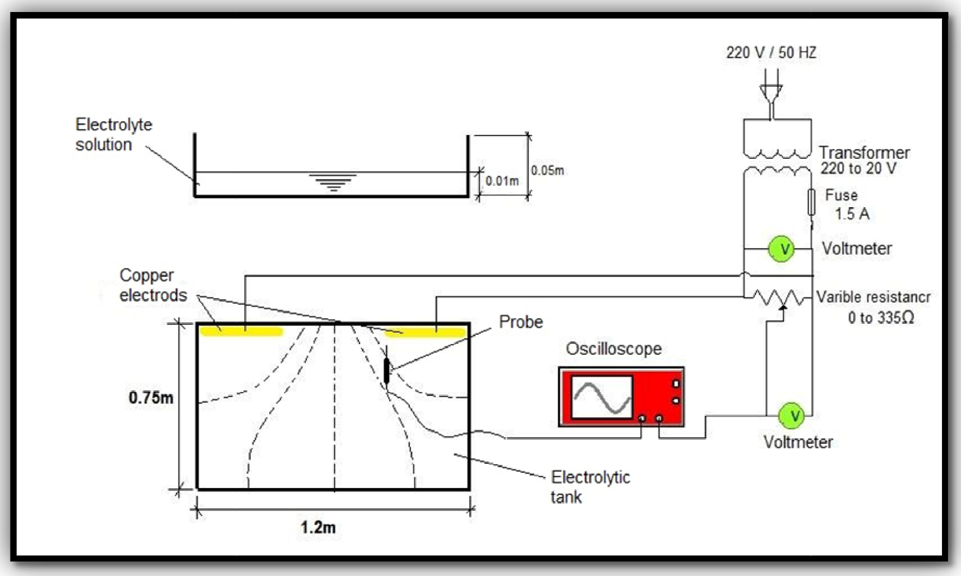

Figure (2) plane of electrical model

In addition, the pantograph has been used for determining the points of zero voltage, where a probe is placedat one end moving inside the solution to determine the zero voltage points in case when a clear point appear on the oscilloscope screen and then remarking these points by the pensile that is installed at the other end of the pantograph on the board. Plastic parts were also used with different lengths and fixed by plastic clay for representing the cutoffs in the model.

6- Boundary condition:

The boundary conditions must be specified for any problem of seepage, the boundary conditions for the model which is used in this experiment are defined as shown in figure (3).

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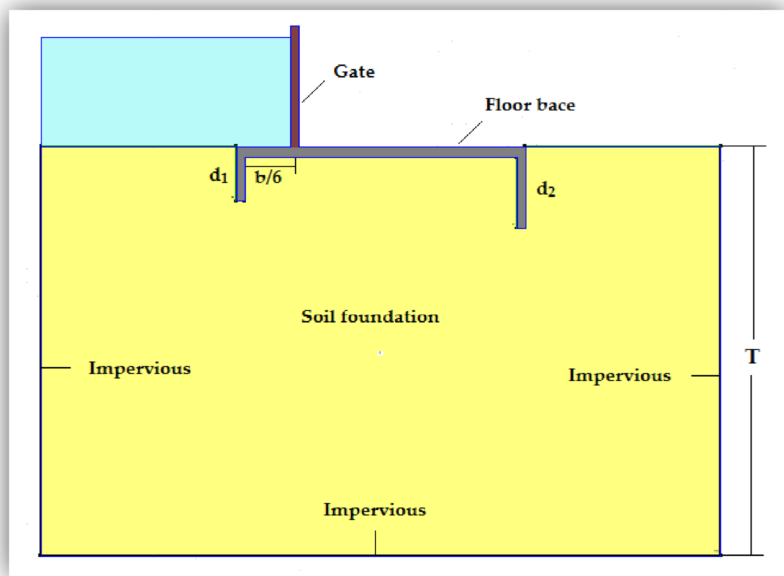

Figure (3) The boundary condition of the model

7- Finite element formulations of water seepage through porous media:

The basic principle of the finite element method is to discrete the domain of problem to finite elements, and these elements may be one, two, or three – dimensional and jointed by nodes, the behavior of the field is represented approximately by a function depending on the nodal values of the field as follows:

$$H^e = \sum_{i=1}^{n} N_i H_i \qquad (3)$$

Where:
H^e: Approximate solution for pizometric head distribution in the element (e).
N_i: Shape function of the element (e).
H_i: Nodal values of head of the element (e).
n: Number of nodes in the element (e).
Equation (3) can be written in matrix form as follow:

$$H^e = \sum_{e=1}^{n_e} [N_i]\{H_i\} \qquad (4)$$

Where:
$[N_i]$: Shape function matrix of element (e).
n_e: Total number of elements in the problem domain.[9]

8- Computer program:

The two - dimensional finite element models Geo- studio, SEEP/W for ground water seepage analysis has been used to plot the equipotential lines and flow lines, therefore computing the pore water pressure under the structure at the gate location.
The Geo-slope software program consists of eight sub-programs: SEEP/W, Slope/W, Sigma/W, Temp/W, Ctran/W, Quake/W, Air/W and Vadose/W.

The steps of creating a numerical model for seepage program can be summarized in the following points:

1- Create problem work space.
2- Draw domain regions.
3- Define material properties.
4- Assign hydraulic boundary conditions.
5- Draw mesh properties.
6- solve the seepage problem and get the results and the plotting the flow nets according to the boundary condition.

The flow nets thatwere plotted by using the Geo- studio software program have been shown from figure (9) to figure (28).

9- Results and discussion:

The results of the laboratory work were obtained for four variable cases of the impervious layer depth as (75 cm, 60 cm, 45 cm, and 30cm), each case consists of (25) models, where the depth of upstream cutoff (d_1) is constant for five cases as (5 cm, 10 cm, 15 cm, 20 cm, and 25 cm) for every depth of those five depths of the upstream cutoff, the depth of downstream cutoff (d_2) will be changed for five times as (5 cm, 10 cm, 15 cm, 20 cm, and 25 cm).

Where the flownet is plotted for all these cases which is (100) cases, the pore water pressure was determined under the hydraulic structure at the gate location in a distance of (b/6), as shown in table (1) and table (2).

The results have been represented in graphical form as shown in figure (4) to figure (8), Where (T_1, T_2, T_3, and T_4) represent the depth of impervious layer of (75 cm, 60 cm, 45 cm, and 30 cm) respectively. The important points have been observed that the effect of increasing the depth of upstream cutoff for reducing the uplift pressure underneath the gate location, is greater than the effect of the downstream depth of cutoff and the impervious layer depth, when (d_1=5 cm) and (d_2=5 cm), the uplift pressure (P_u=12.2 m), and when (d_1=25 cm) and (d_2=5 cm), the uplift pressure (P_u=10 m), and this mean the percentage of reduction in uplift pressure is (18.03 %), and when (T=75 cm), (P_u=12.2) and when (T=30 cm), (P_u=12.8), thus the percentage of reduction is (4.92 %). As well as for the other values of the depth of the upstream cutoff and the depth of impervious layer.

The results which are obtained from the numerical program were close to the results of the experimental program, and this gives an indication of accuracy of electrical analogue model to analysis the seepage problem.

10- Conclusions:

1- In case of increasing the depth of the upstream cutoff, it will be reduced the uplift pressure underneath the hydraulic structures at the gate location, thus, it will lead to reduce the thickness structure floor.
2- The effect of downstream cutoff and impervious layer on reducing the uplift pressure is less than that of the upstream cutoff.
3- The results which are obtained from the experimental work by using electrical analogue model and the numerical program by using Geo-studio software indicate together that the method of electrical analogue has a good accuracy in the analysis of seepage problems, where the average percentage of acceptance between the results of the two methods is (92.561)%

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Table (1) The uplift pressure by experimental and numerical method

d_1(cm)	d_2(cm)	(Pu/γ_w) for											
		Experimental	Numerical T=75	Error %	Experimental	Numerical T=60	Error %	Experimental	Numerical T=45	Error %	Experimental	Numerical T=30	Error %
5	**5**	12.2	12.5	2.46	12.4	13	4.84	12.7	13.4	5.51	12.9	13.7	6.20
	10	13.2	13.9	5.3	13.7	14.5	5.84	13.9	14.8	6.47	14	15	7.14
	15	12.6	13	3.17	12.8	13.5	5.47	13.2	14.2	7.57	13.5	14.9	10.37
	20	13.3	14	5.26	13.5	14.4	6.67	13.7	15	9.49	14	15.5	10.71
	25	13	13.6	4.61	13.2	14	6.06	13.5	14.2	5.18	13.8	14.7	6.52
10	**5**	11.3	11.7	3.54	11.7	12.5	6.84	11.9	12.9	8.40	12.2	13.5	10.65
	10	12.1	12.8	5.78	12.5	13.4	7.2	12.7	13.9	9.45	12.9	14.3	10.85
	15	12.1	12.9	6.61	12.3	13.1	6.50	12.5	13.8	10.4	12.8	14	9.37
	20	12.3	13	5.69	12.7	13.8	8.66	13	14	7.69	13.2	14.5	9.84
	25	12.8	13.8	7.81	13	14.2	9.23	13.2	14.6	10.60	13.4	14.9	11.19
15	**5**	11.2	11.8	5.38	11.4	12.1	6.14	11.6	12.5	7.76	11.4	12.5	9.65
	10	11	11.7	6.36	11.3	11.9	5.31	11.4	12.3	7.89	11.6	12.7	9.48
	15	11.4	12	5.26	11.7	12.3	5.13	11.9	12.6	5.88	12.2	13.1	7.37
	20	11.5	12.4	7.83	11.9	12.8	7.56	12.1	13.2	9.09	12.4	13.6	9.67
	25	12.3	13	5.69	12.5	13.4	7.2	12.8	14	9.37	13.1	14.2	8.39
20	**5**	10.3	10.9	5.82	10.5	11.2	6.67	10.6	11.5	8.49	10.8	11.7	8.33
	10	10.4	11	5.77	10.7	11.5	7.48	10.9	12	10.09	11.2	12.3	9.82
	15	10.7	11.8	10.28	11.2	12.3	9.82	11.3	12.2	7.96	11.5	12.6	9.56
	20	11.6	12.5	7.76	11.8	13	10.17	11.9	13.1	10.08	12.2	13.4	9.84
	25	11.5	12.4	7.83	11.6	12.7	9.48	11.8	13	10.17	12.1	13	7.44
25	**5**	10	10.8	8	10.2	10.9	6.86	10.4	11.2	7.69	10.6	11.4	7.55
	10	9.9	10.5	6.06	10	10.4	4	10.4	11	5.77	10.6	11.5	8.49
	15	10.5	11.2	6.67	11	11.5	4.54	11.2	12	7.14	11.5	12.1	5.22
	20	11.3	12	6.19	11.5	12.2	6.09	11.7	12.5	6.84	12	13	8.33
	25	11.3	11.9	5.31	11.5	12	4.35	11.8	12.8	8.47	12.1	13.3	9.92

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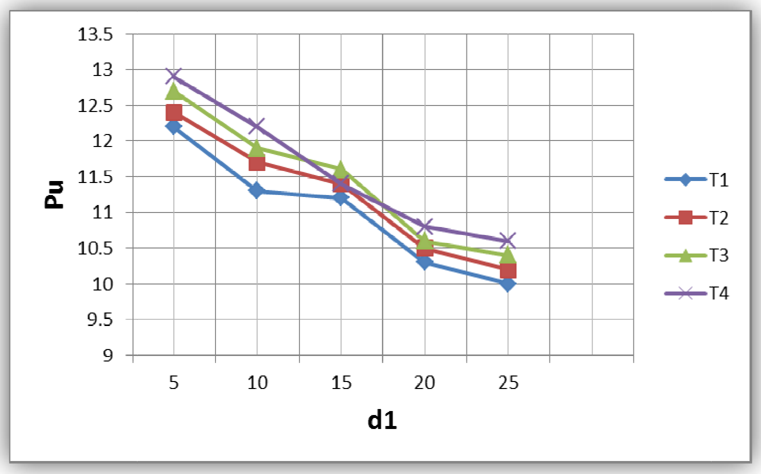

Figure (4) the uplift pressure for four depths of impervious layer when (d_2=5)

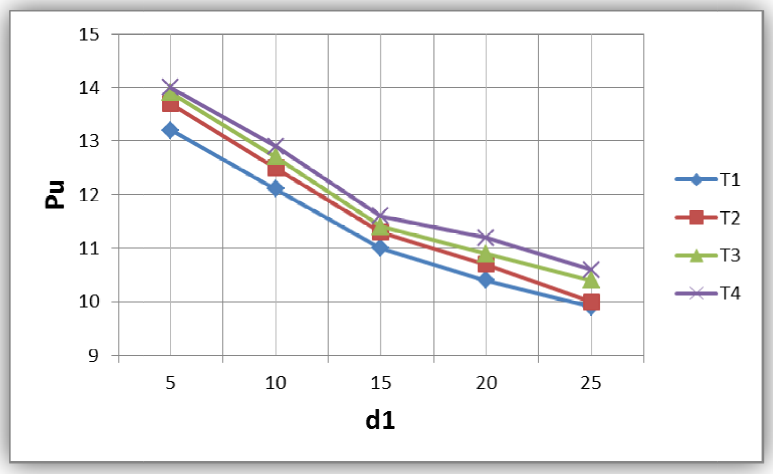

Figure (5) the uplift pressure for four depths of impervious layer when (d_2=10)

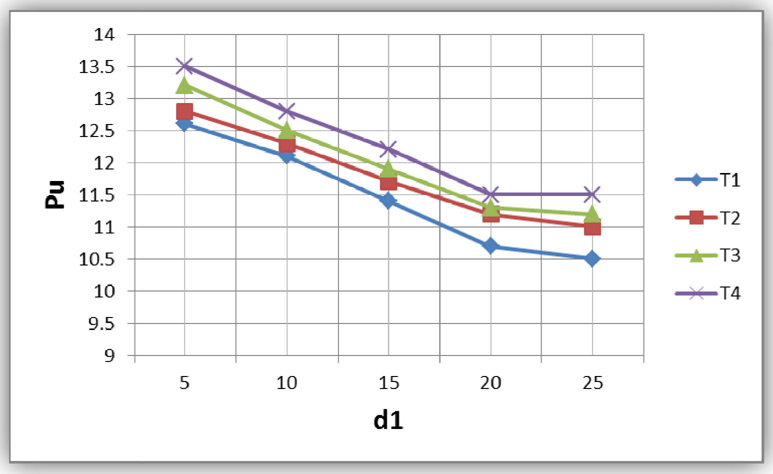

Figure (6) the uplift pressure for four depths of impervious layer when (d_2=15)

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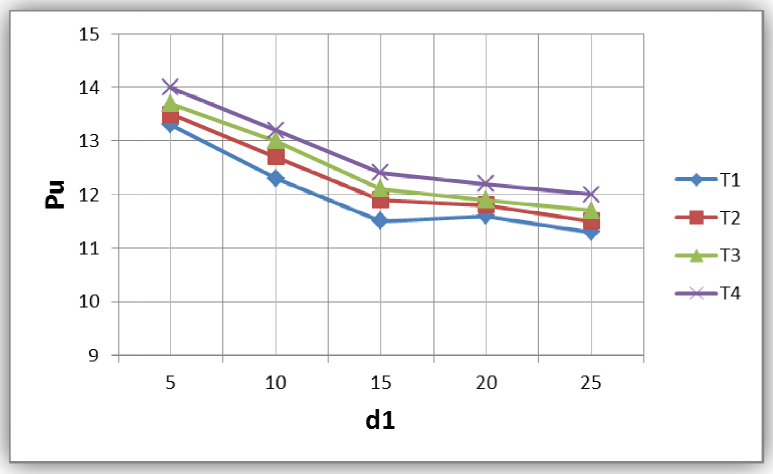

Figure (7) the uplift pressure for four depths of impervious layer when (d_2=20)

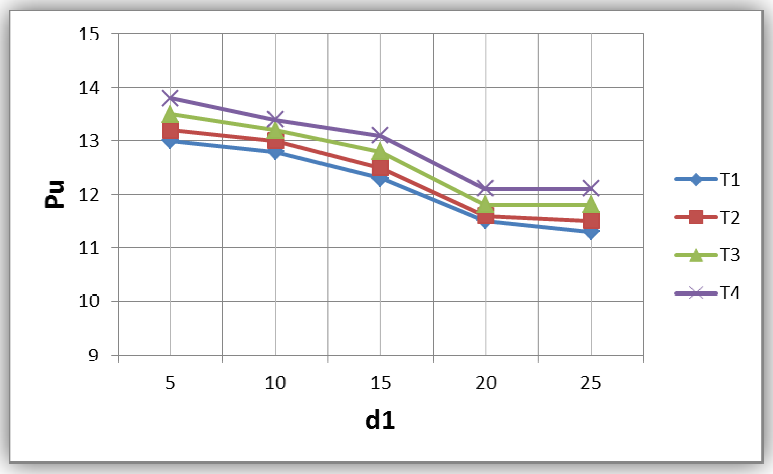

Figure (8) the uplift pressure for four depths of impervious layer when (d_2=25)

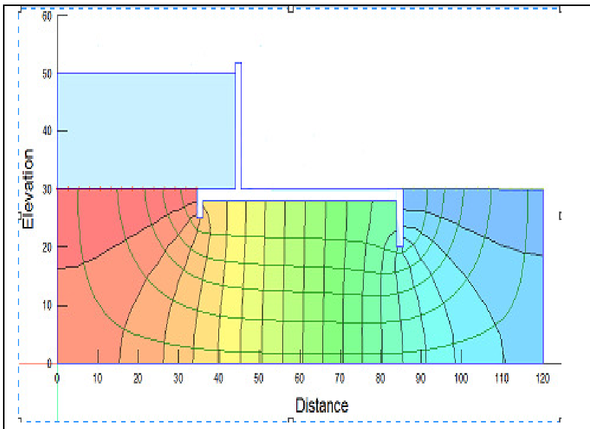

Figure (9) flow net for (T=30, d_1=5, d_2=10)

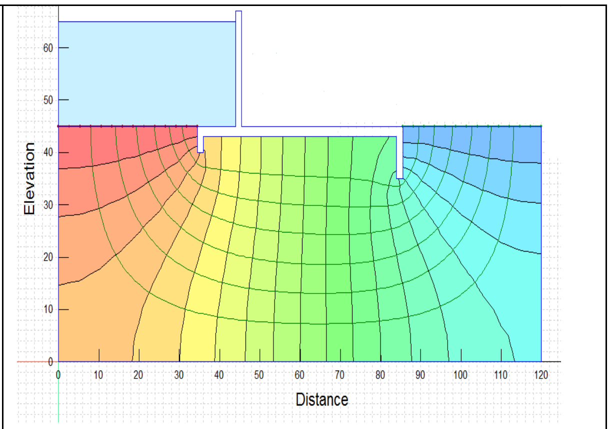

Figure (10) flow net for (T=45, d_1=5, d_2=10)

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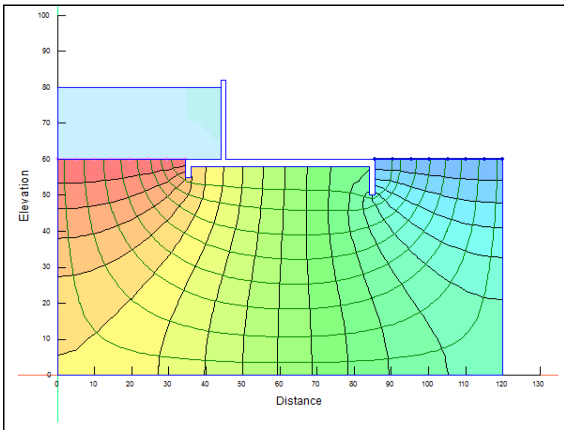

Figure (11) flow net for (T=60, d_1=5, d_2=10)

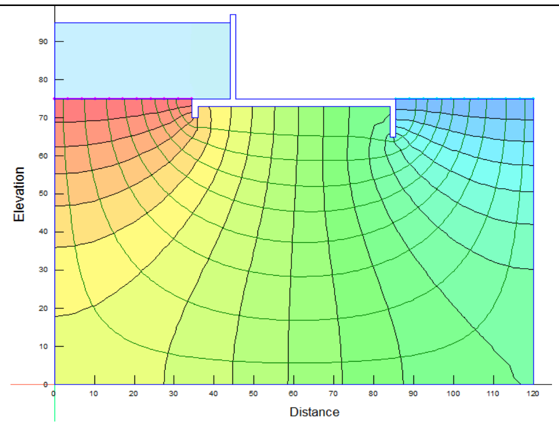

Figure (12) flow net for (T=75, d_1=5, d_2=10)

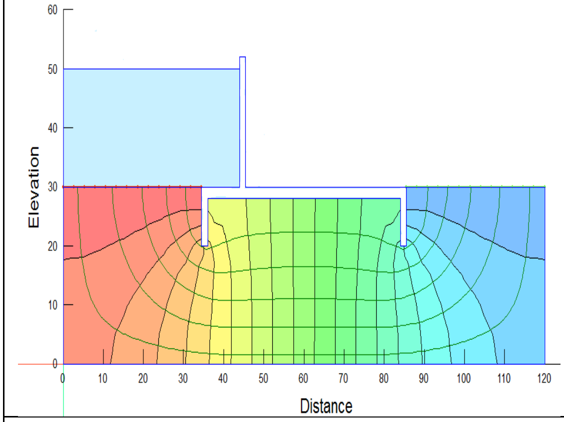

Figure (13) flow net for (T=30, d_1=10, d_2=10)

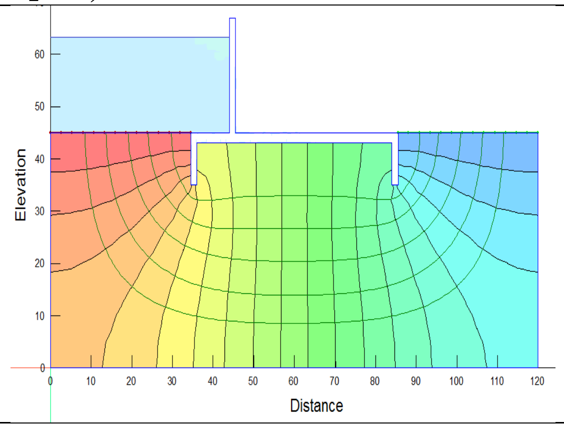

Figure (14) flow net for (T=45, d_1=10, d_2=10)

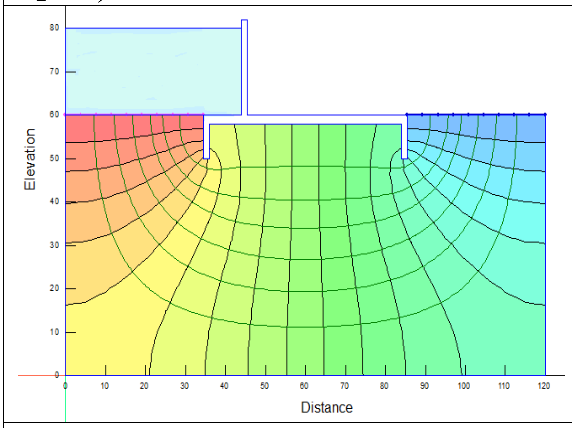

Figure (15) flow net for (T=60, d_1=10, d_2=10)

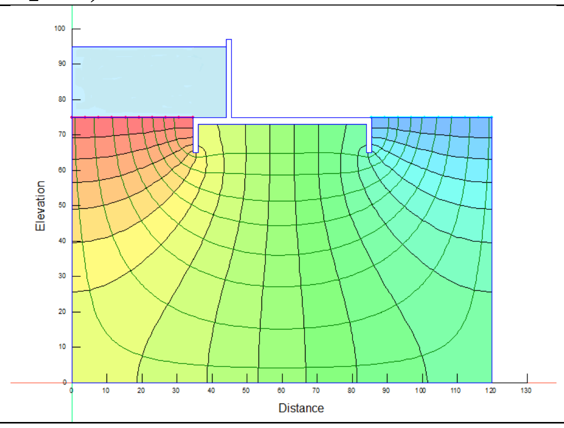

Figure (16) flow net for (T=75, d_1=10, d_2=10)

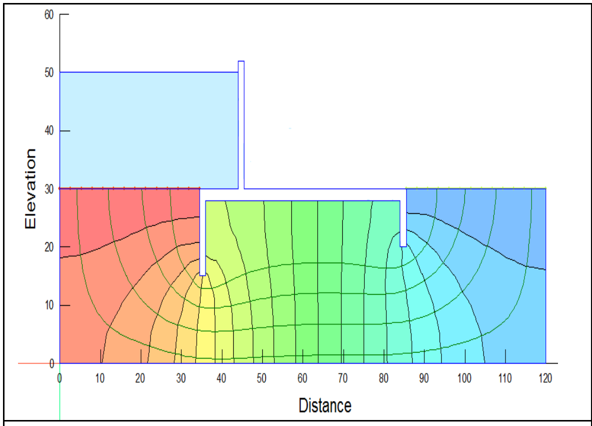

Figure (17) flow net for (T=30, d_1=15, d_2=10)

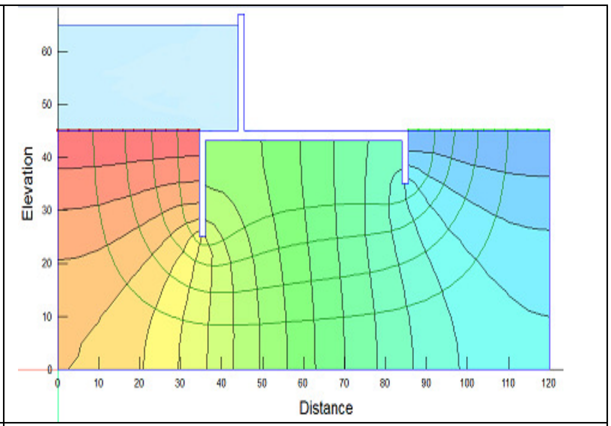

Figure (18) flow net for (T=45, d_1=15, d_2=10)

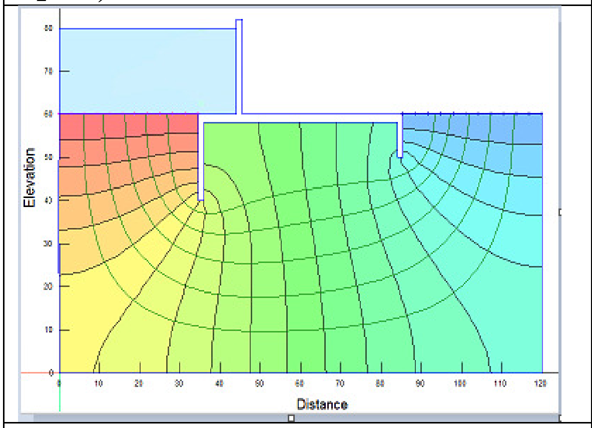

Figure (19) flow net for (T=60, d_1=15, d_2=10)

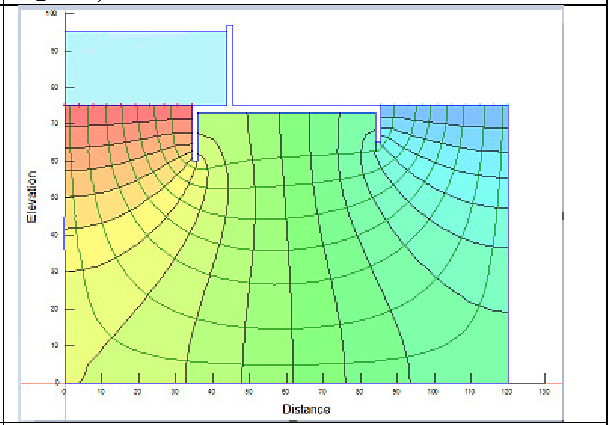

Figure (20) flow net for (T=75, d_1=15, d_2=10)

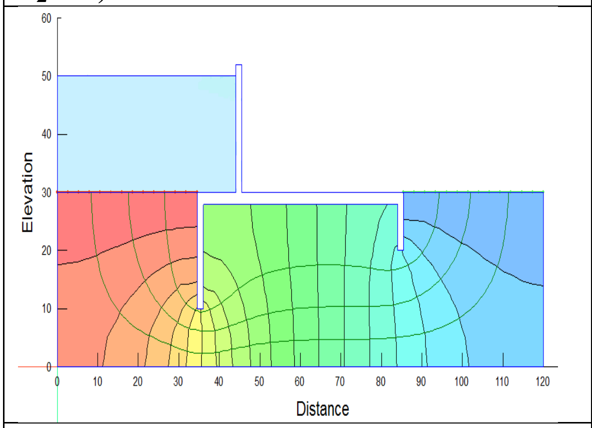

Figure (21) flow net for (T=30, d_1=20, d_2=10)

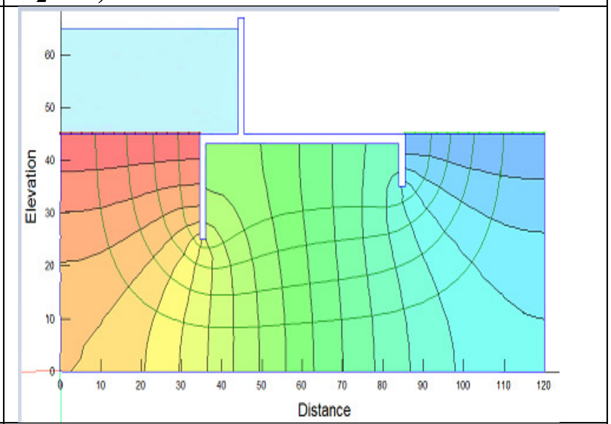

Figure (22) flow net for (T=45, d_1=20, d_2=10)

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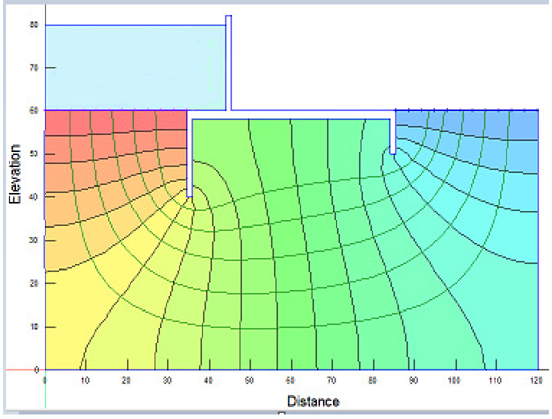

Figure (23) flow net for (T=60, d_1=20, d_2=10)

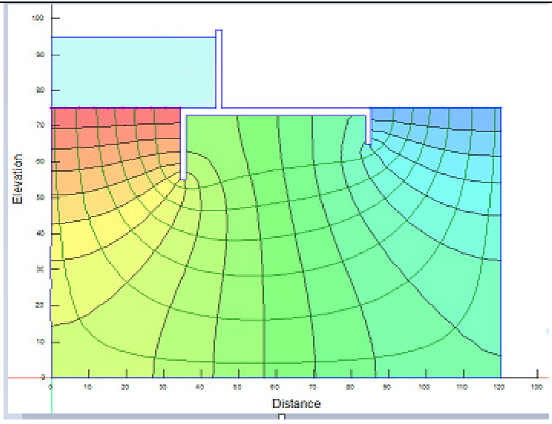

Figure (24) flow net for (T=75, d_1=20, d_2=10)

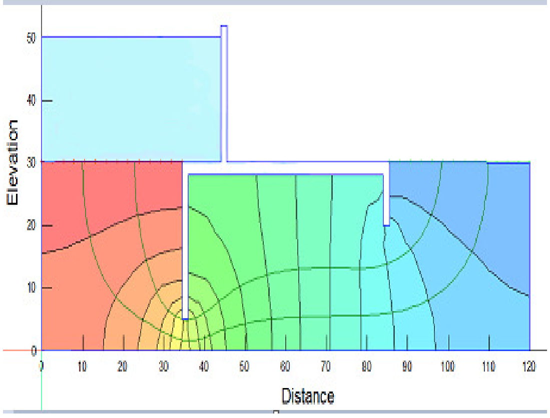

Figure (25) flow net for (T=30, d_1=25, d_2=10)

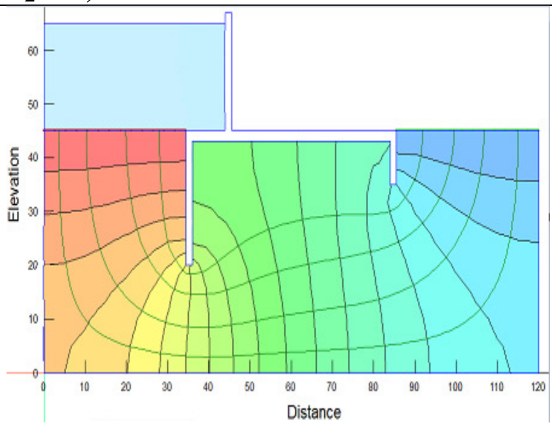

Figure (26) flow net for (T=45, d_1=25, d_2=10)

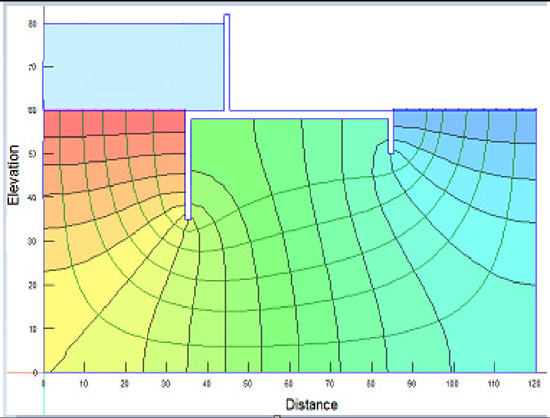

Figure (27) flow net for (T=60, d_1=25, d_2=10)

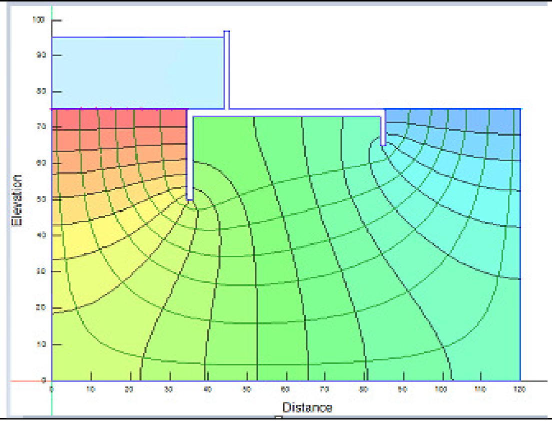

Figure (9) flow net for (T=75, d_1=25, d_2=10)

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