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DEVELOPMENT OF EMPIRICAL FORMULA FOR INFLUENCE OF CAVITIES ON SEEPAGE UNDER SHEET PILE WALL FOR HYDRAULIC STRUCTURES

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Abstract

The research presents an experimental study of the interaction between cavity and adjacent hydraulic structure in sandy soil. Experimental studies were performed to investigate the effects of the different factors (such as cavity locations and size of the cavity) on the quantity of the seepage, steady time and flow line .

Different sizes and locations of the cavity are investigated in flow media. It was found the diameter of the cavity is an important parameter.

Dimensional analysis techniques and (STATISTICA) program were used for finding new formula with based on the experimental data, which are used to compute the quantity of seepage.

This formula was derived to predict the quantity of the seepage in terms of spacing between the sheet pile wall and center of the cavity in upstream and downstream zones, spacing between water level and center of the cavity in upstream and downstream zones.

Keywords: Cavity, Seepage, Sheet Pile Wall, Dimensional analysis, AL-Najaf Soil

تطوير معادلة وضعية لتأثير التكهفات على التسرب اسفل جدران الركائز اللوحية للمنشآت الهيدروليكية

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الخلاصة

يشمل البحث دراسة مختبريه لإيجاد التفاعل بين الفجوة والجدران الساندة المجاورة في الترب الرملية. انجزت الدراسة المختبرية لتخمين تأثيرات العوامل المختلفة (موقع الفجوة، قطر الفجوة) على كمية التسرب مع الزمن وخطوط الجريان.

اقطار ومواقع مختلفة تم دراسة تأثيرها في وسط الجريان. وجد ان قطر التكهف هو اهم عامل. تقنية التحليل البعدي والبرنامج الاحصائي **(STATISTICA)** تم استخدامهم لإيجاد المعادلة الوضعية استنادا على البيانات المختبرية لحساب كمية التسرب .

هذه المعادلة اشتقت لحساب كمية التسرب في صيغة المسافة بين الجدران الساندة ومركز التكهف في منطقة الجهد العالي والجهد الواطئ،المسافة بين منسوب الماء ومركز التكهف في منطقة الجهد العالي والجهد الواطئ.

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1.Introduction

Hydraulic structures are a specific type of engineering structures designed and executed in such a way in order to utilize it to control natural water or save industrial sources to ensure optimum use of water, one of these structures are sheet pile walls.

Hydraulic structures like retaining walls are frequently build upon non porous rock soil or porous soil. As a result of building the sheet piles on porous soil, and forming a difference in water levels between the upstream and downstream across the sheet pile wall the water seeping or filtering through the porous soil under the sheet pile walls. The flow of the seepage below the hydraulic structures can be considered as a steady confined flow **[Harr 1962]** .

There are many reports about seepage under sheet pile wall around the world **(Kozlov,(1939), Terzaghi`s work,(1943)** , **Raymond and Vera, (1968) and Govinda and Siva, 1983)**. This shows the importance of research on seepage problem.

The piping cavities are formed due to water seepage through salt-containing soil (gypsum salts) ,these salts dissolve leaving cavities that weaken the soil of the hydraulic structures foundation. This phenomenon had not been yet studied or analyzed practically or theoretically.

Flow ingress to cavity is very complex and has been reported by various investigators (**Polubarinova-Kochina, (1962), Goodman ,(1965) and Fujii et al.,(1990)).**

Based on (Goodman' equation) ,the quantity flow ingress to cavity decreases with decreasing diameter of the cavity and minimum quantity of flow in cavity located in middle depth ,so the quantity of seepage under sheet pile wall increases.

Analyze the seepage process by using a limited laboratory data to get a new formula, this formula to compute the quantity of the seepage in soil with cavity.

2. Experimental work

In this experimental study, the problem was treated as Two-Dimensional. This is due to the fact that the cavities are arranged in the form of Plain-Strain Condition.**Figure 1** shows a photographic view of the steel box (laboratory model) with inside dimensions of (100 mm) in width, (700 mm) in length and (500 mm) in height. It consists of three compartments, the middle one is used for the preparation of the bed of soil while the outside compartments are used as reservoirs for upstream and downstream levels. The dimensions of the middle compartment is of (500mm) in length, (500mm) in height and (100 mm) in width. This compartment is made of three plates welded to each other with one side portable in the longitudinal direction. The two transverse sides (in the width direction) contain holes at different levels (filter screens with opening10 mm) in order to allow for the flow of water through the soil. The two outside compartments are (100mm) in length, (500mm) in height and (100mm) in width. The water level was controlled by the vertical holes which are located at various levels in the transverse side of the two outer compartment.

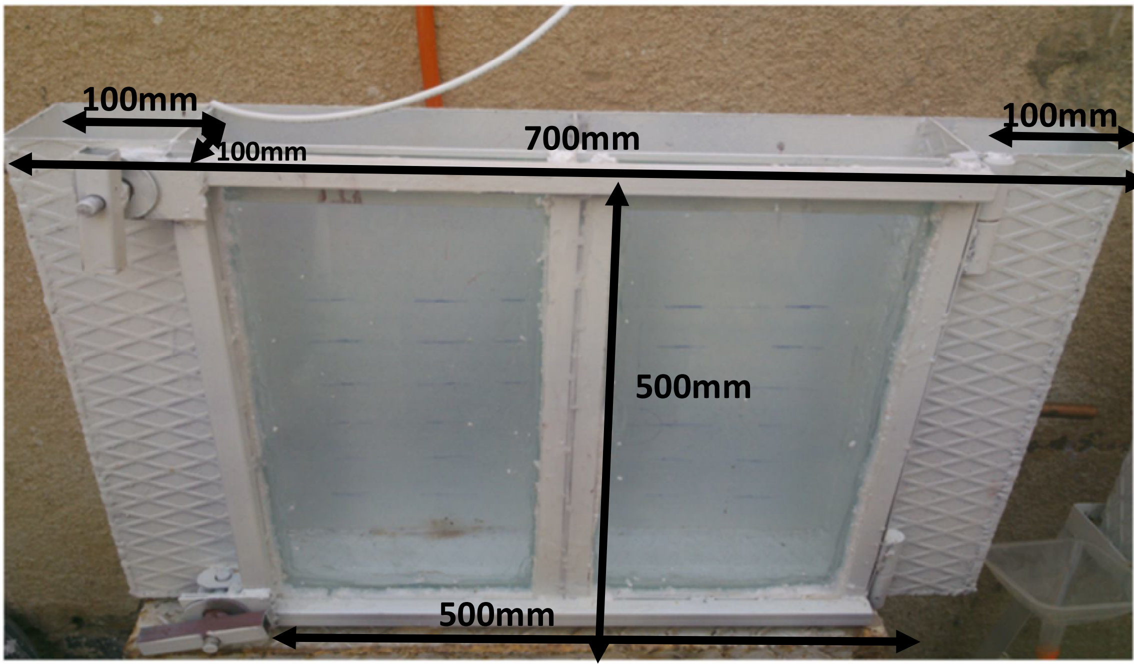

Fig.1 Steel Box Model

3. Cavity and Sheet Pile Wall Models

The cavities were prepared by placing a pipe of (P.V.C) after perforating holes at 2mm in their bodies to allow the flow seep through. Three different diameters have been used to represents the diameter size of cavity are D=75mm, 50mm and 30mm and have the same length T=100mm. The cavities models are show in **Figure 2**.

Rectangular steel sheet pile wall model was manufactured with width 100mm, height 350mm and thickness 2mm as shown in **Figure 3**, the embedded length within a soil was L=150mm. It should be mentioned here that the dimensions of sheet pile wall model with the embedment portion within soil domain were fixed for all test undertaken.

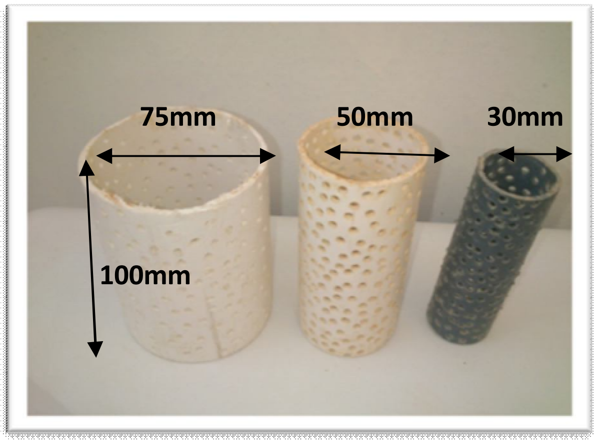

Fig.2 Cavities

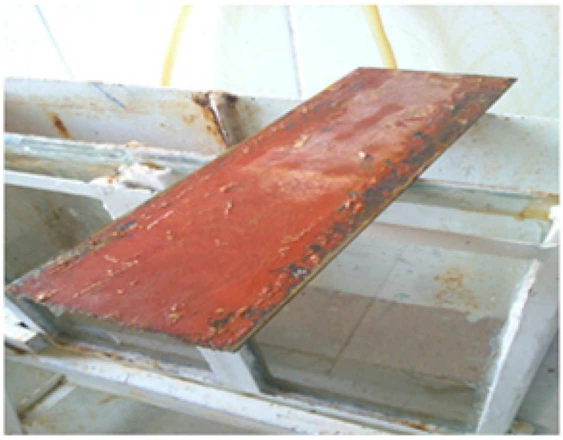

Fig.3 The used Sheet Pile Wall

4.Soil Used

The experimental soil sample was taken from AL-Nasser region of AL-Najaf City from 3.5m underground surface. According the laboratory results of sieve analysis and unified soil classification system, the soil is classified as poorly graded sand (Sp) with a coefficient of uniformity (Cu=3.3) and a coefficient of curvature (Cc=1.2).

5. Model Testing

The difference in water levels between each side of sheet pile are kept constant .The seepage takes place around the sheet pile wall, through soil and cavity. The water in upstream zone was maintained at a constant level by using a continuous supply of water from the top of the upstream reservoir. The outwardness water from downstream is collected in a jar to

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measure the quantity of seepage with time. The test is stopped when flow become steady (the volume of water still constant with time).

6. Dimensional analysis

In the study, there are seven (n=7) variables as shown in **Table 1** having an effect on a discharge as a fallowing functional relationship:-

q (act.)=f(X , Y (u.) , Y (d.) , ρ , D , k)………………..…………eq.(1)

Where:
X= The horizontal distance between center line of the sheet pile wall and center of the cavity in upstream(positive)side and downstream(negative) side,
Yu.= The vertical distance between water level and center of the cavity in upstream zone side,
Yd.= The vertical distance between the water level and center of the cavity in downstream zone,
D= Diameter of the cavity,
ρ= Density of the water,
k = Hydraulic conductivity.

O= f { q(act.) , X , Y(u.) , Y(d.) , D , ρ , k })…………………eq.(2)

According to Buckingham's theorem, the number of dimensionless groups is (n-m=4), where n is a number of variables and m, the number of dimensions, thus:-

Chosen the common variables (ρ , k , D) as repeating variables in each term , so :-

f (π_1 , π_2 , π_3 , π_4) = 0 ………..……………………..……………eq.(3)

Where: $\pi 1 = \rho^{a1} . k^{b1} . D^{c1}$. q(act.)
$\pi_2 = \rho^{a2} . k^{b2} . D^{c2}$. X
$\pi_3 = \rho^{a3} . k^{b3} . D^{c3}$. Y(u.)
$\pi_4 = \rho^{a4} . k^{b4} . D^{c4}$. Y(d.)

And the same way for all retains parameter.
Taking each term and evaluating:

$\pi_1 = \rho^{a1} v^{b1} D^{c1}$ qact.
$\therefore \pi_1$ = q(act.)/(k.D)

By the same way:

π_2= X/D , π_3= Y_u /D , π_4= Y_d /D

The functional relationship which describes scour depth normalized with pier diameter may be written as:

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$q(act.)/(k.D) = f(\ X/D\ ,Y(u.)/D, Y(d.)/D\ )$………………eq.(4)

7. Analysis and discussion of results

Estimating of seepage quantity is an important step in the design of hydraulic structure. To examine such a phenomenon, sets of experiments are performed.

As mentioned in dimensional analysis technique, there are several parameters which may control the seepage quantity.

7.1 Cavity Location

The location of cavity in vertical and horizontal direction has a direct influence on the quantity ratio, steady time and shape flow line, that is, the larger quantity ratio can be observed in middle depth of the cavity in both zones for example at diameter of the cavity 75mm, the maximum quantity of the seepage at Yu./D = 4 and Yd/D =2 as seen in **Figure 4** and the same behavior in other size. This is due to the ingress f low to cavity decreases and that agreement with Goodman' solution. Also, the steady time and shape flow line variation with various location of the cavity as seen in **Figure 5 and 6.**

7.2Cavity Size

Not only the location of the cavity has effect on seepage flow but also the diameter of the cavity for example for cavities at horizontal distance between center sheet pile wall and cavity 95.83mm as shown in **Figure 7 and 8**. The quantity ratio and steady time decrease with increasing diameter of the cavity and the maximum quantity ratio for all model tests at (Yu.=300mm,Yd.=150mm) and that agreement with Goodman' equation.

The diameter of the cavity has effect on shape and number of flow line as seen in **Figure 9** in upstream zone and the same behavior in downstream zone**.** Start time of the seepage flow under sheet pile wall variation with various location and diameter of the cavity in both zones.

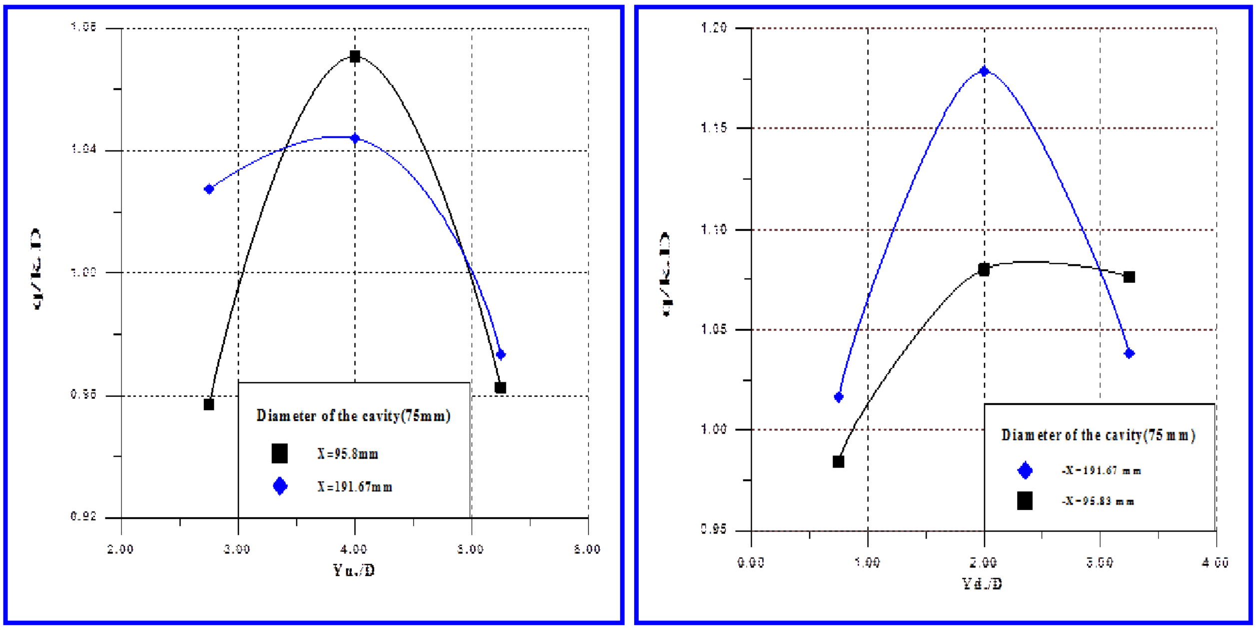

Fig. 4 Effect the Location of the Cavity on Quantity Ratio at Diameter of the Cavity 75mm.

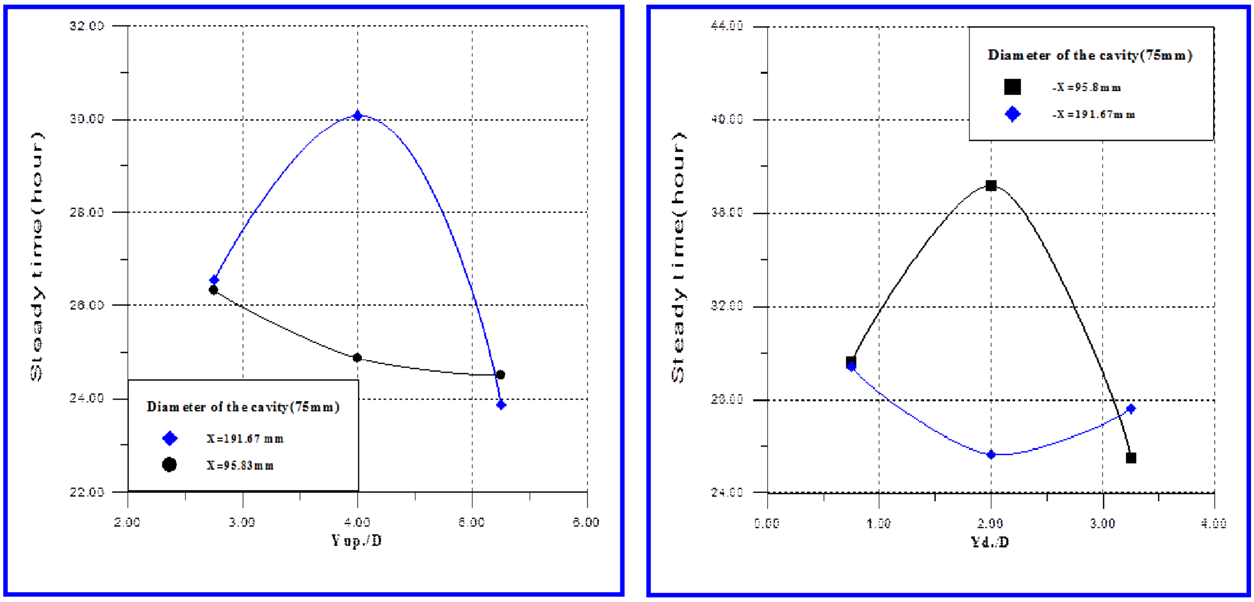

Fig.5 Effect Location of the Cavity on Steady Time for Various Depth Ratio at Diameter of the Cavity 75mm.

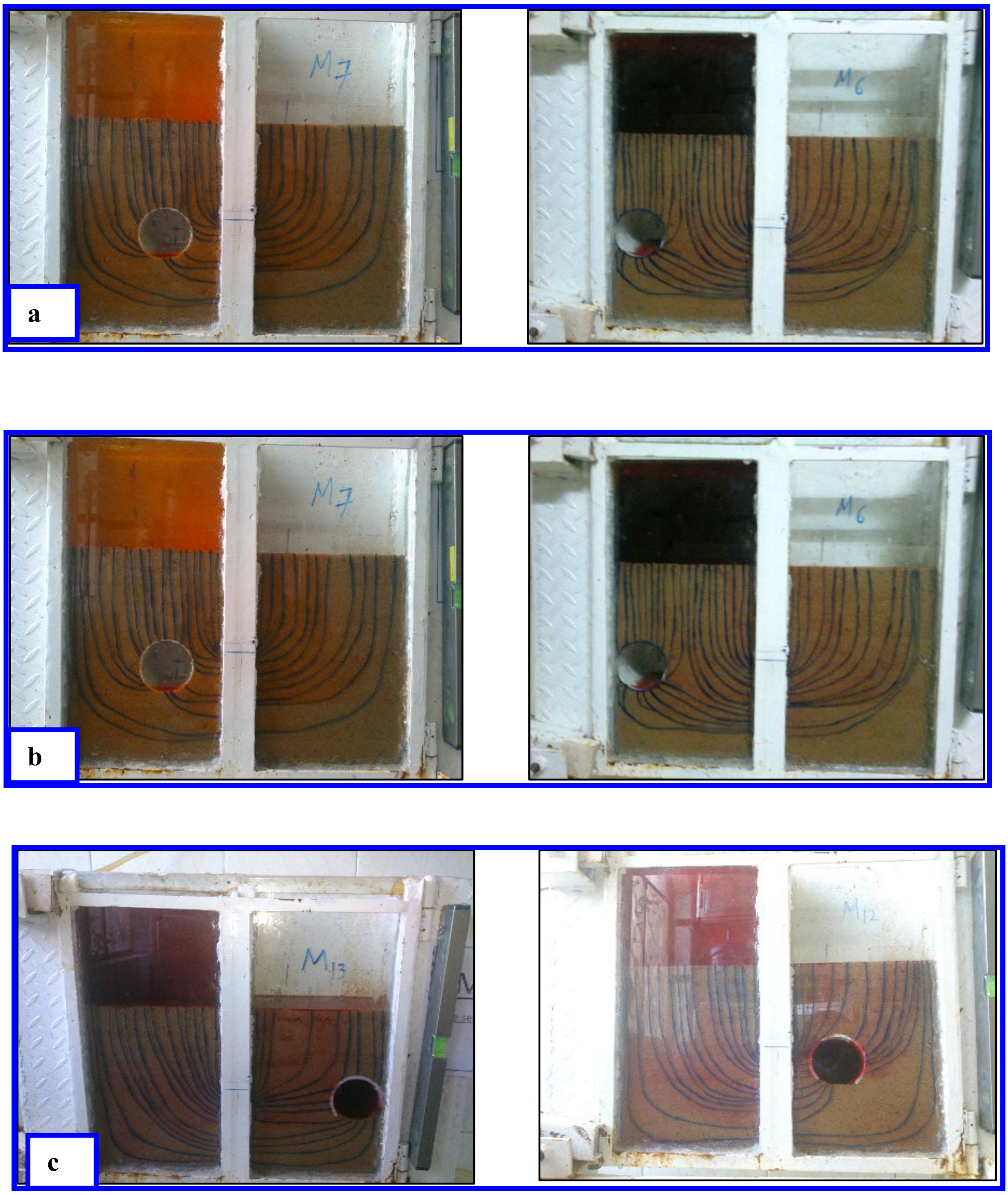

Fig.6 Effect Location of the Cavity on Shape Flow Line in Both Zones at Diameter of the Cavity 75mm. (a)D=75mm, Yu./D=300, (b)D=75mm, Yd./D=150, (c).D=30mm, Yu./D=300

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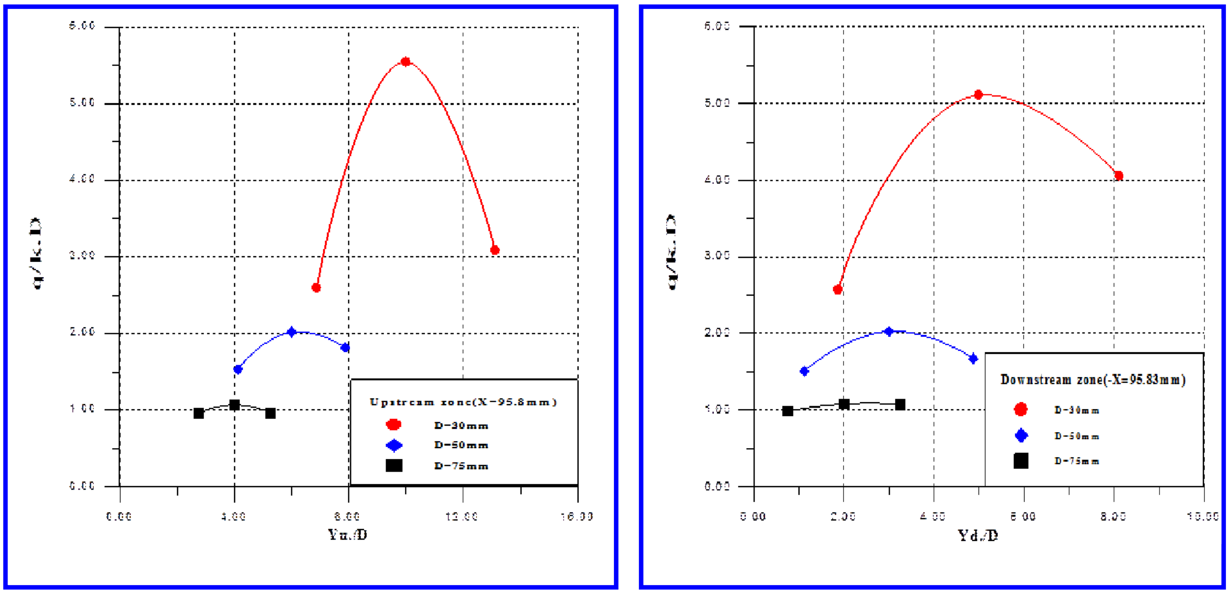

Fig. 7 Effect Size of the Cavity on Quantity of Seepage at Horizontal Distance 95.83mm.

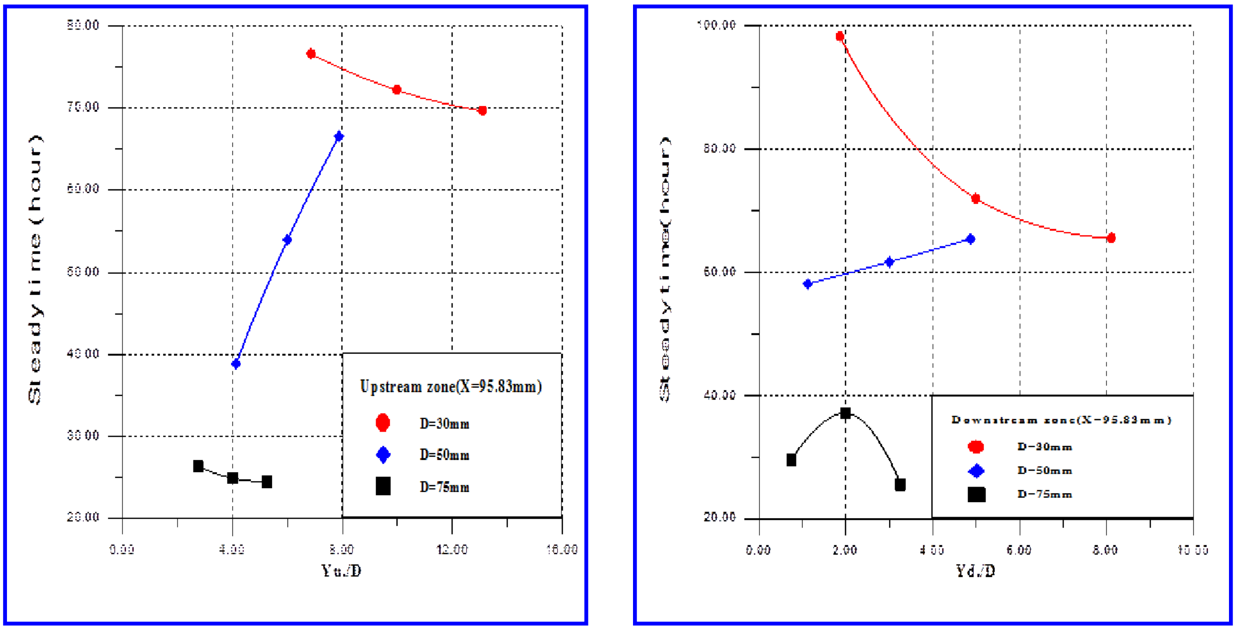

Fig. 8 Effect Size of the Cavity on Steady Time at Horizontal Distance 95.83mm.

Fig.9 Effect Size of the Cavity on Shape of Flow line in Upstream Zone. (a)D=75mm, Yu./D=300, (b)D=50mm, Yu./D=300, (C)D=30mm, Yu./D=300.

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7.3 Development of a New Formula

The seepage flow was a function of some variables, which were discussed previously. The non-dimensional formula was presented:

$q(act.)/(k.D) = f(\ X/D\ , Y(u.)/D, Y(d.)/D\ )$

The computer package (STATISTICA) was used to make analysis for the equation through a nonlinear regression analysis.

$$q/_{k.D} = c \times \left\{ \left(X/_D\right)^{c_1} \times \left(Yu./_D\right)^{c_2} \times \left(Yd./_D\right)^{c_3} \right\}$$

$c = 0.061$ $\quad c_1 = 0.0014$ $\quad c_2 = 2.455$

$c_3 = -0.995$

$R^2 = 0.86$

So, the equation becomes:

$$\left\{q/_{k.D}\right\} = 0.061 \times \left\{ \left(X/_D\right)^{0.0014} \times \left(Yu./_D\right)^{2.455} \times \left(Yd./_D\right)^{-0.995} \right\} \text{...........eq.(5)}$$

The coefficient of determination (R^2) for this formula is (0.86).

8. Conclusions

Under the limitations imposed on this investigation the following conclusions can be drawn.

1. In upstream zone, the maximum danger influence on seepage quantity are noted when the cavity located at Yu.=300mm and increase with decreasing the horizontal distance between the cavity and sheet pile wall, but minimum danger influence can be observed with cavity located at (X=95.83 and Y=56.25mm).

2. For diameter of cavity 75mm at depth ratio (Yu./D=4), the quantity ratio increases with the cavity horizontal location X decreases, but this pattern is reversed for depth ratio (Yu./D=2.75 and 5.25) and the same behavior for other diameters.

3. For cavity located at X=191.67mm in upstream zone, the slight effect of Yu. on the seepage quantity ratio when its diameter greater than 30mm.

4. In downstream zone, the maximum disadvantage influence on increase the seepage quantity are noted when the cavity is located at Yd.=150mm. the value of seepage increases with increasing cavity horizontal location and minimum seepage quantity for cavity located at (X=95.83mm and Yd.=56.25mm).

5. For diameter of cavity 75mm at depth ratio (Yd./D=2 and 0.75), the quantity ratio increases with the cavity horizontal location X increases, but this pattern is reversed for depth ratio (Yd./D=3.25) and the same behavior for other diameters.

6. If the cavity located at X=95.83mm in downstream zone, the slight effect of Yu. on the seepage quantity ratio when its diameter greater than 30mm.

7. The cavity located in shallow depth in soil sample Y=56.25, has higher influence on quantity seepage in upstream zone than those in downstream zone.

8. When the cavities are located in middle depth of the soil sample at150mm, the danger influence of the cavity on seepage quantity increases due to increase the horizontal ratio X/D in downstream zone, but this behavior inversed in upstream zone.

9. For deep cavity, the effect horizontal ratio on seepage quantity is little in both sides of the sheet pile wall.

10. Low values of the quantity seepage can be noted when the cavity diameter is small and becomes high with increasing cavity diameter.

11. The amount of seepage for soil without cavity is lower than those of the soil with cavity.

12. The steady time and start time of seepage are varied with various locations of the cavity in both side of the sheet pile wall.

13. The steady time increase with decreasing diameter of cavity.

14. The shapes of the flow line depend upon location and diameter of the cavity. The maximum number of the flow line for cavity located at depth 150mm under ground level in both sides of the sheet pile wall. The levels of the water into cavities are high in downstream zone and become low for cavities in upstream zone.

15. When the diameter of the cavity increases, the number of the input flow line to cavity increases, but the number of output flow line from cavity decreases.

16. The results obtained from experimental study are compared with analytical' solution (Goodman' equation) and (Slide V5.0) program and a good agreement has been found between them.

17. The empirical formula (5) to estimate the quantity of the seepage can be used in situ.

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List of Symbols

q (act.) quantity of seepage under sheet pile wall
D Diameter of the cavity
T Length of the cavity
X The horizontal distance between center line of the sheet pile wall and center of the cavity
Yu The vertical distance between water level and center of the cavity in upstream zone side
ρ Water density
k Hydraulic conductivity
Cu Uniformity Coefficient
Cc Coefficient of gradation
L The embedded length of sheet pile wall within a soil
G The high of the sheet pile wall above ground level
Ts Height of the homogenous sample
W Width of bed sill
H Hydraulic head
h_1 or h_2 The height of the water level above the bottom of the two outer compartments of steel container