Effect of the existence of under drain on Uplift pressure and exit gradient

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Abstract

The effects of the existence of an under drain pipe beneath the foundation of a hydraulic structure, on each uplift pressure, and exit gradient are investigated. More specifically the effect of the horizontal and vertical locations and the diameter of this under drain pipe were investigated. The (Geo-Studio 2007) Seep/w software was used for simulating different geometrical configurations of a typical hydraulic structure model. Results indicate that the existence of this drain will reduce the pressure head beneath the foundation of the structure. The observed reduction in uplift pressure was found considerable. As the drain diameter increases the pressure head decrease more and more. This results in a decrease in the required volume of the structure to achieve the required factor of safety against uplift as a greater diameter for the drain pipe. A 100% decrease in this volume where observed where the under drain location is near the u/s sheet pile (location –D-). The exit gradient was found to decrease also in general when a drain pipe is exist near the upstream sheet pile. However, it was found to increase when the drain pipe was located below the downstream sheet pile especially (location-G-). For this case the downstream length of protection (L) increase from (2.837m compared to the case of no drain) to (4.70 m for with drain at location G) that means about 65.67% increases. This may be attributed to the densification of the stream lines near the downstream side when the drain was located in this position, the increase in the protection length required was found to be more as the diameter of the drain pipe increase.

Keywords: Uplift pressure, Exit gradient, Geo Studio-seep/w, under drain pipe.

1. Introduction

For dams built on permeable soil foundation, the water percolates through the soil and exerts uplift pressures and may carry soil particles with it leading to undermine erosion. Therefore a dam founded on permeable soil has to be designed against uplift pressure and piping (Mansuri,B.,et al.). Because failures in the foundation of such structures are more frequent in practice than other types of failures then the foundation of that structures should be given the greatest importance in analysis and design as compared with other parts of the structure. One of the most important problems that cause damage to hydraulic structures is seepage through and/or under dams, which occurs due to the difference in water level between the upstream and downstream sides of hydraulic structure. (El-Jumaily, and AL-Bakry, 2013), The uplift pressure is maximum just in this point that the water enters the foundation upstream of hydraulic structure, thus the volume of super structures is very important in order to resist the uplift pressure, if this volume is insufficient against that pressure then the failure of hydraulic structure may occur. If the downstream exit gradient is greater than critical exit gradient then piping will occur.

Control of these failures may be accomplished by using cutoffs or sheet piles on upstream or/and downstream, filter trench or, pressure relief wells on the downstream side. In this paper the seepage under the hydraulic structure was analyzed with under drain pipe in the foundation, and the effect of (diameter, vertical and horizontal locations) of under drain pipe was investigated on uplift pressure and hydraulic gradient. The structure is located over homogeneous anisotropic soil layer. Numerical simulation is carried out using Geo-Studio-Seep/w software, for different variations of related variables.

Many researchers were worked in this scope (uplift pressure and exit gradient reduction in hydraulic structure). A large number of experiments were carried out with using of such (cutoff at u/s and/or d/s, using blanket, relief wells, and filter, ...etc.) as effective measures to reduce seepage forces and exit gradient, the following are some researches which deals with the reduction in exit gradient and uplift pressure.

(Al-Suhaili, 2009) had investigated analytical solution for exit gradient variation downstream of inclined sheet pile. The effect of angle of inclination of the sheet pile with the downstream side was investigated. Results indicate that the exit gradient is decreased as the angle was increased. The length of protection against piping was also investigated. The results indicate low variation of this protection length with the angle of inclination. The required protection length was found minimum for an angle of $(5 * {}^{\pi}/_{6})$.

(Azizi, et.al, 2012) had investigated the weep hole and cut-off effect in decreasing of uplift pressure and exit gradient (Case Study: Yusufkand Mahabad Diversion Dam). By simulating it in Seep/W software. Effect of weep holes location and different depth of the dam cutoff walls on uplift pressure and on exit hydraulic gradient was investigated. Results show that upstream cutoff with 8 meter depth decreases uplift force about 63% and decreases exit gradient 79% with respect to the case of without cutoff case. Installing weep hole in downstream stilling basin decreases the uplift force by 8% and decreases exit gradient by 74% more than without weep hole.

(Mansuri and Salmasi, 2013) had investigated the effect of horizontal drain length and cutoff wall on seepage and uplift pressure in heterogeneous earth dam with numerical simulation. The difference of this research is the type of drain pipe and it is location which is a set of horizontal drain pipe together was located at downstream between the earth dam body and the foundation. For this purpose various horizontal drain lengths and cutoff wall depth extend under the earth dam in different location of foundation. Seepage analysis, hydraulic gradient and uplift pressure, were computed by numerical simulation, using Seep/w software. Results show that increasing horizontal drain length, will slightly increasing seepage rate and increasing hydraulic gradient. Optimum location of cut off wall for reduction of seepage rate and piping was found in the middle of dam foundation. By increasing the cut off wall depth, seepage from earth dam and its foundation was reduced. Different locations of the cutoff wall in dam foundation were found to have little effect on exit hydraulic gradient. Installation of cut off wall in middle of foundation, results 19.68 percent decreasing in hydraulic gradient than that obtained for a cut off wall located in the upstream side of dam.

(Shayan and Tokaldani, 2013) had investigated the effects of blanket, drains, and cutoff wall on reducing uplift pressure, seepage, and exit gradient under hydraulic structures. To investigate the effectiveness of these measures, individually or in accordance with others, a large number of experiments were carried out on a laboratory model, the physical conditions of all experiments were simulated with a mathematical model. Having compared the data obtained from experiments with those provided from the mathematical model, a good correlation was found between the two sets of data indicating that the mathematical model could be used as a useful tool for calculating the effects of various measures on designing hydraulic structures. Based on this correlation a large number of different inclined angles of cutoff walls, lengths of upstream blankets, and various positions of drains within the mathematical model were simulated. It was found that regardless of their length, the blankets reduce seepage, uplift pressure and exit gradient. However, vertical cutoff walls are the most effective. Moreover, it was found that the best positions of a cutoff wall to reduce seepage flow and uplift force are at the downstream and upstream end, respectively. Also, having simulated the effects of drains, it was found that the maximum reduction in uplift force takes place when the drain is positioned at a distance of 1/3 times the dam width at the downstream of the upstream end. Finally, it was indicated that the maximum reduction in exit gradient occurs when a drain is placed at a distance of 2/3 times of the dam width from upstream end or at the downstream end.

The above cited research illustrates that so many efforts had been done to reduce the uplift pressure and exit gradients downstream of hydraulic structures. These methods are varied as using blankets, inclined sheet piles, weep holes and others. None of these researches had investigated a drain located under the foundation of the hydraulic structures, however there are some works that had used a drain in an earth dam for reducing the effect of seepage.

There are considerable other works related to exit gradient and uplift pressure in hydraulic structures exist in the literature, but none of them considers the existence of a drain pipe under the foundation of the structures. The above cited researches are the most relevant to the work done herein. This fact also makes the comparison of the results of previous works with the results of the present work not justifiable. The results hence were compared to the physical model built herein for the sake of comparison.

2. Theory

3-A-Seepage equation

Darcy's law and Coefficient of permeability equation is

$$q = -kAi \tag{1}$$

Where q is seepage discharge (cubic meters per second), k is hydraulic conductivity coefficient (meter per second), A is the cross sectional area (m2) and (i) is the flow hydraulic gradient. In many cases the flow of water through a soil mass is not in one direction only, nor is it uniform over the entire area perpendicular to the flow. Determination of quantity of seepage and distribution of seepage pressure for steady state seepage and uniform isotropic soil can be done with methods based on Laplace equation since for this case it is the equation that govern the flow. When the soil is considered as homogeneous anisotropic then the two dimensional steady state seepage differential equation that governs the flow has the form of equation (2):

$$K_x \frac{\partial^2 h}{\partial x^2} + K_y \frac{\partial^2 h}{\partial y^2} = 0 \qquad (2)$$

Where Kx and Ky are the coefficients of hydraulic conductivity in the x and y direction, respectively (meters per second), h is the total head (meters) in any point (x,y) in the soil layer, and q is the seepage discharge (cubic meter per second per unit area). Numerical methods help for solving such differential equation which results into a set of algebraic equations for the head at selected points in the soil layer defined by the discretization method. "Seep/w" is a well- known software that can be used to solve this equation by adopting the finite element method.

3-B- Numerical simulation

Geo-Studio Seep/w (http://www.geo-slope.com) is a finite element software product for analyzing groundwater seepage and excess pore-water pressure dissipation problems within porous materials such as soil and rock. This software was used herein to make the required analysis for a typical problem of seepage analysis under a hydraulic structure with different geometrical dimensions of the length of the foundation, U/S and D/S cutoffs length, for a given soil layer properties and given head difference between U/S and D/S sides of the structure. In addition to that an under drain with given diameter and given vertical and horizontal locations, will be exist. These features will be modeled using the Geo-Studio seep/w software. For this modeling suitable boundary conditions should be used along the boundaries of the field of the problem.

The boundary conditions for this example are as the water level in upstream is 5 meter, water level in downstream is set to zero (the most critical case in simulation occurs when water level differences between upstream and downstream be maximum), also the foundation's floor, its right, left, and bottom sides are impermeable (zero flow). In order to apply the boundary conditions for the drain pipe, the boundary condition on the perimeter of the pipe can be specified as a potential seepage face. The implication is that seepage will enter the drain only along that portion of the perimeter where the water pressure is zero or positive. (GEO-SLOPE International Ltd.)

Geo-Studio Seep/w software can automatically generate unstructured pattern of quadrilateral and triangular elements. In this study, unstructured pattern of quadrilateral elements used in this simulation total number of used elements were selected about 1237 elements and there are smaller elements around the drain pipe for more accuracy and the hydraulic conductivity of (Kx=0.00022m/sec, as measured in the laboratory) for sandy soil was used as shown in figure 1. This case hown in figure 1 was applied for a drain pipe of diameter of (0.4), located at the downstream side, just for illustration of the distribution of equipotential and flow lines.

In addition to the first case (model without under drain), 24 cases were modeled as shown in figure 1, firstly the effect of the location of under drain pipe was investigated on each (uplift pressure, exit gradient, and seepage discharge) with eight relative various locations for under drain pipe (X/B = -1/5, 1/5, 4/5, 6/5), (Y/D=1/5, 2/5), as shown in fig.(2), while in the next step the effect of under drain pipe diameter (d) with three relative various values of (d/D = 0.10/5, 0.20/5, 0.30/5) were investigated on each (uplift pressure, exit gradient, and seepage discharge) as shown in figure 2, hence the seepage discharge was selected for 1m width of the hydraulic structure.

Where:

X= the horizontal location of the drain center from the origin. (m)
B= width of the structure base (m).
D= depth of impervious layer. (m)

Figure (1) indicates a radial distribution of equipotential lines, around the drain pipe. The equipotential lines distribution away from the drain are following the natural expected seepage direction.

3. Methodology

The methodology used to investigate the effect of the existence of the under drain on uplift pressure, exit gradient and seepage discharge is to adopt a typical model of the structure, as shown in figure (2). Different cases were modeled with different under drain diameters and different vertical and horizontal locations of the drain pipe. Other data will kept constant as follows:

Upstream water head (H) =5m.
Downstream water head =0m.
Bed width of the structure (B) =5m.
Length of U/S and D/S sheet piles (S1, S2) =1m.
Depth of impervious layer (D) =10m.
Coefficient of hydraulic conductivity(K)=0.00022 m/sec.

For each case amount of uplift force U,F. (see fig.3) and the required volume of the super structure V, that achieve the factor of safety against uplift pressure and the required length of downstream protection L to achieve the factor of safety against piping are calculated.

In order to calculate V and L a factor of safety against uplift pressure and exit gradient according to the equations (3,4) must be used which are assumed as 2 and 3 respectively. (Varshney, R.S., et al, 1977)

$$\mathrm{F.O.S}_{\mathrm{uplift}} = \frac{\gamma c * V}{\mathrm{U.F}} \geq 2 \qquad (3)$$

$$\frac{\mathrm{icr}}{\mathrm{i}} \geq 3 \qquad (4)$$

Where
$F.O.S_{uplift}$: The factor of safety against uplift pressure,
V: volume of hydraulic structure,
γc: wieght density of concrete (for super structure) which is assumed as 2.4 ton/m3,

icr: is the critical exit gradient ≈ 1 (Braja. M. Das 2008).

i: computed exit gradient at the downstream of hydraulic structure

U, F: Uplift force

$$U, F = F1 + F2 + F3 \quad (5)$$

$$F1 = \frac{P1+P2}{2} * 0.5 * 1 * \gamma_W \quad (6)$$

$$F2 = \left\{\frac{P3+P4}{2} + \frac{P5+P6}{2} + \dots\dots\dots + \frac{P_{n-1}+P_n}{2}\right\} * \Delta x * 1 * \gamma_W \quad (7)$$

$$F3 = \left\{\frac{P_{n+1}+P_{n+2}}{2}\right\} * 0.5 * 1 * \gamma_W \quad (8)$$

Where:
P1, P2: are pressure heads under upstream sheet pile (s1) with (0.5m) width.
P3….P_n: are pressure heads between U/S and D/S sheet piles (under the base of the hydraulic structure).

P_{n+1}, P_{n+2}: are pressure heads under downstream sheet pile (s2) with 0.5m width.

Then by using equation 3 the required volume of super structure can be calculated, but for the length of downstream protection the Geo-Studio program can draw a contour line of 0.333 exit gradient (for the factor of safety against piping of 3 and then the location of this line can be used to estimate for L as shown in figure 4. for some cases the amount of uplift pressure is negative that is meaning doesn't need a volume of super structure against uplift pressure.

4. Results and discussion

25 cases with (H=5m, B=5m, S1=1m, S2=1m, Kx/Ky=1, D=10m) were investigated. The first case without drain while the others with using underdrain pipe with eight various locations (A, B, C, D, E, F, G, and H) as shown in table (1) below (the coordinates of the drain pipe location is originated from U/S sheet pile as shown in (figure 2). And three various drain pipe diameters (d) of (0.2m, 0.4m, 0.6m), the locations of four sets of ((X/B= -1/5, 1/5, 4/5, 6/5), (Y/D=1/5, 2/5)) were investigated in Seep/w software and results for uplift pressure were recorded to evaluate the required volume of super structure (the total weight of the structure to resist the uplift forces) V(m^3) against uplift pressure according to the factor of safety of 2, the required downstream length of protection for factor of safety against piping of 3 was recorded.

Results provide strong evidence for a considerable reduction in uplift pressure head, exit gradient and seepage discharge for all cases with using under drain pipe in foundation, a family of curves to indicate the effect of the position and the drain diameter on uplift pressure head and exit gradient are shown in figures (4 to11) below. These figures indicate the variation of uplift pressure head along bed width of the super structure and hydraulic exit gradient variation along the downstream side of the structure. The pressure head beneath super structure had a considerable decrease after installing underdrain pipe and with increasing its diameter the pressure head decreases more, hence and the required volume (V). This reduction may be attributed to the fact that the existence of the drain will lead some of the seepage flow to be diverted towards the drain, rather than towards the downstream side of the structure. This will cause a redistribution of the streamlines to a different pattern than that obtained for the case without the drain. Actually what was observed is that the seepage flows are completely or partially diverted towards the drain, with considerable amount for the latter case. As the diameter of the drain increases the seepage drawing capacity of this drain will be increased and that is the reason of obtaining more reduction in uplift pressure and exit gradient. This is actually expected but the main scope of this paper is to find the variations in reduction capacity of the drain for both the uplift pressure and the exit gradient, as affected by the diameter of the drain and its horizontal and vertical locations.
The percent decrease in the volume range between 6.47-12.2 for diameter variation from 0.2m to 0.4m, and between 0.0-7.71% for diameter variation from 0.4m to 0.6m The decrease in uplift pressure is much more, when the drain location is under the structure base between the two sheet piles than that observed when the drain location is either at the u/s side or at the d/s side of the structure which is tend to 100% decrease in V especially where the under drain location near u/s sheet pile (location –D-).
The exit gradient was also found to considerably decrease with installing drain pipe for some of the cases. For these cases the more the drain diameter the more is the decrease, these case are where the location of underdrain is A, B, C, and D, for which it was found that there are no need for downstream length of protection (L). For the under drain at locations E, F, G and H the exit gradient was found to increase ,hence L increased for example from 2.837m for zero location to (4.70 m) for location G) which is a percent increase of 65.67%. This may be attributed to the densification of the stream lines near the downstream are when the drain is located in this position. All these variations are shown in table 2.
Fig. 5-a shows the pressure head distribution under the structure for case A for different drain

diameter, the reduction in the required volume of super structure -62.64% "negative sign indicate the reduction in volume (V)" for diameter 0.2m as a comparable with the case of **zero location**, and this reduction is much more increased with using diameters of 0.4m, 0.6m about -74.68% and -84.18% respectively. Fig. 5, b shows the variation of the exit gradient along the downstream side of the structure, for different drain diameter, the reduction in the required length of protection as compared with the case of **zero location** required L =2.837m is for diameter 0.2m is 0.0 m, and for diameters of 0.4, 0.6m the required L are found zero means 100% reduction. Generally it can be observed that the existence of the drain will reduce the uplift pressure and hence will reduce the required volume of the superstructure to achieve the required factor of safety.

Fig. 6,a shows the pressure head distribution along the structure foundation for the case of drain location (B), the reduction in the required (V) is found more than that for the case of drain location A, which is -69.72%, -80.80%, -89.03% for the diameters of 0.2m, 0.4m, 0.6m respectively, this means that if the drain pipe horizontal location is at the upstream side of sheet pile (S1) the required volume of the super structure V and uplift pressure will decrease more with the increase of the depth of underdrain pipe (vertical location). Similar results are also observed for the length of the downstream protection (L), as shown in figure 6-b.

Figures (7-a, and 7-b) show the pressure distribution and the exit gradient respectively, for the case of the drain location (C), the reduction in (V) is much more than the two previous locations that is -89.96%, -100.0%, -100.0% for diameters of 0.2m, 0.4m, 0.6m respectively. For the downstream length of protection (L), it decrease but with smaller percent than the decrease found for cases of drain locations A and B.

Figures 8-a, and 8-b sows the pressure distribution and the exit gradient respectively, for the drain location D, which is the same case location C, but with more depth (vertical location) of the drain. This case shows a maximum reductions in uplift pressure, which are (-83.93%, -96.12%, -100.0%) for the diameters of 0.2m, 0.4m, 0.6m respectively. For the L values the reduction is 100% for all diameters.

Figures 9-a, 9-b to 12-a, and 12-b shows the pressure distribution and exit gradient variation for the rest of drain location cases E, F, G, and H, respectively, where the first two cases the drain horizontal location is upstream of the d/s cutoff with the second one of lower vertical location, while the second two cases are for horizontal location downstream of the d/s sheet pile with the second one for deeper vertical location of the drain. For all these cases the reduction in uplift pressure and V decrease as the drain pipe move horizontally towards the downstream sheet pile S2. The length of protection L will be increase but not greater than the case of **zero location.** Table 2 gives the percent reduction in the V and L values for all of the cases with different diameters. These results indicates in general that the reduction in uplift pressure is always effective as a drain pipe is used, while for the exit gradient this true only when the drain is not located at the downstream side, while for the case when it is located in the downstream side an increase in the near toe of the structure location was observed for the diameter of drain 20 cm as shown in figures (11-b and 12-b). For larger diameters the reduction in exit gradient is observed all over the downstream side of the structure. This may be attributed to the fact that as the drain located in the downstream side accompanied with relatively small drain diameter, the stream lines will be directed to the drain with relatively low drain capacity, and this will increase the head, hence increase the exit gradient.

5. Conclusions

The following conclusions can be deduced from the analysis done:

5.1. In all cases the existence of a drain will reduce the uplift pressure under the foundation and the exit gradient downstream of the structure, which reduces the required volume of the super structure and the length of the downstream protection, respectively. The range of the reduction is (37-100) percent in volume and (0.92-100), percent.

5.2. The reduction in the volume is found increase with the diameter of the drain, more reduction is observed when the diameter increase from 0.2 m to 0.4 m that that when increased from 0.4 to 0.6m.

5.3. For the horizontal locations near the upstream cutoff of the structure the reduction in L is more than for the locations near the D/S cutoff.

5.4. The maximum reduction in both V and L was observed for the case when the drain is located near the upstream cutoff D/S of it.

5.5. For the drain pipe location upstream of heel sheet pile (S1) and between the two sheet piles (S1, and S2) the required volume of super structure –V- and uplift pressure will be decrease with the increase of the depth of underdrain pipe and the same as for –L-. but that condition with vice versa occur for the drain pipe location downstream of toe sheet pile (S2)

6. Recommendation

6.1. It is worth to mention that the present simulation of the drain pipe do not include filter around it. It is recommended to investigate the effect of the existence of the filter in future research.

6.2. Moreover, it is recommended to study the effect of the existence of the drain pipe on the seepage flow discharge.

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تأثير وجود انبوب البزل على ضغط الأصعاد و تدرج الخروج

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المستخلص :

تم فى هذا البحث دراسة تأثير وجود انبوب البزل تحت أساس المنشأت الهيدروليكية على كل من ضغط الاصعاد تحت المنشأ وتدرج الخروج فى مؤخره . بشكل اكثر دقة تأثير كل في قطر انبوب المبزل وموقعه الافقي والشاقولي مما تقل مقدار التأثير على حجم المنشأ المطلوب وطول الحماية المطلوبة في مؤخره على التوالي . تم استخدام برامجيات (جيوستوديو –2007) لنمذجة عدة حالات لنموذج منشأ هيدروليكي بتحقيق تغاير القطر انبوب المبزل وموقعيه الافقي والشاقولى . أظهرت النتائج بشكل عام ان وجود انبوب البزل يقلل في كل من ضغط الاصعاد وتدرج الخروج و بذلك يقل حجم المنشأ المطلوب وحجم الحماية المطلوبة في مواخر المنشأ . تراوح مدى النقصان في حالة عدم وجود انبوب بزل (37 – 100)% فى حجم المنشأ ، و(92 – 100)% في طول الحماية المطلوب . كما وجد بانه كلما زاد القطر كلما زاد النقصان في الحجم وان هذا النقصان كان أكبر عنه زيادة القطر في (0.2 الى 0.4)م كما هو عليه عند زيادته من (0.4 الى0.6)م . كما وجد بان للموقع الافقي للمبزل تأثيراً فعالاً على الحجم المطلوب حيث وجد بأنه النقصان في هذا الحجم يصل الى (100%) عندما يكون المبزل في مؤخر المنشأ . كما وجد بأن طول الحماية المطلوبة بشكل عام يقل فيما عدا حالة وجود المبزل في هذا الموقع حيث يتغلب على العكس زيادة بمقدار (65.67%) .

الكلمات المفتاحية : ضغط الأصعاد ، تدرج الخروج ، جيو ستوديو ، أنبوب البزل .

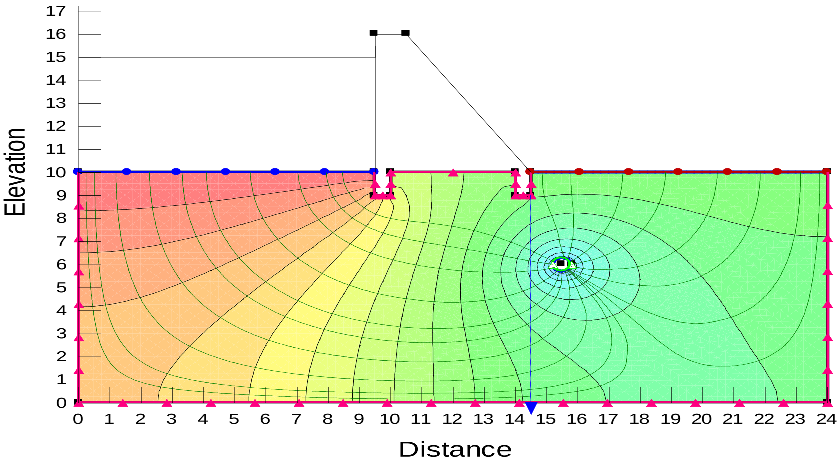

Fig.1: Cross section of hydraulic structure, flow lines and equipotential lines that used in Geo-Studio software.

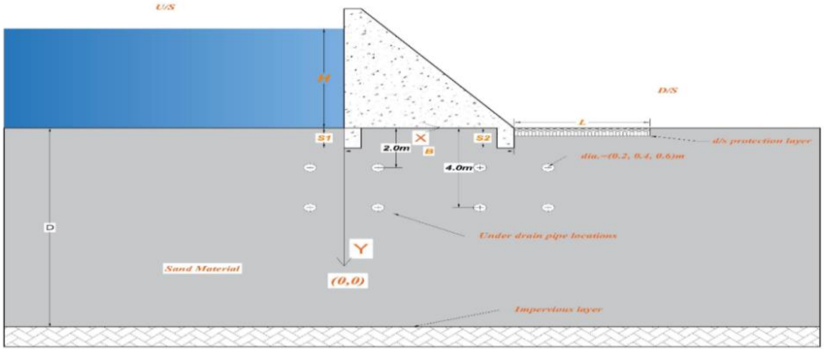

Fig.2: Model Identification.

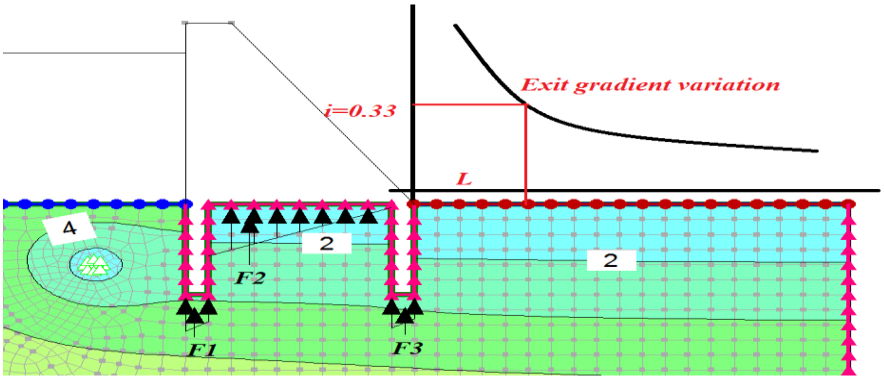

Fig.3: Uplift force distributions.

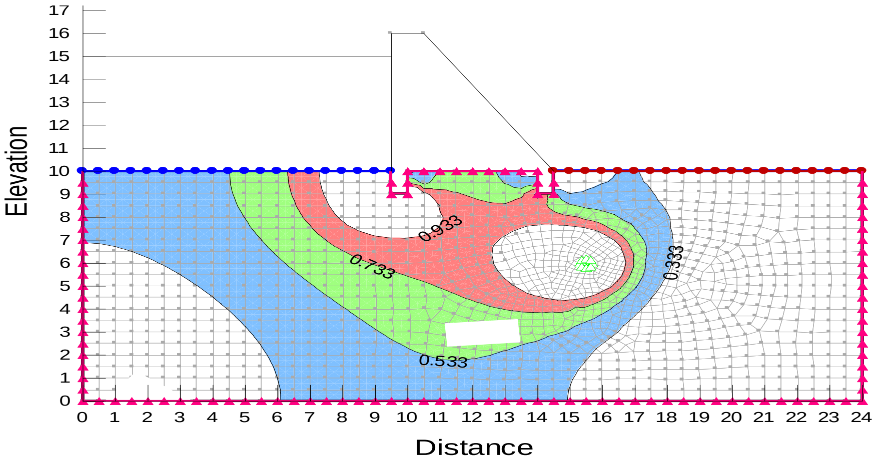

Fig.4: Exit gradient contour line for 0.333(critical).

Table1: Eight various drain pipe relative locations.

Location name	Horizontal location/Bed width (X/B)	Vertical location/Bed width (Y/D)
A	-0.2	0.2
B	-0.2	0.4
C	0.2	0.2
D	0.2	0.4
E	0.8	0.2
F	0.8	0.4
G	1.2	0.2
H	1.2	0.4

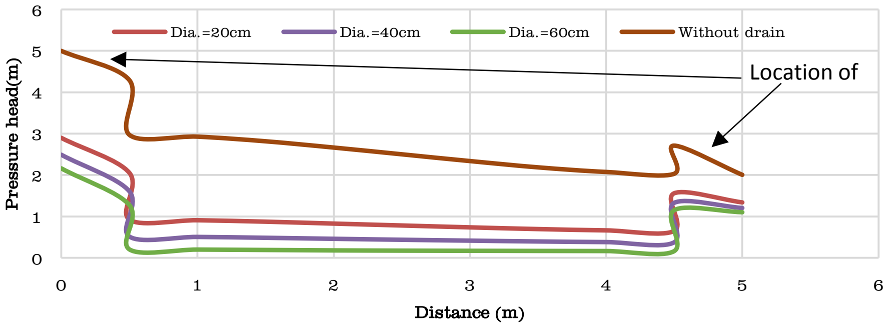

Fig. (5, a) : Pressure head distribution beneath super structure .Location of drain (A) U/S of S1(X=-2, Y=2).

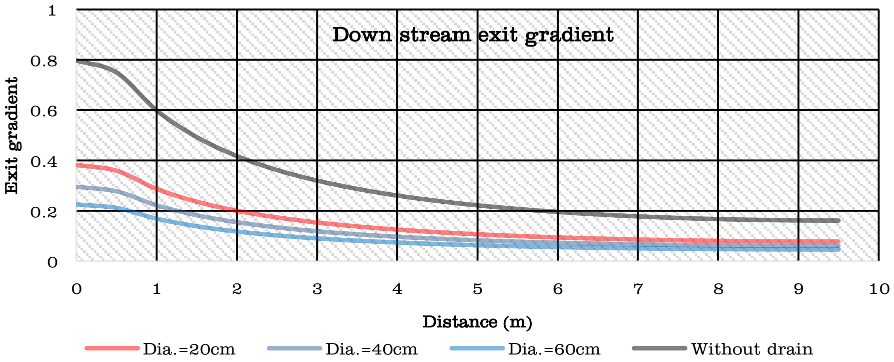

Fig. (5-b) : Downstream Exit gradient Location of drain (A) U/S.

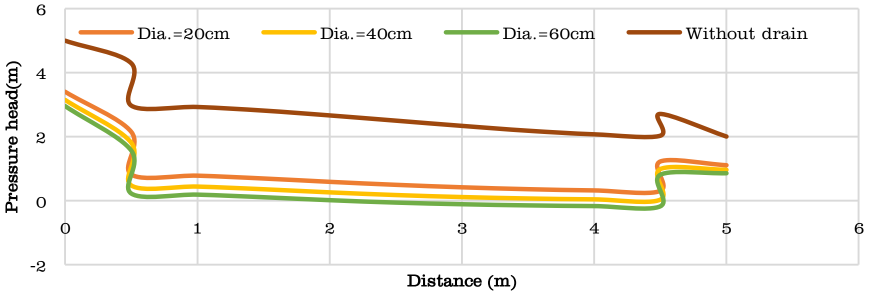

Fig. (6-a): Pressure head distribution beneath super structure .Location of drain (B) U/S of S1 (X=-2, Y=4).

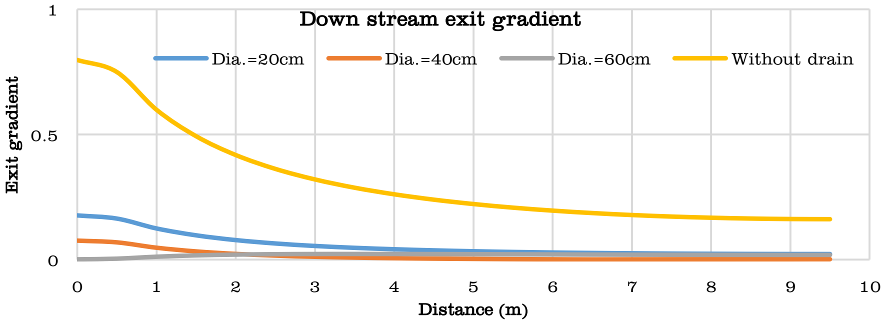

Fig. (6-b): Downstream Exit gradient. Location of drain (B) U/S of S1 (X=-2, Y=4).

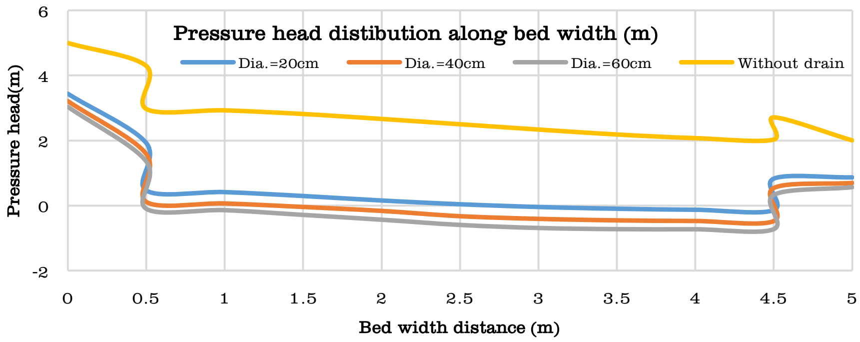

Fig. (7-a) : Pressure head distribution beneath super structure .Location of drain (C) between the two sheet piles, near the U/S one(X=1, Y=2).

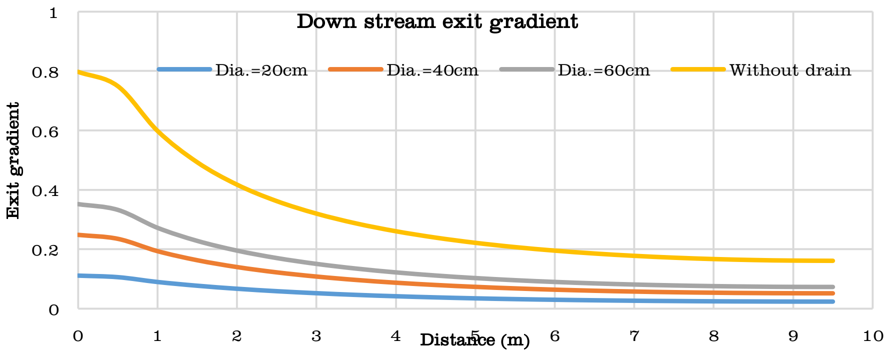

Fig. (7-b) : Downstream Exit gradient. Location of drain (C) between the two sheet piles, near the U/S one(X=1, Y=2).

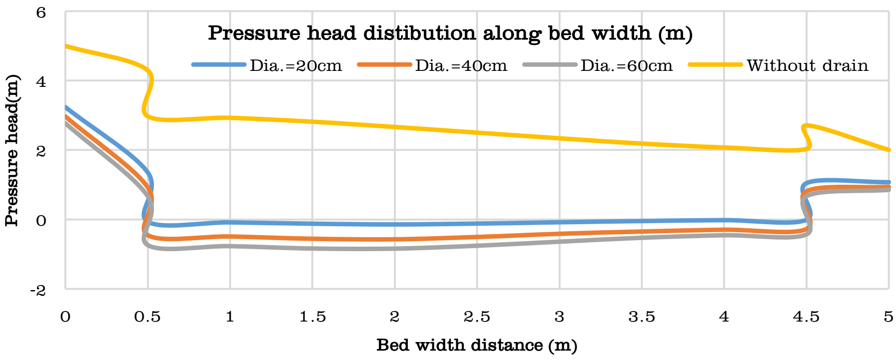

Fig. (8-a) : Pressure head distribution beneath super structure. Location of drain (D) between the two sheet piles, near the U/S one(X=1, Y=4).

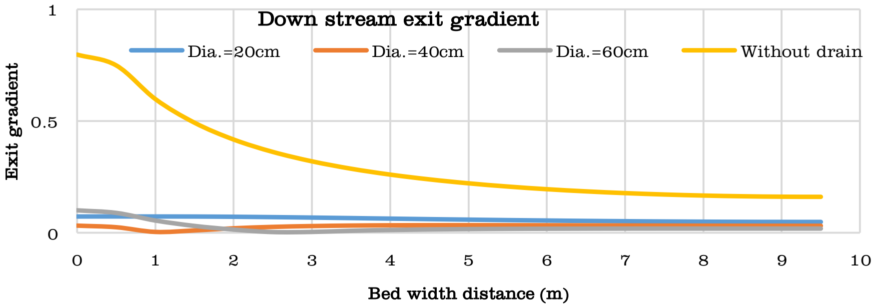

Fig. (8-b) : Downstream Exit gradient. Location of drain (D) between the two sheet piles, near the U/S one(X=1, Y=4).

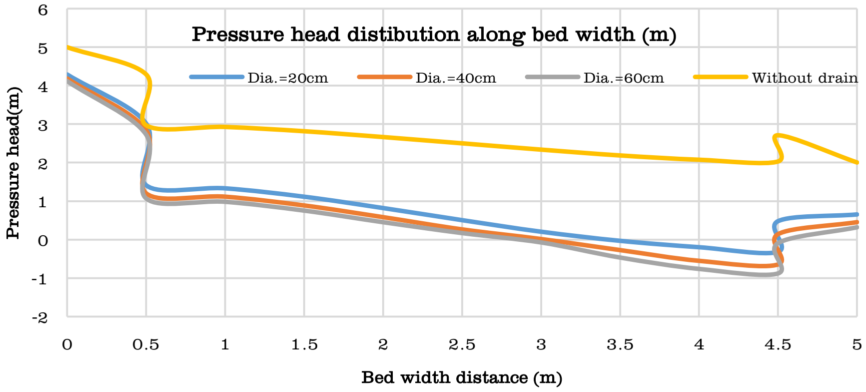

Fig. (9-a): Pressure head distribution beneath super structure. Location of drain (E) between the two sheet piles, near the D/S one (X=4, Y=2).

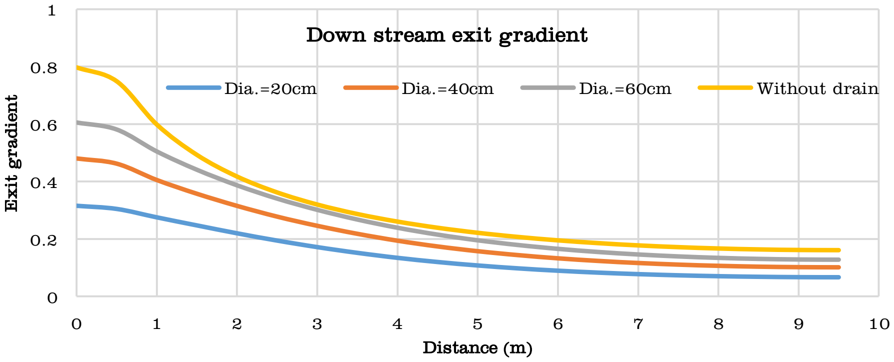

Fig. (9-b): Downstream Exit gradient. Location of drain (E) between the two sheet piles, near the D/S one (X=4, Y=2).

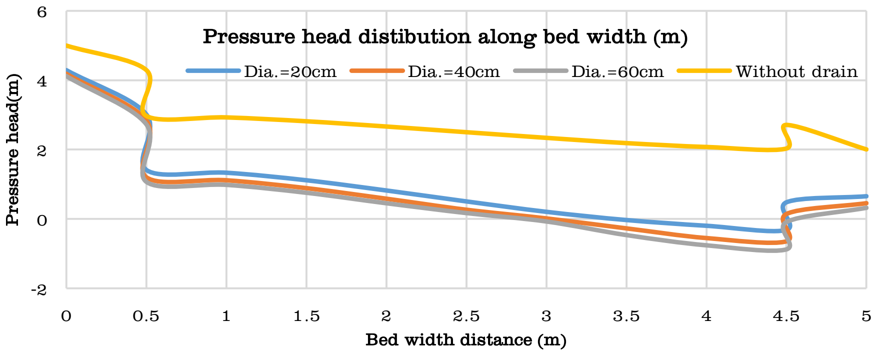

Fig. (10-a) : Pressure head distribution beneath super structure. Location of drain (F) between the two sheet piles, near the D/S one (X=4, Y=4).

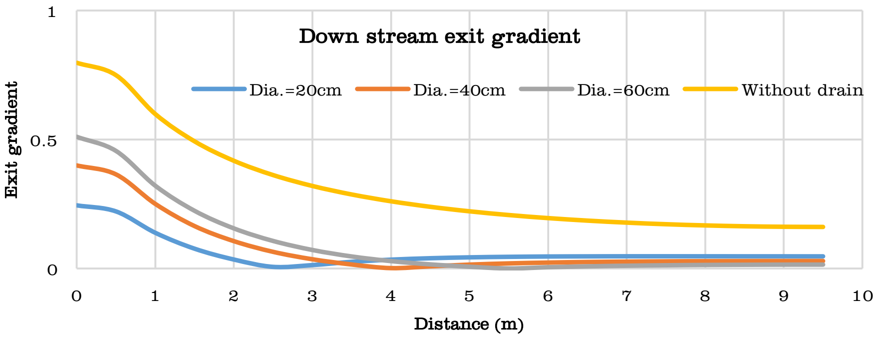

Fig. (10-b) : Downstream Exit gradient. Location of drain (F) between the two sheet piles, near the D/S one (X=4, Y=4).

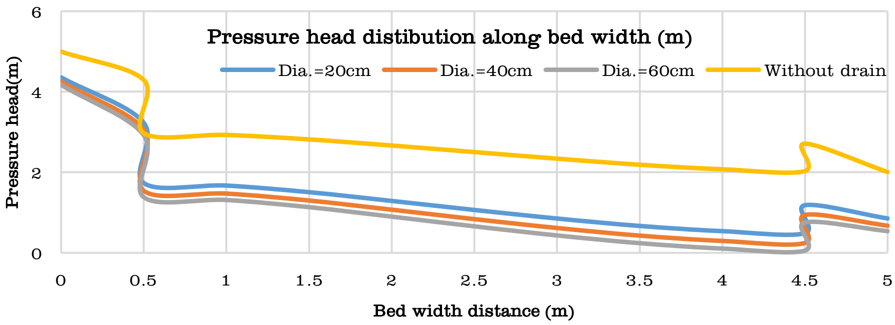

Fig. (11-a) : Pressure head distribution beneath super structure. Location of drain (G) D/S of S2(X=6, Y=2).

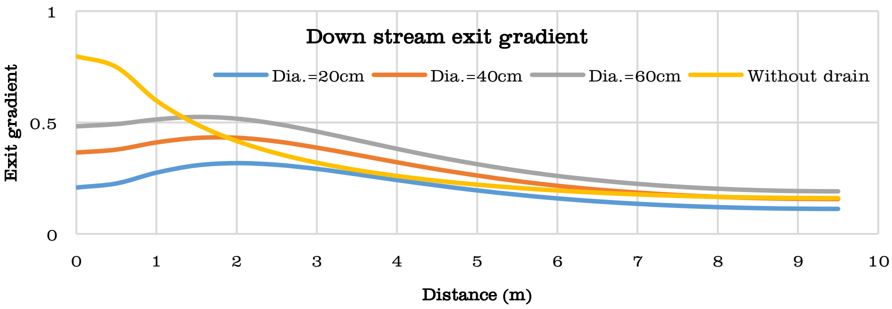

Fig. (11-b) : Downstream Exit gradient. Location of drain (G) D/S of S2(X=6, Y=2).

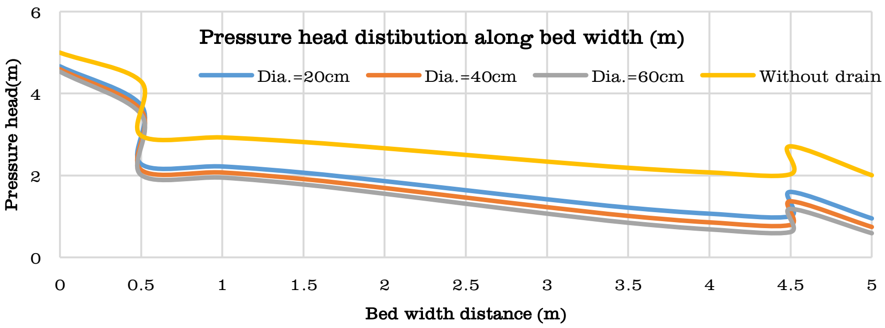

Fig. (12-a) : Pressure head distribution beneath super structure. Location of drain (H) D/S of S2 (X=6, Y=4).

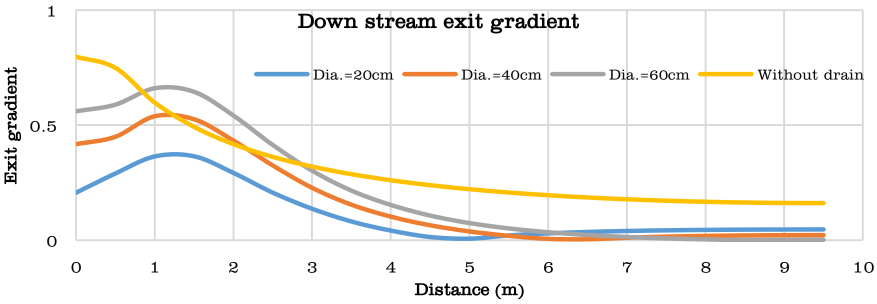

Fig. (12-b) : Downstream Exit gradient. Location of drain (H) D/S of S2 (X=6, Y=4).

Table 2 : Variation of Volume and Length of protection for cases in figures (5 to12) (with and without). drain

case no.	Drain location	Dia.(m)	X(m)	Y(m)	Volume of structure (m^3)	Exit gradient - i	Length of protection (m)	% Change in V	% Change in L
1	Without drain(zero location)	0	0	0	11.250	0.797	2.837	--------	-------
2	A-Location of drain U/S of S1	0.2	-1	2	4.248	0.271	0	-62.24	-100.00
		0.4	-1	2	2.848	0.165	0	-74.68	-100.00
		0.6	-1	2	1.780	0.084	0	-84.18	-100.00
3	B-Location of drain U/S of S1	0.2	-1	4	3.406	0.080	0	-69.72	-100.00
		0.4	-1	4	2.160	0.034	0	-80.80	-100.00
		0.6	-1	4	1.234	0.120	0	-89.03	-100.00
4	C-Location of drain between the two sheet piles, near the U/S one	0.2	1	2	1.130	0.073	0	-89.96	-100.00
		0.4	1	2	0.000	0.032	0	-100.00	-100.00
		0.6	1	2	0.000	0.100	0	-100.00	-100.00
5	D-Location of drain between the two sheet piles, near the U/S one	0.2	1	4	1.810	0.111	0	-83.91	-100.00
		0.4	1	4	0.440	0.248	0	-96.09	-100.00
		0.6	1	4	0.000	0.352	0.482	-100.00%	-83.01%
6	E-Location of drain between the two sheet piles, near the D/S one	0.2	4	2	3.550	0.244	0	-68.44	-100.00
		0.4	4	2	2.550	0.399	0.651	-77.33	-77.05
		0.6	4	2	1.950	0.510	0.955	-82.67	-66.34
7	F-Location of drain between the two sheet piles, near the D/S one	0.2	4	4	7.740	0.205	1.726	-31.20	-39.16
		0.4	4	4	7.010	0.417	2.476	-37.69	-12.72
		0.6	4	4	6.410	0.559	2.863	-43.02	0.92
8	G-Location of drain D/S of S2	0.2	6	2	7.740	0.205	1.726	-31.20	-39.16
		0.4	6	2	7.010	0.417	2.476	-37.69	-12.72
		0.6	6	2	6.410	0.559	2.863	-43.02	0.92
9	H-Location of drain D/S of S2	0.2	6	4	5.620	0.207	0	-50.04	-100.00
		0.4	6	4	4.730	0.365	3.876	-57.96	36.62
		0.6	6	4	4.030	0.482	4.7	-64.18	65.67