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THE EFFECTIVE CONFIGURATION OF RELIEF WELLS DISTRIBUTION ON THE STABILITY FOR BARRAGES FLOOR

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The hydraulic structures (dams, barrages, regulators…..) are complicated constructions and need an accurate technical and economical visibility studies; prepare design, execution and effective technique to be followed for maintenance.

The percolation length is one of the most important items controlling the design of the water structures especially for apron length and thickness

Seepage under the apron of the hydraulic structures was controlled by providing the apron with row or more of steel piles , but the sheet piles now is very high costs comparing by others options at the same time, and to improve the apron conditions of the old structure, the sheet piles is not possible to implement.

In present paper, an apron with multiple rows of relief wells starting by one row of relief wells till six rows of relief wells were put under testing in different arrangements .

An analog model was used with variable depths and distances between the relief wells rows in different arrangements. 96 runs were performed for one row of relief wells case, 84 runs were performed for two rows of wells case, 72 runs for three rows of relief wells case, 60 runs were performed for four rows of relief well case, 48 runs were done in five rows of relief case and 36 runs were performed in six rows of relief wells case. 429 reading node for every test run are recorded and plotted by using the surfer software.

The conclusions, from the analysis of the obtained model results was as follows: The effective position in the potential of apron exit edge located near the edge of the apron for six rows of relief wells rows at (20%-30%-40%-50%-60%-80%)Lap respectively, measured from upstream of an apron. The effective percentage reduced in potential of the apron exit edge is 73% and located at the 80% from the apron total length for six rows of relief wells (20-30-40-50-60-80). The efficiency of the U.S. relief wells is greater than that for the D.S. relief wells.

INTRODUCTION

Seepage under the aprons of hydraulic structures on permeable soil is one of the most important parameter that governs the apron design and maintenance the structure stability with time. Providing aprons of control structures with relief wells at critical sections is the usual approach that is adopted to achieve safe of these structures against uplift pressures on aprons, undermining, and horizontal piping.

Practically, the relief wells arrange in rows staggered one to another, and distribute on the apron, downstream of the regulator piers after designing the number of relief wells and the gird shape (rows in x& y directions), as shown in fig (1).

As for the vertical piping downstream the apron toe, security is achieved partly by eliminating undermining (5) and partly by providing the zone just downstream the apron toe by some means such as perforated covers of concrete of blocks, Cutoffs, undoubtedly have a very good effect in retarding the piping process, as they originally maintain mild hydraulic gradient by increasing length of creep line, and hence participate much in decreasing the exit gradient value at the apron toe.

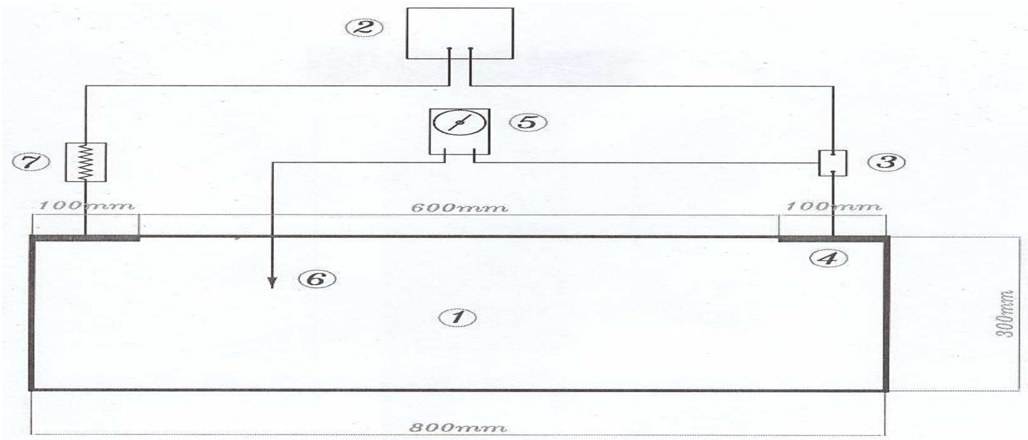
In the present study, the variable depths (d/T= 16.7%, 25% and 33.3%) and distances (X_w/L_{ap}= 20%, 30%, 40%,50%, 60%, 70% and 80%) of tested relief wells rows.

Fig. (1): The arrangement of relief wells distribution downstream regulator apron

The finished apron upper surface seems as a plain with little openings filled with filter, gravel, as shown in Fig. (2).

Fig. (2): The final surface of apron with relief wells (left side) – R.w pipe filled with gravel

The Electrical model (analog model) was used to perform the experiments, they are restricted to steady flows, and the simpler types assume homogeneous isotropic aquifers. They are adaptable also for analysis of seepage through soils on which structures such as, earths dams, masonry dames, regulators etc.. As shown in Fig. (3).



1: glass tank model 2: D.C power supply 3: Rosetta 4- Copper plate
5: Multtimeter 6: Measurements proper 7: Rheostat
Fig. (3): Experimental model

The experimental model used, was based upon the known similarity between the flow of the electric current through an electrical conductor and the percolating water through porous media (ground water flow), where in the first condition, the movement of the electric current is proportional to the voltage drop through the electrical conductor while, in the second condition the velocity of the percolating water through the permeable soil is proportional to the flow hydraulic gradient.

Since, the flow of the electric current through an electrical conductor is governed by Ohm's law while the flow of water through permeable soil is governed by Darcy' law, then the similarity between these two laws is achieved (1, 2, 3, 5).The elementary form of Ohm' law is expressed at

$$I = -s \quad dE/dX \qquad (1)$$

Where:
I: is the electric current per unit area through a material of specific conductivity s.
dE/dX: is the voltage gradient in the current direction "x"

And the elementary from Darcy's law for the water flow through permeable soil is expressed as:

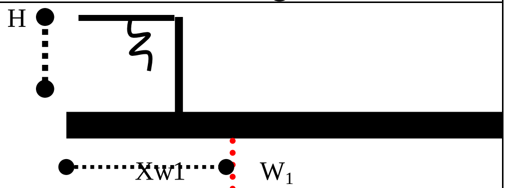
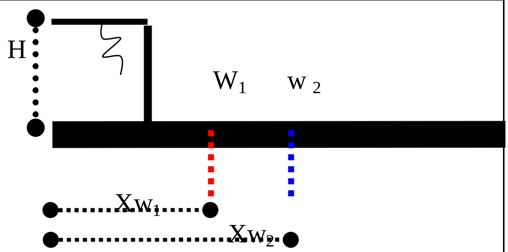
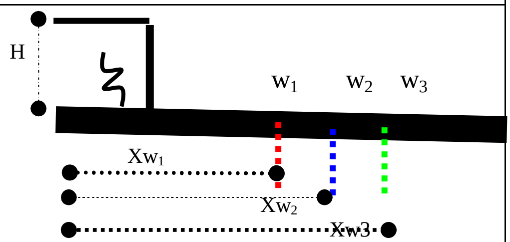
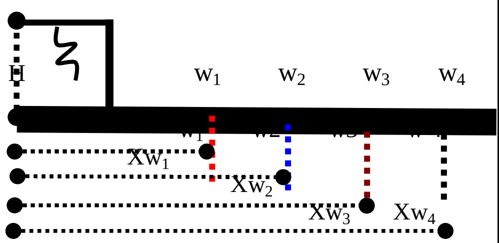
$$v = -k\, dh/ds \qquad (2)$$

Where:
v: is the velocity of the flowing water through a soil of permeability coefficient k,
dh/ds: is the hydraulic gradient of the potential head for the percolating water in the direction of flows:

EXPERIMENTAL RUNS

An apron provided with relief wells in six cases was used: as shown in Table (1).

Table (1): The apron with relief wells cases

Apron case	Case diagram
1- One row of relief wells: Well length (50, 75 or 100 mm) at a distance x_{w1}= (0.20, 0.30, 0.40, 0.50, 0.60, 0.70 and 0.80 l_{ap}) and X_{W1}, measured from the apron upstream side), one row of relief wells case shown in Fig. (4).	 Fig. (4): Apron provided with one row of relief wells.
2 - Two rows of relief wells: Well length (50, 75 or 100 mm) at distances (measured from the upstream side): Fist row: (X_{w1}=20% L_{ap}) while, second row: (X_{w2}= 30%, 40%, 50%, 60%, 70%, and 80% L_{ap}). The two rows of relief wells case shown in Fig. (5).	 Fig. (5): Apron provided with two rows of relief wells
3 - **Three rows of relief wells**: Well length (50, 75 or 100 mm) at a distances (measured from the apron upstream side): First row of wells: (X_{w1}= 0.20 L_{ap}).**and** the second row of wells: (X_{W2}= 0.30 L_{ap}.) **While** the third row of wells located at (X_{w3} =0.40, 0.50, 0.60, 0.70& 0.80 L_{ap}). The three rows of relief wells case shown in Fig. (6).	 Fig. (6): Apron provided with three rows of relief wells
4- **Four rows of relief wells**: Well length (50, 75 or 100 mm) at a distances (measured from the apron upstream side): First row of wells **at (**X_{w1}= 0.20 L_{ap}**)**, the second row of wells: (X_{W2}= 0.30 L_{ap})**, the** third row of relief wells: (X_{W3}= 0.40 L_{ap}), **while the** fourth row of well: (X_{w4} =0.50, 0.60, 0.70 or 0.80 L_{ap}). The four rows of relief wells case shown in Fig. (7).	 Fig. (7): Apron provided with four rows of relief wells

5- **Five rows of relief wells**:
Well length (50, 75 or 100 mm) at a distances (measured from the apron upstream beginning):
First row of wells **at** (X_{w1}= 0.20 L_{ap})**,** the second row of wells: (X_{W2}= 0.30 L_{ap}.) . Also, the third row of relief wells fixed at (X_{W3}= 0.40 L_{ap}.)**, the** fourth row of relief well located at (X_{w4} =0.50 L_{ap}) **and the** fifth row of wells examined under (X_{w5} =0.60, 0.70 and 0.80 L_{ap}). The five rows of relief wells case shown in Fig. (8).

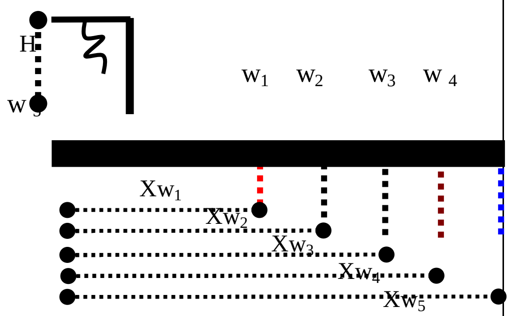


Fig. (8): Apron provided with five rows of relief wells

6- **Six rows of relief wells**:
Well length (50, 75 and 100 mm) at a distances (measured from the apron upstream beginning):
First row of wells**:** (X_{w1}= 0.20 L_{ap})**.the** second row of wells: (X_{W2}= 0.30 L_{ap}.), **the** third row of relief wells: (X_{W2}= 0.40L_{ap}.)**, the** fourth row of relief wells: (X_{w4} =0.50L_{ap}) **.the** fifth row of relief wells at (X_{w4} =0.60 L_{ap})**.and the** Sixth row of relief wells: (X_{w6} =0.70 and 0.80 L_{ap}). The six rows of relief wells positions shown in Fig. (9).

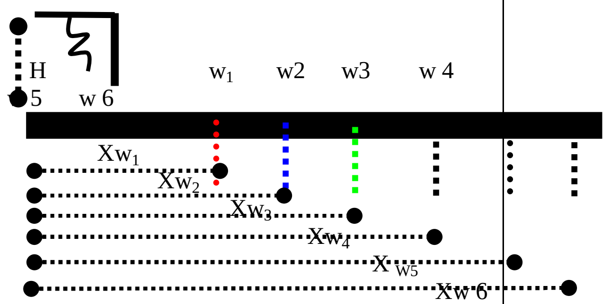


Fig. (9): Apron provided with six rows of relief wells

RESULTS AND ANALYSIS

The dimensional analysis for the variables involved in the problem indicated that:

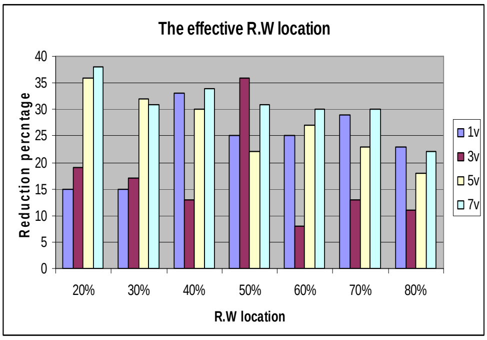
a- Exit gradients at D.S edge:

1- One Row of Relief Wells:

Table (2): The percentage of effect of relief wells on the apron exit edge for all positions

R. w position X_w/L_{ap}	One row of relief wells											
	Exit edge Potential				Relief well effect Potential				% effect potential			
	1v	3v	5v	7v	1v	3v	5v	7v	1v	3v	5v	7v
20%	0.44	0.74	0.83	0.92	0.08	0.18	0.46	0.57	15	19	36	38
30%	0.44	0.76	0.88	1.03	0.08	0.16	0.41	0.46	15	17	32	31
40%	0.35	0.80	0.90	0.99	0.17	0.12	0.39	0.50	33	13	30	34
50%	0.39	0.59	1.00	1.02	0.13	0.33	0.29	0.47	25	36	22	31
60%	0.39	0.85	0.94	1.04	0.13	0.07	0.35	0.45	25	8	27	30
70%	0.37	0.80	0.99	1.04	0.15	0.12	0.30	0.45	29	13	23	30
80%	0.40	0.82	1.06	1.16	0.12	0.10	0.23	0.33	23	11	18	22
without r.w	0.52	0.92	1.29	1.49								

As shown in Fig. (9') the percentage of the potential head reduced for all locations of one row of relief wells case.



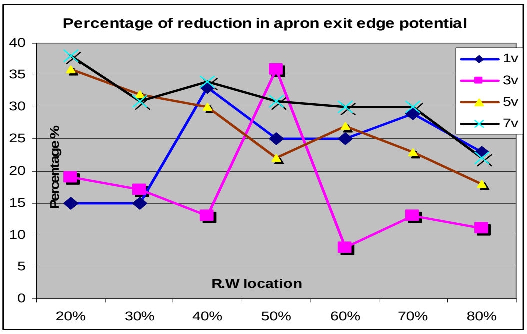


Fig. (9'): The change in exit edge potential for one row of R.W locations

From Table (1) and by analysis the results, the most effective position for the one row of relief wells case is as shown in Fig. (9') the comparison between the potential head under the exit edge of the apron affected by the relief well position with the exit edge of the apron (without relief wells) case indicated:.

The best position for one row of relief wells case with the tested head 7m is 20%, then the potential head of the exit edge was reduced by 38% compared with the potential head of the apron without relief wells case. Also for the head 5m the best position is 20%, and then the potential head of the exit edge reduced 36% from the potential head of the exit edge of the free apron. While the best position for the head 3m is 50%, the potential head reduced 36% from the potential head of exit edge of the free apron case. But the best position for the low head 1m is 40%, then, the potential reduced 33% from the potential head of the exit edge of the free apron case.

2-Two Rows of Relief Wells:

Table (3): comparison for exit edge potential between two rows of relief wells and free apron

R.w Position	Potential head				Effect of relief wells				Effect Percentage			
	1v	3v	5v	7v	1v	3v	5v	7v	1v	3v	5v	7v
20-30	0.43	0.67	0.80	0.86	0.09	0.25	0.49	0.63	17	27	38	42
20-40	0.43	0.64	0.81	0.99	0.09	0.28	0.48	0.50	17	**30**	37	33
20-50	0.38	0.74	0.76	0.86	0.14	0.18	0.53	0.63	27	19	41	42
20-60	0.37	0.62	0.83	0.93	0.15	0.30	0.46	0.56	29	33	36	37
20-70	0.29	0.64	0.84	0.79	0.23	0.28	0.45	0.70	**44**	**30**	35	47
20-80	0.32	0.66	0.70	0.74	0.20	0.26	0.59	0.75	38	28	**46**	**50**
without R.w	0.52	0.92	1.29	1.49								

From Table (3) and by analysis the results: the most effective position for the two rows of relief wells and Fig. (10) the comparison between the potential head under the exit edge of the apron affected by the relief well position with the edge exit of free apron (without relief wells) indicated:.

The best position for the head **7m** is **(20%-80%)**, the potential head of the exit edge was reduced by **50%** from the potential head of the free apron. Also for the head **5m** the best position is **(20%-80%),** and then the potential head of the exit edge reduced **46%** from the potential head of the exit edge of the free apron. While the best position for the head **3m** is **(20%-70%),** the potential head reduced **30%** from the potential head of exit edge of the free apron case. But the best position for the low head **1m** is **(20%-70%),** then, the potential reduced **44%** from the potential head of the exit edge of the free apron case.

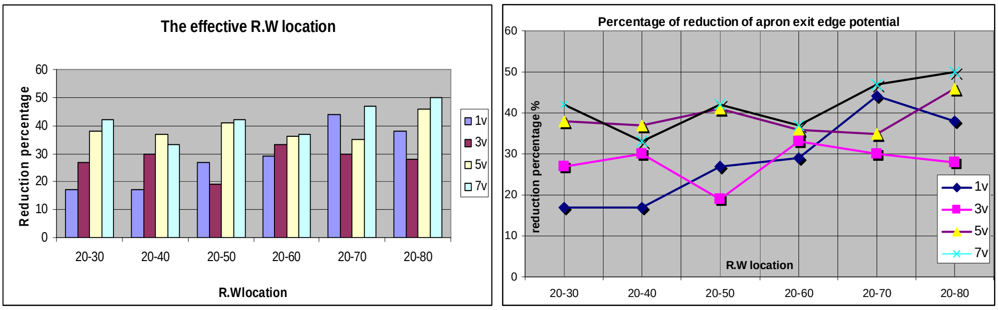


Fig. (10): The effect of the relief well position on the apron exit edge potential head

3- Three Rows of Relief Wells

Table (4): Potential of exit edge of the apron for three rows of relief wells or without relief wells

R.w Position	Potential head				Effect of relief wells				Effect Percentage			
	1v	3v	5v	7v	1v	3v	5v	7v	1v	3v	5v	7v
20-30-40	**0.37**	**0.62**	**0.79**	**0.86**	0.15	0.30	0.50	0.63	29	33	39	42
20-30-50	**0.37**	**0.67**	**0.89**	**0.89**	0.15	0.25	0.40	0.60	29	**27**	31	40
20-30-60	**0.37**	**0.49**	**0.65**	**0.67**	0.15	0.43	0.64	0.82	29	**47**	**50**	**55**
20-30-70	**0.36**	**0.60**	**0.68**	**0.72**	0.16	0.32	0.61	0.77	31	35	47	52
20-30-80	**0.35**	**0.57**	**0.71**	**0.73**	0.17	0.35	0.58	0.76	**33**	**38**	45	51
Without r.w	0.52	0.92	1.29	1.49								

From Table (4) and by analysis the results: the most effective position for the three rows of relief wells and Fig. (11) the comparison between the potential head under the exit edge of the apron affected by the relief well position with the edge exit of free apron (without relief wells) indicated:.

The best position for the head **7m** is **(20%-30%-60%)**, the potential head of the exit edge was reduced by **55%** from the potential head of the free apron. Also for the head **5m** the best position is **(20%-30%-60%),** and then the potential head of the exit edge reduced **50%** from the potential head of the exit edge of the free apron. While the best position for the head **3m** is **(20%-30%-60%),** the potential head reduced **47%** from the potential head of exit edge of the free apron case. But the best position for the low head **1m** is **(20%-30%-80%),** then, the potential reduced **33%** from the potential head of the exit edge of the free apron case.

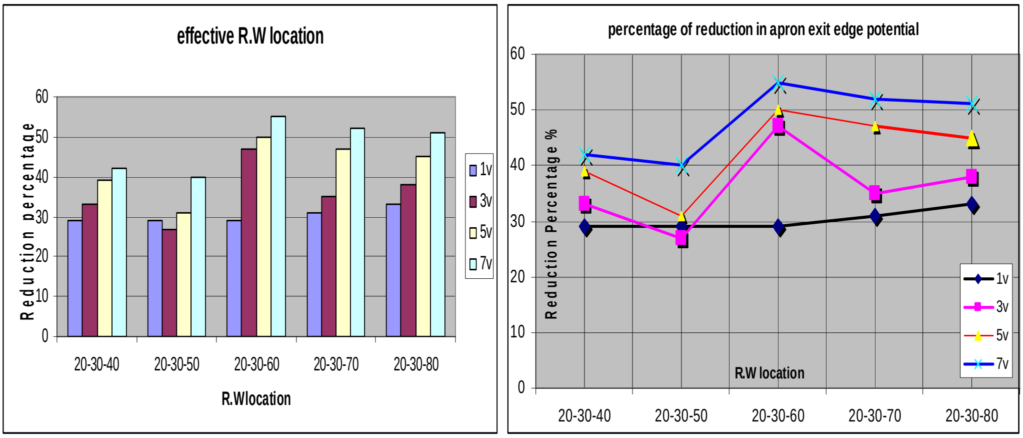


Fig. (11): The potential of exit edge of three rows of relief wells

4- Four Rows of Relief Wells

Table (5): Comparison for exit edge potential between four rows of relief wells and free apron

R .w Position	Potential head				Effect of relief wells				Effect Percentage			
	1v	3v	5v	7v	1v	3v	5v	7v	1v	3v	5v	7v
20-30-40-50	**0.30**	**0.49**	**0.58**	**0.66**	0.22	0.43	0.71	0.83	29	33	39	42
20-30-40-60	**0.37**	**0.51**	**0.59**	**0.63**	0.15	0.41	0.70	0.86	29	**27**	31	40
20-30-40-70	**0.33**	**0.52**	**0.50**	**0.63**	0.19	0.40	0.79	0.86	29	**47**	**50**	**55**
20-30-40-80	**0.34**	**0.47**	**0.50**	**0.60**	0.18	0.45	0.79	0.89	**31**	35	47	**52**
Without r.w	0.52	0.92	1.29	1.49								

As follows the percentage of the effect of the relief wells on the exit of the apron due to the four rows of relief wells case is shown in Fig. (12).

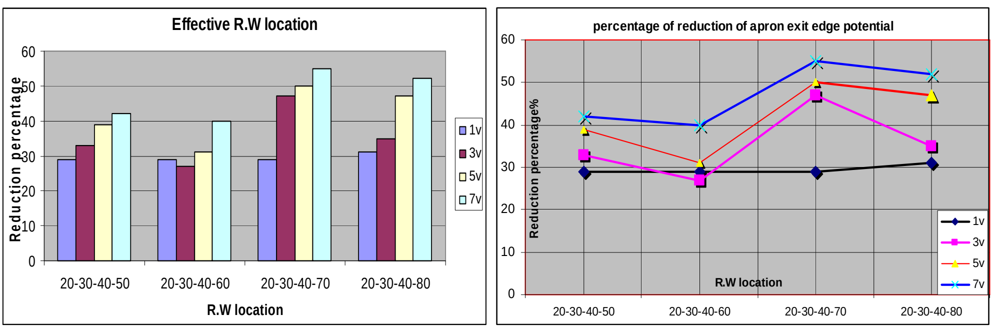


Fig. (12): Four rows of relief wells exit change

From Table (5) and by analysis the results: the most effective position for the four rows of relief wells and Fig. (12) the comparison between the potential head under the exit edge of the apron affected by the relief well position with the edge exit of free apron (without relief wells) indicated:.

The best position for the head **7m** is **(20%-30%-40%-70%)**, the potential head of the exit edge was reduced by **55%** from the potential head of the free apron. Also for the head **5m** the best position is **(20%-30%-40%-70%),** and then the potential head of the exit edge reduced **50%** from the potential head of the exit edge of the free apron. While the best position for the head **3m** is **(20%-30%-40%-70%),** the potential head reduced **47%** from the potential head of exit edge of the free apron case. But the best position for the low head **1m** is **(20%-30%-40%-80%),** then, the potential reduced **31%** from the potential head of the exit edge of the free apron case.

5- Five Rows of Relief Wells

The percentage of the effect of the relief wells on the exit edge of the apron include in Table (5)

Table (6): The relief wells effect on the exit edge potential for five rows of relief wells

Position	Potential head				Effect of relief wells				Effect Percentage			
	1v	3v	5v	7v	1v	3v	5v	7v	1v	3v	5v	7v
20-30-40-50-60	**0.25**	**0.46**	**0.58**	**0.61**	0.27	0.46	0.71	0.88	52	50	55	59
20-30-40-50-70	**0.18**	**0.39**	**0.49**	**0.50**	0.34	0.53	0.80	**0.99**	**65**	**58**	62	**66**
20-30-40-50-80	**0.18**	**0.35**	**0.45**	**0.52**	**0.34**	**0.57**	**0.84**	0.97	**65**	**62**	**65**	**65**
Free apron	**0.52**	**0.92**	**1.29**	**1.49**								

As follows the percentage of effect of relief wells on exit edge of the apron for the five rows of relief wells is shown in Fig. (13).

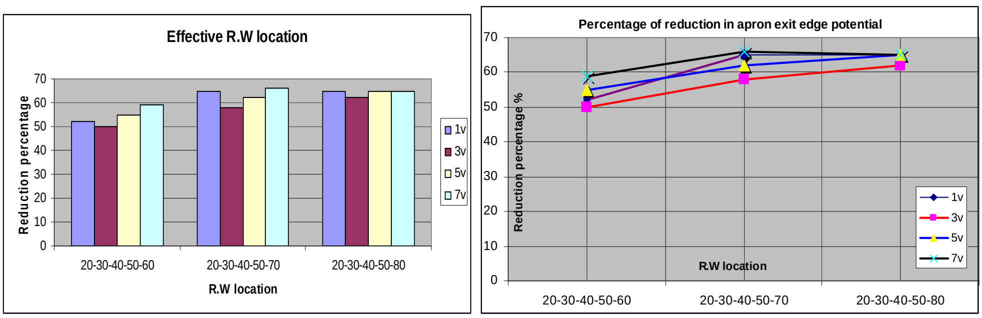


Fig. (13): Five rows of relief wells

From Table (6) and by analysis the results: the most effective position for the five rows of relief wells and Fig. (13) the comparison between the potential head under the exit edge of the apron affected by the relief well position with the edge exit of free apron (without relief wells) indicated:.

The best position for the head **7m** is **(20%-30%-40%-50%-70%)**, the potential head of the exit edge was reduced by **66%** from the potential head of the free apron. Also for the head **5m** the best position is **(20%-30%-40%-50%-80%),** and then the potential head of the exit edge reduced **65%** from the potential head of the exit edge of the free apron. While the best position for the head **3m** is **(20%-30%-40%-50%-80%),** the potential head reduced **62%** from the potential head of exit edge of the free apron case. But the best position for the low head **1m** is **(20%-30%-40%-50%-80%),** then, the potential reduced **65%** from the potential head of the exit edge of the free apron case.

6- Six Rows of Relief Wells

Table (7): Comparison for exit edge potential between six rows of relief wells and an apron without relief wells

Position of relief wells rows	Potential head				Effect of relief wells				Effect Percentage			
	1v	3v	5v	7v	1v	3v	5v	7v	1v	3v	5v	7v
20-30-40-50-60-70	**0.16**	**0.37**	**0.41**	**0.61**	0.36	0.55	0.88	0.88	69	**60**	**68**	59
20-30-40-60-60-80	**0.14**	**0.38**	**0.44**	**0.46**	0.38	0.54	0.85	1.03	**73**	**59**	66	**69**
Apron without R.W	0.52	0.92	1.29	1.49								

As follows the percentage of relief wells on exit edge of the apron is shown in Fig. (14).

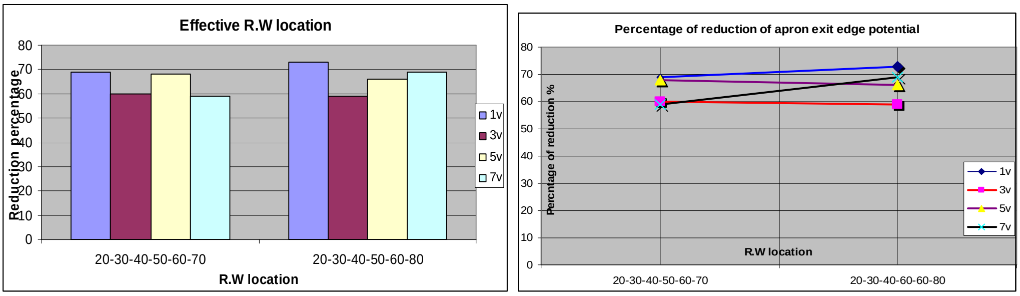


Fig. (14): Six rows of relief wells

From Table (7) and by analysis the results: the most effective position for the four rows of relief wells and Fig. (14) the comparison between the potential head under the exit edge of the apron affected by the relief well position with the edge exit of free apron (without relief wells) indicated:.

The best position for the head **7m** is **(20%-30%-40%-50%-80%)**, the potential head of the exit edge was reduced by **59%** from the potential head of the free apron. Also for the head **5m** the best position is **(20%-30%-40%-50%-70%),** and then the potential head of the exit edge reduced **68%** from the potential head of the exit edge of the free apron. While the best position for the head **3m** is **(20%-30%-40%-50%-70%),** the potential head reduced **60%** from the potential head of exit edge of the free apron case. But the best position for the low head **1m** is **(20%-30%-40%-50%-80%),** then, the potential reduced **73%** from the potential head of the exit edge of the apron without relief wells case.

b- Percolation Length:

The depth of the relief wells (d_{w1-n}), founded on a homogenous permeable soil of thickness (T), permeability (K) and for a given relative position X_{w1-n}/L_{ap} of the relief well, we have:

$(X_{w1-n}/L_{ap}) = \psi\,(C_V, C_H, C_R, F_{w1-n}/\Delta h_{LV}, R_{w1-n}/\Delta h_{LV}, F_{w1-n}/R_{w1-n})$………………… (3)

Number of models 15 models constituting 45 experimental runs were carried out on an electric analogue and the measurement of different potential at various points of the flow field were affected by using a digital ammeter of high sensitivity. For each model the total (H_0) was taken 1.00, 3.00, 5.00 and 7.00 V according to the assigned run to be carried out on the model. Also, the potential difference readings (F_{w1-n}) and (R_{w1-n}) are taken for the whole diversification of 45 runs corresponding to the adopted ratio:-

- 0.167, 0.25and 0.33 for the depth ratio d_{w1-n}/T. for six rows
- -0.20, 0.30, 0.40, 0.50, 0.60, 0.70 and 0.80 for the relative position ratio $X_{w1-n}/L_{ap.}$for six rows

Used the formula (4) to calculate the creep length under apron hydraulic structures:

$L_P = \Sigma L_V + C_H \times \Sigma L_H$ ……………………………………………………….. (4)

We get the value of (C_H) and the values of (F_{w1-n}) and (R_{w1-n}) from table (8) to table (14), for the potential head (H_0) =3v.

Table (8): One row of relief wells

d/T	d/L_{ap}	X/L_{ap}	Δh_{LV}	Δh_{LH}	C_V	C_H	C_R	F	R	F/ Δh_{LV}	R / Δh_{LV}	F /R
0.167	0.083	0.20	0.50	2.50	0.17	0.83	.20	0.30	0.20	0.60	0.40	1.50
		0.30	0.35	2.65	0.12	0.88	0.13	0.20	0.15	0.57	0.43	1.33
		0.40	0.29	2.71	0.10	0.90	0.10	0.17	0.12	0.58	0.42	1.41
		0.50	0.25	2.75	0.08	0.92	0.08	0.16	0.09	0.64	0.36	1.77
		0.60	0.20	2.80	0.07	0.93	0.07	0.10	0.10	0.50	0.50	1.00
		0.70	0.25	2.75	0.08	0.92	0.08	0.13	0.12	0.52	0.48	1.08
		0.80	0.10	2.90	0.03	0.97	0.03	0.06	0.04	0.60	0.40	1.50
0.25	0.125	0.20	0.31	2.69	0.13	0.87	0.15	0.17	0.14	0.54	0.46	1.31
		0.30	0.31	2.69	0.13	0.87	0.15	0.19	0.12	0.61	0.39	1.58
		0.40	0.21	2.79	0.07	0.93	0.07	0.12	0.09	0.57	0.43	1.33
		0.50	0.23	2.77	0.08	0.92	0.08	0.12	0.11	0.52	0.48	1.09
		0.60	0.18	2.82	0.06	0.94	0.06	0.10	0.08	0.55	0.45	1.25
		0.70	0.21	2.79	0.07	0.93	0.07	0.11	0.10	0.52	0.48	1.10
		0.80	0.12	2.88	0.04	0.96	0.04	0.07	0.05	0.58	0.42	1.40
0.33	0.167	0.20	1.00	2.00	0.33	0.67	0.50	**0.59**	**0.41**	0.59	0.41	1.53
		0.30	0.64	2.36	0.213	0.786	0.270	**0.37**	**0.27**	0.57	0.42	1.37
		0.40	0.54	2.46	0.180	0.820	0.219	**0.31**	**0.23**	0.57	0.42	1.13
		0.50	0.32	2.68	0.106	0.890	0.119	**0.22**	**0.10**	0.68	0.31	2.20
		0.60	0.11	2.89	0.037	0.963	0.038	**0.08**	**0.03**	0.73	0.27	2.67
		0.70	0.16	2.84	0.053	0.94	0.056	**0.12**	**0.04**	0.75	0.25	3.00
		0.80	0.09	2.91	0.030	0.970	0.030	**0.07**	**0.02**	0.78	0.22	3.50

From Table (8) indicated that:

1- The effect of relief wells front is greater the effect of rear of relief wells in the flow direction.

2- The one row of relief wells is not enough to effect on flow paths

Table (9): Two rows of relief wells

d/T	d/ Lap	X/Lap	ΔhLV	ΔhLH	CV	CH	CR	F	R	F/ ΔhLV	R / ΔhLV	F /R
0.16	0.083	0.20-0.30	0.32	2.68	0.11	0.89	0.12	**0.20**	**0.12**	0.62	0.38	1.66
		0.20-0.40	0.27	2.73	0.09	0.91	0.10	**0.17**	**0.10**	0.62	0.38	1.70
		0.20-0.50	0.34	2.66	0.11	0.89	0.12	**0.20**	**0.14**	0.57	0.43	1.42
		0.20-0.60	0.33	2.67	0.11	0.89	0.12	**0.20**	**0.13**	0.60	0.40	1.54
		0.20-0.70	0.28	2.78	0.09	0.91	0.10	**0.17**	**0.11**	0.60	0.40	1.54
		0.20-0.80	0.26	2.74	0.09	0.91	0.10	**0.16**	**0.10**	0.61	0.39	1.60
0.25	0.125	0.20-0.30	0.55	2.45	0.18	0.82	0.22	0.30	0.25	0.54	0.46	1.20
		0.20-0.40	0.51	2.49	0.17	0.83	0.20	0.29	0.24	0.57	0.43	1.20
		0.20-0.50	0.40	2.60	0.13	0.87	0.15	0.22	0.18	0.55	0.45	1.22
		0.20-0.60	0.46	2.54	0.15	0.85	0.17	0.25	0.21	0.54	0.46	1.19
		0.20-0.70	0.47	2.53	0.156	0.844	0.17	0.27	0.20	0.58	0.42	1.35
		0.20-0.80	0.49	2.51	0.16	0.84	0.19	0.27	0.22	0.55	0.45	1.22
0.33	0.167	0.20-0.30	1.57	1.43	0.523	0.477	1.10	**0.90**	**0.67**	0.57	0.42	1.34
		0.20-0.40	1.63	1.37	0.534	0.466	1.14	**0.79**	**0.64**	0.48	0.39	1.23
		0.20-0.50	1.65	1.35	0.55	0.45	1.22	**0.87**	**0.78**	0.52	0.47	1.11
		0.20-0.60	1.58	1.42	0.52	0.47	1.10	**0.83**	**0.75**	0.52	0.45	1.10
		0.20-0.70	1.86	1.14	0.62	0.38	1.60	**1.01**	**0.85**	0.54	0.45	1.20
		0.20-0.80	1.47	1.53	0.49	0.51	0.96	**0.78**	**0.69**	0.53	0.49	1.08

As follows the relief wells effect on vertical and horizontal flow paths, Fig. (15).

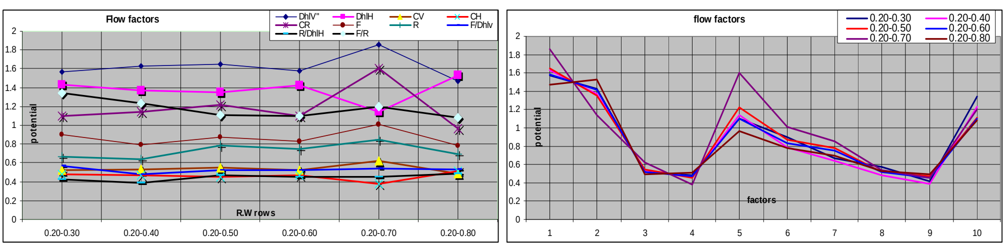


Fig. (15): Flow factors

For the two rows of relief wells: from Table (9) and Fig. (15) indicated that:

1- The vertical potential increase with the increase of the relief wells depth.

2- The factor of horizontal flow (C_H) depend on the relief well depth, (> 50% for the shallow depths < 50% for deep depths).

3- The best relief well depth is (d/T =33%) and the best position is (20%-70%)

Table (10): Three rows of relief wells (d/T=0.16 – d/L_{ap}=0.083

d/T	d/L_{ap}	X/L_{ap}	Δh_{LV}	Δh_{LH}	C_V	C_H	C_R	**F**	**R**	F/ Δh_{LV}	R / Δh_{LV}	F /R
0.16	0.083	0.20-0.30-0.40	0.37	2.63	0.12	0.88	0.14	**0.22**	**0.15**	0.59	0.41	1.46
		0.20-0.30-0.50	0.35	2.65	0.12	0.88	0.14	**0.23**	**0.12**	0..65	0.35	1.91
		0.20-0.30-0.60	0.39	2.61	0.13	0.87	0.15	**0.23**	**0.16**	0.59	0.41	1.41
		0.20-0.30-0.70	0.33	2.67	0.11	0.89	0.12	**0.21**	**0.12**	0.63	0.37	1.75
		0.20-0.30-0.80	0.41	2.59	0.14	0.86	0.16	**0.25**	**0.16**	0.62	0.38	1.56
0.25	0.125	0.20-0.30-0.40	0.57	2.43	0.19	0.81	0.23	**0.32**	**0.25**	0.56	0.44	1.28
		0.20-0.30-0.50	0.61	2.39	0.23	0.77	0.30	**0.34**	**0.28**	0.54	0.46	1.21
		0.20-0.30-0.60	0.56	2.44	0.19	0.81	0.23	**0.33**	**0.23**	0.58	0.42	1.43
		0.20-0.30-0.70	0.42	2.58	0.14	0.86	0.16	**0.25**	**0.17**	0.59	0.41	1.41
		0.20-0.30-0.80	0.51	2.49	0.17	0.83	0.20	**0.29**	**0.22**	0.57	0.43	1.31
0.33	0.167	0.20-0.30-0.40	1.72	1.28	0.57	0.43	1.32	**0.93**	**0.79**	0.54	0.45	1.17
		0.20-0.30-0.50	1.83	1.17	0.61	0.39	1.56	**0.98**	**0.85**	0.53	0.46	1.15
		0.20-0.30-0.60	1.81	1.19	0.60	0.40	1.50	**0.96**	**0.85**	0.53	0.46	1.12
		0.20-0.30-0.70	1.72	1.28	0.57	0.43	1.32	**0.93**	**0.79**	0.54	0.45	1.16
		0.20-0.30-0.80	1.46	1.54	0.48	0.52	0.92	**0.77**	**0.69**	0.53	0.47	1.11

As follows the effect of relief wells on flow paths factors

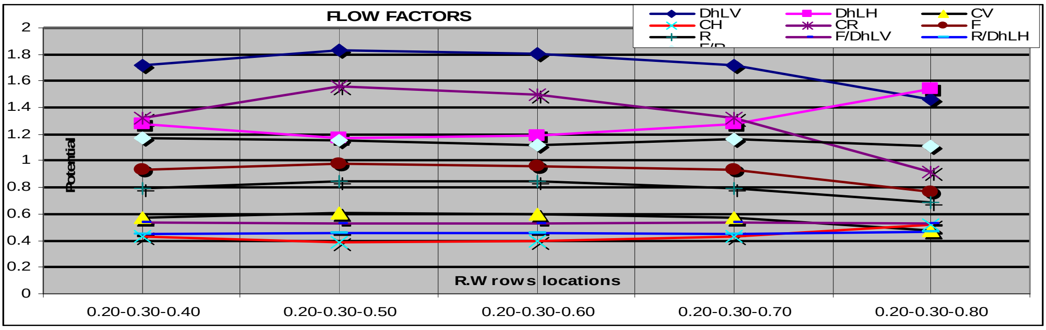


Fig. (16): Flow factors for three rows of relief wells

For three rows of relief wells, from Table (10) and Fig (16) (indicated that:

1- Vertical path effect depends on the relief well depth.
2- Horizontal path > 50% of total flow for d/T < 33%.
3- The best position of relief wells rows to minimize the horizontal flow path is (20%-30%-50%)

Table (11): Four rows of relief wells ($d/T_=0.16$ – d/L_{ap} =0.083)

d/T	d/L_{ap}	X/L_{ap}	Δh_{LV}	Δh_{LH}	C_V	C_H	C_R	F	R	$F/\Delta h_{LV}$	$R/\Delta h_{LV}$	F/R
0.16	0.083	0.20-0.30-0.40-0.50	0.40	2.6	0.13	0.87	0.15	0.25	0.15	0.62	0.38	1.67
		0.20-0.30-0.40-0.60	0.24	2.76	0.08	0.92	0.086	0.17	0.07	0.70	0.30	2.42
		0.20-0.30-0.40-0.70	0.53	2.47	0.18	0.82	0.21	0.31	0.22	0.58	0.42	1.40
		0.20-0.30-0.40-0.80	0.45	2.55	0.15	0.85	0.17	0.27	0.18	0.60	0.40	1.50
0.25	0.125	0.20-0.30-0.40-0.50	0.52	2.48	0.17	0.83	0.20	0.31	0.21	0.59	0.41	1.47
		0.20-0.30-0.40-0.60	0.55	2.45	0.18	0.82	0.22	0.31	0.24	0.56	0.44	1.29
		0.20-0.30-0.40-0.70	0.46	2.54	0.15	0.85	0.18	0.28	0.18	0.60	0.40	1.55
		0.20-0.30-0.40-0.80	0.54	2.46	0.18	0.82	0.22	0.32	0.22	0.59	0.41	1.45
0.33	0.167	0.20-0.30-0.40-0.50	1.59	1.41	0.53	0.47	1.12	0.86	0.73	0.54	0.45	1.16
		0.20-0.30-0.40-0.60	1.58	1.42	0.53	0.47	1.12	0.85	0.73	0.54	0.45	1.16
		0.20-0.30-0.40-0.70	1.44	1.56	0.48	0.52	0.92	0.79	0.65	0.51	0.48	1.21
		0.20-0.30-0.40-0.80	1.46	1.54	0.49	0.51	0.96	0.80	0.66	0.54	0.45	1.21

As follows the relief wells effect on vertical flow path Fig. (16).

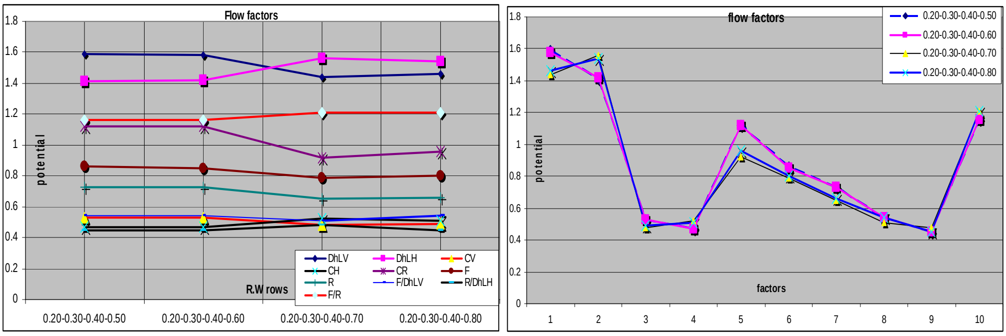


Fig. (17): Effect of relief wells on flow paths

For four rows of relief wells, from Table (11) and Fig (17) indicated that:

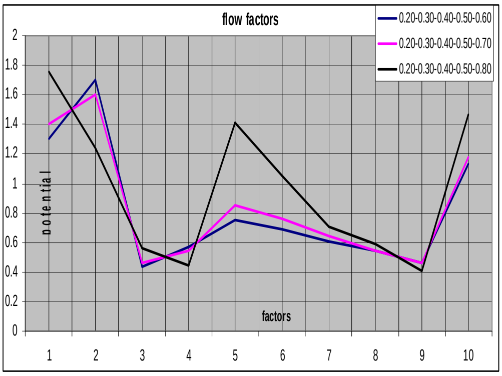
1- The best position of relief wells rows, to minimize the horizontal flow path are (20%-30%-40%-50%) or (20%-30%-40%-60%)

2- The best depth for four relief wells rows is (d/T= 33%).

3- Front potential of relief wells refer to the biggest value from the total potential of the relief wells, is bigger for the shallow depths of the relief wells than for deep relief wells.

Table (12): Five rows of relief wells ($d/T_=0.16$ – d/L_{ap}=0.083)

d/T	d/L_{ap}	X/L_{ap}	Δh_{LV}	Δh_{LH}	C_V	C_H	C_R	F	R	F/ Δh_{LV}	R/ Δh_{LV}	F/R
0.167	0.083	0.20-0.30-0.40-0.50-0.60	0.28	2.72	0.09	0.91	0.10	0.22	0.06	0.78	0.21	3.67
		0.20-0.30-0.40-0.50-0.70	0.51	2.49	0.17	0.83	0.20	0.34	0.17	0.67	0.33	2.00
		0.20-0.30-0.40-0.50-0.80	0.33	2.67	0.11	0.89	0.12	0.21	0.12	0.63	0.36	1.75
0.25	0.125	0.20-0.30-0.40-0.50-0.60	0.57	2.43	0.19	0.81	0.23	0.34	0.23	0.59	0.41	1.47
		0.20-0.30-0.40-0.50-0.70	0.57	2.43	0.19	0.81	0.23	0.34	0.23	0.59	0.41	1.47
		0.20-0.30-0.40-0.50-0.80	0.48	2.52	0.16	0.84	0.19	0.29	0.19	0.60	0.40	1.52
0.33	0.167	0.20-0.30-0.40-0.50-0.60	1.30	1.70	0.43	0.57	0.75	0.69	0.61	0.54	0.46	1.13
		0.20-0.30-0.40-0.50-0.70	1.40	1.60	0.46	0.54	0.85	0.76	0.64	0.54	0.46	1.18
		0.20-0.30-0.40-0.50-0.80	1.76	1.24	0.56	0.44	1.41	1.05	0.71	0.59	0.41	1.47



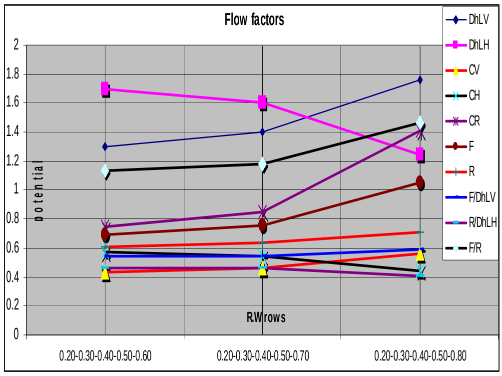


Fig. (18): Effect of five rows of relief wells on flow factors

From Table (12) and Fig. (18) indicated that:

1- The vertical potential increase with the increase of the relief wells depth.

2- The factor of horizontal flow (C_H) depend on the relief well depth, (> 50% for the shallow depths and ≤ 50% for deep depths).

Table (13): Six rows of relief wells ($d/T_=0.16$ - d/L_{ap}= 0.083)

d/T	d/L_{ap}	X/L_{ap}	Δh_{LV}	Δh_{LH}	C_V	C_H	C_R	F	R	F/ Δh_{LV}	R/ Δh_{LV}	F/R
0.167	0.083	0.20-0.30-0.40-0.50-0.60-0.70	0.85	2.15	0.28	0.72	0.38	0.58	0.27	0.68	0.31	2.14
		0.20-0.30-0.40-0.50-0.60-0.80	0.58	2.42	0.19	0.81	0.23	0.35	0.23	0.60	0.39	1.52
0.25	0.125	0.20-0.30-0.40-0.50-0.60-0.70	0.73	2.27	0.24	0.76	0.31	0.42	0.31	0.58	0.42	1.35
		0.20-0.30-0.40-0.50-0.60-0.80	0.58	2.42	0.19	0.81	0.23	0.38	0.20	0.66	0.34	1.90
0.33	0.167	0.20-0.30-0.40-0.50-0.60-0.70	1.30	1.70	0.43	0.57	0.75	0.69	0.61	0.53	0.47	1.11
		0.20-0.30-0.40-0.50-0.60-0.80	1.79	1.21	0.60	0.40	1.50	0.95	0.84	0.53	0.47	1.13

As follows the effect of relief wells on the flow paths factors showed in Fig. (18)

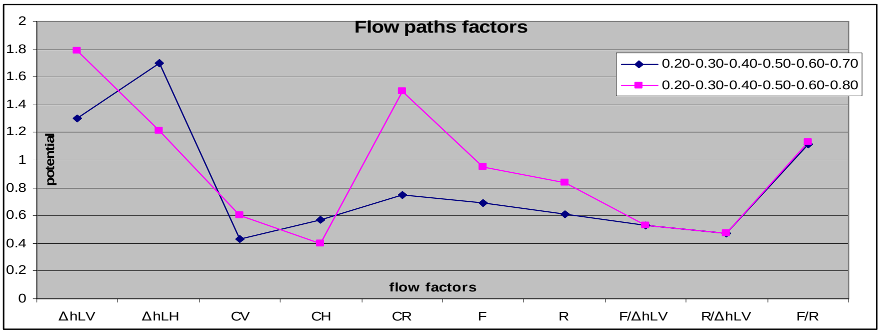


Fig. (19): Relief wells flow factors

From Table (13) and Fig. (19) indicated that:

1- The vertical potential increase with the increase of the relief wells depth.

2- The factor of horizontal flow (C_H) depend on the relief well depth, (> 50% for the shallow depths and ≤ 50% for deep depths).

Table (14): the best relief wells rows for flow factors

d/T	d/L_{ap}	X/L_{ap}	Δh_{LV}	Δh_{LH}	C_V	C_H	C_R	F	R	F/ Δh_{LV}	R/ Δh_{LV}	F/R
33%	16.33%	20-70	1.86	1.14	0.62	0.38	1.60	1.01	0.85	0.54	0.45	1.20
		20-30-50	1.83	1.17	0.61	0.39	1.56	0.98	0.85	0.53	0.46	1.15
		20-30-40-60	1.58	1.42	0.53	0.47	1.12	0.85	0.73	0.54	0.45	1.16
		20-30-40-50-80	1.76	1.24	0.56	0.44	1.41	1.05	0.71	0.59	0.41	1.47
		20-30-40-50-60-80	1.79	1.21	0.60	0.40	1.50	0.95	0.84	0.53	0.47	1.13

As follows the relief wells rows factors showed in Fig. (20).

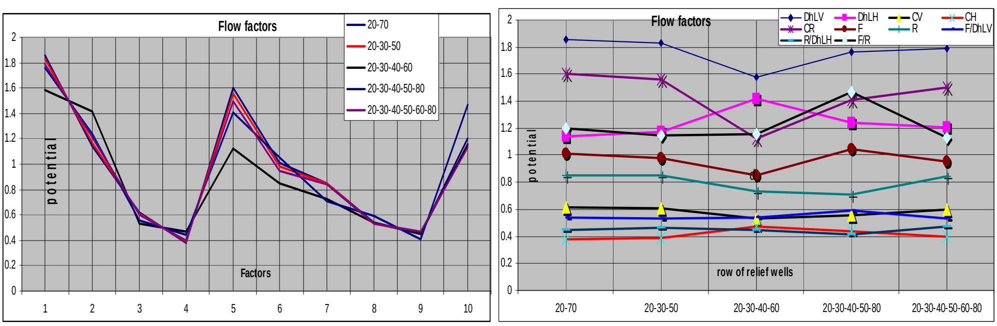


Fig. (20): Relief wells best row

CONCLUSION

Baled on the analysis of the obtained model results are:

1. The optimum position for reducing exit gradient was located at positions, (20%-30%-40%-50%-60%-80%) L_{ap}.

2. The effective reduction percentage in potential of the apron exit edge was 73% at the position (20%-30%-40%-50%-60%-80%)L_{ap}.
3. The percolation length can be shortening by using multi number from relief wells.
4. The factor of horizontal flow (C_H) depend on the relief well depth, (> 50% for the shallow depths and ≤ 50% for deep depths).
5. The best position of relief wells rows, to minimize the horizontal flow path are (20%-70%)L_{ap}.
6. The best depth for relief wells rows is (d/T= 33%).
7. Horizontal path > 50% of total flow for d/T < 33%.
8. The minimum effective row number is two rows of relief wells, first row at 20% from apron length and second at 70% from apron length.

NOTATIONS

C_H: horizontal path coefficient
$C_{R:}$ coefficient ratio , C_V/C_H
$C_{V:}$ vertical path coefficient
d_w: relief well depth
F_w: front potential for relief wells
L_{ap}: apron length
$L_{H:}$ horizontal length.
L_P: percolation length
L_V: vertical length.
R_w: rare potential of relief wells row
T: The subsoil layer thickness under the apron.
X_w: relief well position
Δh_{LV} vertical flow path
Δh_{LH} horizontal flow path
20%-30%-40%.. The position of relief wells rows as a percentage of the apron length measured from apron upstream

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اثر التوزيع الفعال لابار التخفيف على سلامه فروشات القناطر

لما كانت منشآت الحجز الهيدروليكيه مثل السدود والهدارات و القناطر...من المنشآت ذات الاهميه الخاصه فى ضبط وتوزيع المياه فى القنوات المكشوفه ، فهى تحتاج لعنايه خاصه فى اعمال التصميم والتنفيذ والمتابعه والصيانه لضمان السلامه وكفاءه الاداء.

وحيث ان قوى الدفع الرأسيه اسفل الفروشات الصلبه لمثل تلك المنشآت من اهم القوى المؤثره التى يجب اخذها فى الاعتبار عند تصميم هذه المنشآت.

فقد تم اختيار موضوع الدراسه والمتعلق ببحث التوزيع الامثل لابار التخفيف كأهم طرق تخفيف قوى الدفع الرأسيه على الفروشات الصلبه لمثل تلك المنشآت بغرض الوصول لامثل المواضع لتنفيذ تلك الابار خلف المنشآت التى تقلل قوى الدفع الرأسيه لاقل قيمه لها.

وقد تم استخدام النموذج الكهربى المعروف لدراسه المتغيرات الداخله فى الدراسه مثل عمق الابار ، توزيع الابار وعدد الصفوف على النحو الموضح بالدراسه .

وقد تم التوصل الى ان استخدام عدد سته صفوف من ابار التخفيف بالتوزيع المقترح فى الدراسه تعطى خفضا فى قوى الدفع الرأسيه بمقدار 73% عنها فى حاله عدم استخدام ابار التخفيف.

كما اتضح ان كلما كان الصف الاخير من ابار التخفيف اقرب ما يمكن من نهايه الفرش كلما كان اكثر تأثيرا.