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## **DEVELOPMENT EQUATION FOR DETERMINATION THE START TIME OF SEEPAGE UNDER HYDRAULIC STRUCTURE RESTING ON SOIL CONTAINING A CAVITY**

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### **Abstract:**

*This study aims to introduce a formula for determination the start time of seepage when single cavity presence at a specific location within the homogenous soil under a hydraulic structure. The investigation aims to observe the effect of cavity locations and size on the start time of seepage. The experimental work has been done in three stages, the first stage includes 36 models of 75mm in diameter cavity, while the second and the third stages includes eight models for each with 100mm and 34mm diameter of cavity respectively. The analysis of result shows that, generally, the effect of cavity was positive in term of increasing the time of starting the seepage. To generate the deterministic formula the SPSS statistical software was used and the results of multiple regressions are checked by statistical indices. By this process more realistic formula has been proposed with acceptable reliability.*

**Keywords:** Start Time; Seepage; Cavity; Homogenous Soil; Deterministic Formulae.

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### **1. Introduction**

In the case of the construction of hydraulic structures on soils containing high gypsum content, it is probable that gypsum at several locations will be dissolved by water action as a result of water leakage through the gypsum layers. The presence of these cavities when it created below the hydraulic structures has direct impact on the behavior of the seepage and a start time of seepage. Accordingly, it is important to study this effect and investigate its negative and positive aspects. [1] was developed the empirical formula for calculating the amount of seepage under a sheet pile wall with presence of cavity based on the results of the 33 experimental models [2] studied by the experimental work the impact of presence of cavity on the stability of dam during water flow. The results identified the best location of sheet pile in the case of presence the cavity at different locations.

## 2. Experimental Work

Figure (1) illustrate the components and dimensions of the seepage tank that used in the experimental work. The testing tank model was manufactured from acrylic of 10mm thickness. The dam and sheet pile models are also manufactured from the same material. The dimensions of the width, height and length of model of the dam are 200mm, 250mm and 620mm respectively. These dimensions have been selected to be firstly in consistent with the size of the undertaken tank and secondly based on the context that followed by the previous researches for the similar works (e.g., [3], [4] and [5]) Where, at the mentioned works the ratio of the length of structure to the length of the test tank was equal to 53%, 20% and 25% respectively. Two sheet pile wall (cut off) are used at the upstream and the downstream up to depth 200 mm under the base of the dam model. The reason of their adoption is to prevent the boiling, where it occurrence without presence of cutoff is inevitable due to rapid and easy of flow to seep within the adjacent layer of the dam base, which certainly leads to occurrence of the piping phenomenon. Thus the used of cutoff is essential. All experiments were performed under a constant head,  $H = 150$  mm. Fig. (2) Shows a photographic view of the model used in this study.

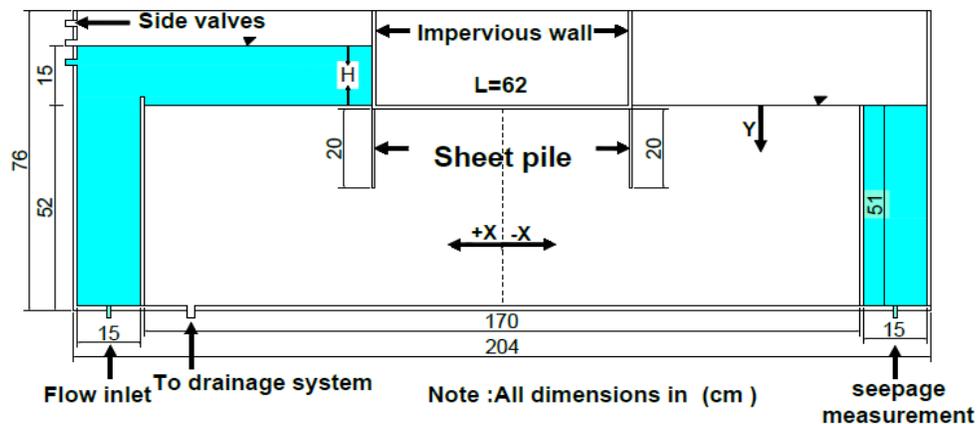


Figure 1: The components and dimensions of model



Figure 2: Shows a photographic view of the model used in this study

### 2.1. Cavities Model and Soil Used

The cavity feature used in the work is a piece at 200 mm length of PVC, the surface is punctured by 1.5 mm drill at random positions to allow the flow seepage through it and then well covered with a semi permeable lid to prevent the movement of sand particles inside. Three diameter pipes were used as a feature of cavities with a diameter of 34, 75 and 100 mm are placed to extend across the width of the tank model. Granular material passing from the sieve No.14 and retained on the sieve No.200 was used, with  $d_{50}$  equal to 0.4 mm. The constant head permeable test was performed and the result of coefficient of permeability ( $k$ ) was equal to  $8.07 \times 10^{-4}$  m/sec.

### 3. Description of Testing Procedure

Work has been done at three stages, the first stage includes 36 models with using the cavity of 75mm in diameter. The second and third stage involves eight models for each stage with a cavity of diameter 100 mm and 34mm respectively. Figs. (3), (4) and (5) illustrate the location of cavity at first, second and third stage respectively. It worth mention here, the first run was conducted at "without cavity" model, where the results of this test be certified as a data base for comparison purposes.

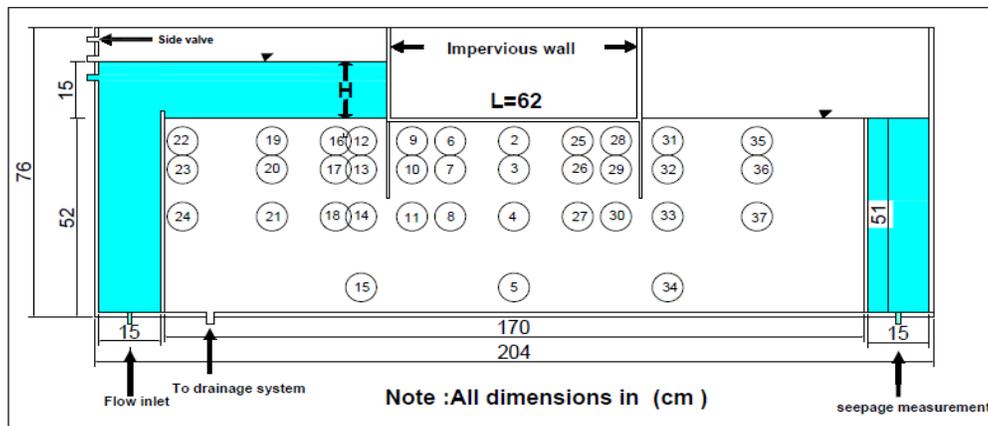


Figure 3: Locations of cavity in 75 mm diameter at the first stage

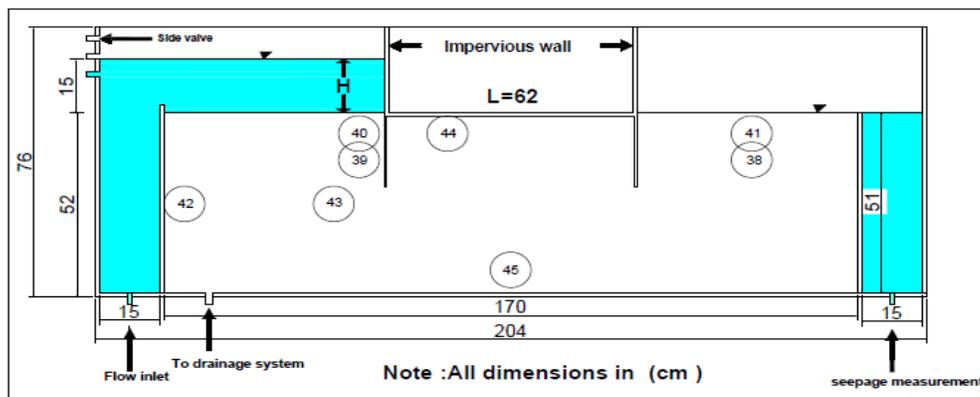


Figure 4: Locations of cavity in 100 mm diameter at the second stage

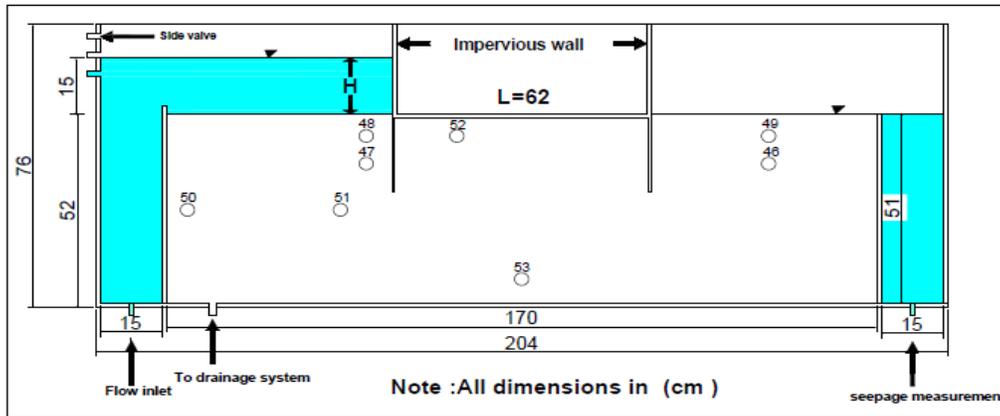


Figure 5: Locations of cavity in 34 mm diameter at the third stage

#### 4. Deterministic Equation

Multiple nonlinear regression models were developed by using (SPSS statistical program V.24) to simulate the experimental results. The results of 37 models were used to create equation. The results of the other 15 models were used for verification. The data for verification is randomly selected from the ranges of the experiments data to cover all domains of the boundary conditions. To create a deterministic equation for determination of the start time of seepage with presence of a cavity, it should be identify the dependent and independent variables in the form of dimensionless parameters. Consequently, the results obtained from the experimental work were recorded in dimensionless form by dividing the discharge on the cavity of diameter (D) and soil permeability (k) a selection was made for the dependent and independent variables used to create this deterministic equation by the following functional relationship;

$$\frac{t}{t_0} = f\left(\frac{q}{kD}\right) \tag{1}$$

Different deterministic models have been tested by statistical analysis and the process is rested to the following model;

$$Y = C \times X^{C_1} \tag{2}$$

The result of multiple regression shows that;

$$C = 0.3062 \text{ and } C_1 = - 0.5082$$

Therefore, the start time of seepage can be given by the following equation;

$$Y = 0.3062 X^{-0.5082} \tag{3-a}$$

It leads to;

$$\frac{t}{t_0} = 0.3062 \left(\frac{q}{kD}\right)^{-0.5082} \tag{3-b}$$

Five statistical indices used to check the reliability of the proposed formulae these indices are; the coefficient of determination  $R^2$ , mean bias error (MBE), root mean square error (RMSE), Nash Sutcliffe Efficiency Coefficient (NSEC) and the percent bias (PBIAS). The statistical indicators of model (3-b) are;  $R^2=0.89$ ,  $RMSE=0.2402$ ,  $MBE=0.003256$ ,  $PBIAS=0.24644$  and  $NSEC=0.9697$ . The PIAS indicator indicates a tendency of model is nearly perfect. The other indicators is reliable where the value of these indicators within the range of acceptable performance [6]. Figure (6), shows the predicted start time of seepage by using Eq.4-b and comparing the results with the measured data points. In Fig. (7), the verification of the deterministic model is illustrated with the remaining fifteen points of the measured data. The statistical indicators of the verification process are;  $R^2=0.95$ ,  $RMSE=.01703$ ,  $MBE=0.00023$ ,  $PBIAS=0.01804$  and  $NSEC=0.9816$ . Depending on the above indicators the deterministic model of Eq.3-b can be adopted with acceptable reliability.

## 5. Results and Discussions

For the base model (without cavity), the start time of seepage was after 91 minutes. This time is recorded from the beginning of flow through porous media at the upstream up to starting the water to downfalls in the graduated cylinder at the downstream side. The same procedure was performed to measure the start time of seepage for the rest of the experiments to identify the effect of the location of the cavity on the start time of seepage compared with the values of the base test. The percentages of the variation for the first stage are listed in Table (1) as resulted by applicable the following form;

$$\% \Delta t = \left[ \frac{t - t_0}{t_0} \right] \times 100 \quad (4)$$

Where,  $\% \Delta t$  is the percentage of reducing or increasing the start time of seepage with presence of the cavity less than or greater than the start time of seepage "without cavity test". The "+" sign refers to increase and vice versa. The "t" is the start time of seepage which recorded with the presence of a cavity, and the " $t_0$ " considered the base quantity of the start time of seepage. As listed in Table (1) the results show that the effect of cavity at first stage was generally positive on the start time of seepage as compared with the time of the base model. Accordingly, the presence of cavity at any location under the apron of structure leads to delay the starting time of seepage. The only case that has diverged from this base is when the cavity was at  $X/L=-0.95$  and  $Y/L=0.2$ , where the start time of seepage decreased about 5.5% in comparison with the base test. The great influence was when the cavity located at  $X/L=0.4$  and  $0.6$  with all depths undertaken, where at which the higher start times were recorded. These times ranged between 104.4% and 217.6% the time registered at base model. The best location within this context is at  $X/L=0.6$  and  $Y/L=0.2$ , where at which the higher delay in the start time of seepage was achieved. Depending on the start time of seepage the lowest time recorded in the first stage was 86 minutes when a cavity was located at the location  $X/L=-0.95$ ,  $Y/L=0.2$ , at this location a slight effect on the start time of seepage from changing of cavity size was observed, where the time recorded was 91 and 82 minute when the large " $D=100\text{mm}$ " and the small " $D=34\text{mm}$ " cavity presence respectively. However, this trend is not constant at all locations of cavity. where at the best location in the first stage according to seepage start time at  $X/L=0.6$ ,  $Y/L=0.2$ , changing the diameter of the cavity from 75 mm to 34 mm or 100 mm led to sharp decrease in the start time of seepage. This decrease was greater in the case of presence a small cavity at the same location, where with small cavity the start time of seepage decreased about 71% in comparison with intermediate size of cavity while with

large cavity the start time of seepage decreased about 65%. Therefore, it can be concluded that, the size of cavity has a direct effect on the start time of seepage, but, this effect depends basically on the location of the cavity. On the other hand a direct correlation between the start time of seepage and the seepage quantity has been registered, where the delay of the former leads to decrease the amount of the later.

Table 1: Start time of seepage (D=75mm)

X/L	Y/L=0.08	Y/L=0.2	Y/L=0.4	Y/L=0.7
0	+16.4	+37.3	+64.8	+6.6
0.25	+34	+24.2	+93.4	---
0.4	+137	+121	+104.4	---
0.6	+135.1	+217.6	+127.5	+116.5
0.7	+77	+56	+51.6	---
0.95	+20.8	+30.8	+35.2	---
1.3	+26.4	+24.2	+4.4	---
-0.25	+24.2	+27.5	+20.9	---
-0.4	+2.2	+22	+45.5	---
-0.6	0	+33	+14.3	+13.2
-0.95	+5.5	-5.5	+3.3	---

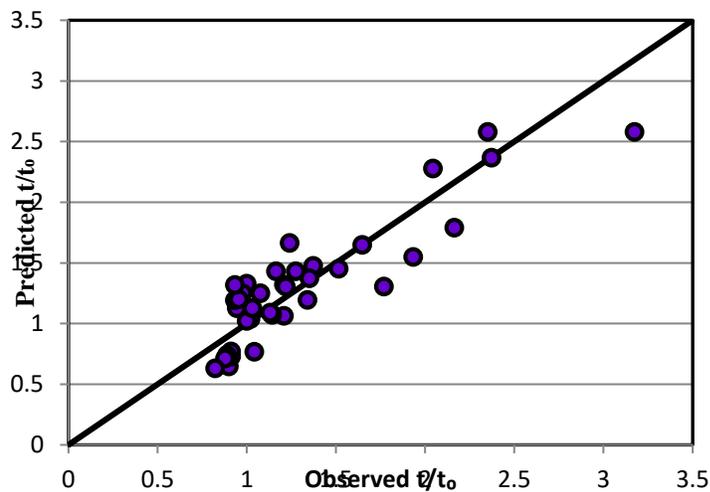


Figure 6: Correlation between observed and predicted  $t/t_0$

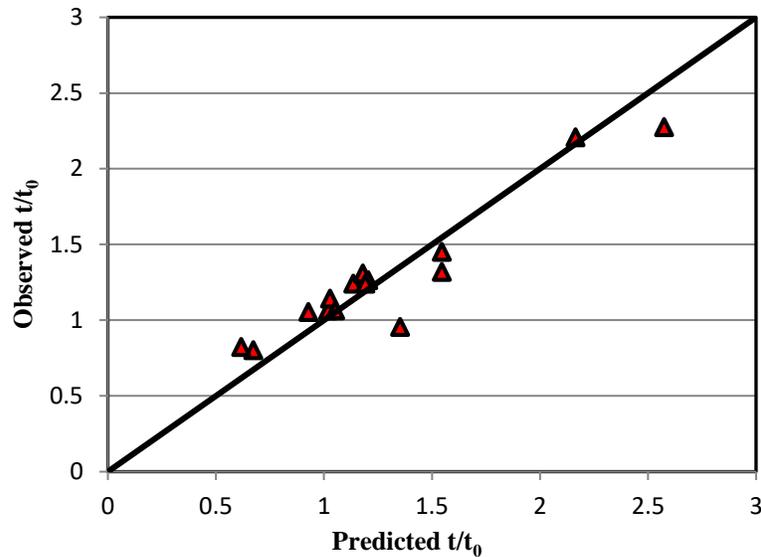


Figure 7: Verification of Eq.4-b

## 6. Conclusions

the effect of cavity at first stage was generally positive on the start time of seepage as compared with the time of the base model where the time of seepage start delayed when a single cavity presence at different locations under hydraulic structure except one location at  $X/L=-0.95$ ,  $Y/L=0.2$  where at this location the seepage flow start early by 5.5% in comparison with the base test. However, the largest delayed in the start time of seepage was recorded when cavity located at  $X/L=0.6$ ,  $Y/L=0.2$  where at this location the seepage flow start delayed by 217.6% in comparison with the base test. Finally, Equation 3-b can be used to predict the start time of seepage.

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