Research Article

Effect of Presence of Single Cavity Upstream Side of Sheet Pile Wall on Steady Time and Quantity of Seepage

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When the sheet pile is used as the reservoir wall or retains the action of saturated fills and cuts for construction works, it will be certain that the seepage occurs from the back side (retained side) to the working place (opposite side). Often, the rate of seepage and its quantity in homogenous strata depends mainly on the permeability of soil. However, the presence of cavity certainly has a direct impact on trend, steady time, and the quantity of seepage. The present study considered a preliminary attempt to measure this impact through physical model. Eighteen model tests are conducted to study the effect of different locations and diameters (size) of single cavity on the seepage problem when it is presented at upstream side (back side) of the sheet pile wall. Period of completion every model test ranged from four to seven days. The start time of seepage when the water began to flow from the downstream side (working place) ranged between 13min and 26min, which depended on the location of cavity and its size. However, the results show that the quantities of seepage generally increase with the smallest size of a cavity and with the farthest horizontal distance from the sheet pile. The maximum quantity has been recorded when the cavity is located at the same level of sheet pile end.

1. Introduction

Sheet piles are interlocking walls which are designed to resist horizontal forces as they are embedded in soils. They are also used as retaining systems. The interaction between soil and percolating water enters into several groups of problems in earth work engineering one group involves the estimate of the quantity of water that will enter a pit during construction. Hydraulic structures, like retaining walls, are frequently installed into porous soil. As a result due to porosity and a difference in water levels between the upstream and downstream the water seeps under the sheet pile walls. The flow of the seepage accordingly can be considered as a steady confined flow [1].

AL-Najaf City at the middle of Iraq is founded over different types of fluvial sediments, sabakha, sand dunes, sand sheet, gypsum sediments, and sedimentary rocks [2]. In Al-Najaf soil, the gypsum is within the sedimentary deposits. In general, the gypsum is found in the form of crystal in

the surface layer or crusts or recrystallized from evaporated ground water. Many existing gypsum are located in Al-Najaf soil and, with continuous ground water movement, the gypsum dissolves and generates many cavities of different shapes at various locations below ground surface [3]. In gypsum soil the piping occurs due to chemical action by dissolving salt (gypsum salt) with seeping water and then leaving a cavity. This phenomenon had not been yet studied or analyzed practically or theoretically with presence of sheet pile wall.

Up to date, many investigations have been conducted to study the nature of water flowing underground; various theories and investigations were put forward to predict seepage phenomenon and still a number of experiments are in progress to make the engineering structures safe. The available works and studies concerning the problem of seepage under sheet piles are limited to soils without cavities. Kozlov (1939) (cited by [4]) analyzed the problem of flow toward a sheet pile coffer dam in a homogeneous soil in the

case where the bed rock was infinitely deep. Govinda and Siva (1983) (cited by [5]) utilized the coordinate transformation and subsequent use of virgin's solution to develop the flow field around a vertical sheet pile embedded in homogenous isotropic porous media of infinite depth. Ghaly et al. [6] studied the behavior of model single-pitch screw anchor sheet pile when installed into dense sand subjected to upward seepage flow and modified the experimental setup to allow preparation of submerged sand and to provide upward seepage flow at a constant rate. Al-Kubaisy [7] studied the effect of soil nonlinearity and construction sequence on the behavior of sheet pile wall. The analyzing of the results was directed to use of alternative methods for estimating the local failure in the soil and the overall stability of wall-soil system. AL-Bakry [8] studied the seepage through/ underneath hydraulic structures by adoption various structures equipped with sheet pile. The finite volume method was employed for analysis. Sakai and Maeda [9] focused on the evolution effect of air bubbles in pore water on seepage failure and performed model test sheet pile embedded in box soil. Aziz and Jawad [10] studied the method for estimating the quantity of seepage under sheet pile wall empirically. The aim is to find the influence of seepage on the stability and durability of the sheet pile.

Close to the subject of this study, there are some studies that have been interested in the impact of tunnel presence on the seepage problem. Polubarinova and Kochina (1962) (cited by [11]) derived an approximate expression for estimation the discharge for horizontal tunnel in a fully saturated, homogeneous medium. Goodman (1965) (cited by [12]) considered the tunnel lying beneath a lake or large river. The author considered the lake or river to be an infinite source of water; the equation was derived accordingly for calculating the seepage quantity with steady state inflow along the length of the tunnel. Fujii and Kacimov [13] adopted some proposed methods available in literature for analyzing the seepage into horizontal drains and axisymmetric flow into cavities. The case of empty drain under ponded soil surface is studied and existence of drain providing minimal seepage rate with an optimal depth of drains is presented. Lei [11] derived an analytical expression for hydraulic head, the stream function, and the inflow rate of the two-dimensional, steady ground water flow near a horizontal tunnel. The studied case is a tunnel present in a fully saturated, homogeneous, and isotropic and a constant hydraulic head condition achieved around its perimeter. Farhadian et al. [14] investigated the validity of analytical equations in computing a groundwater seepage discharge into tunnels in different values of R/H (tunnel radius/water table height above tunnel); using optimization by regression analysis the optimization had been performed on analytical equations. Recently, Maatooq et al. [15] performed an experimental study of the interaction between cavity and adjacent sheet pile in a sandy soil. The study derived a formula could be used to predict the quantity of seepage in terms of spacing between the sheet pile wall and center of the cavity at the upstream and the downstream zones and the spacing between water level and the center of the cavity at both zones.

It could be concluded from the above related state of arts, solely those conducted by Aziz [3] and Maatooq et al. [15],

no research was specifically close to the impact of the cavity when it was present within the influence of a flow lines on the behavior of seepage.

2. Model and Procedure

The soil sample was taken from AL-Nasser district of AL-Najaf City from 3.5m under the ground surface where the gypsum soil is a dominant type of this district. According to the laboratory tests which have been conducted on specimen of this soil, it could be classified as a poorly graded sand (Sp) with a coefficient of uniformity ($C_u=3.3$) and a coefficient of curvature ($C_c=1.2$), natural water content 6.56%, natural wet density $\rho_w=1.643\text{mg/m}^3$, natural dry density $\rho_d=1.61\text{mg/m}^3$, the Specific Gravity $G_s=2.68$, and the hydraulic permeability k was found equal to 6.849×10^{-5} m/sec.

The testing model was manufactured from steel box with a glass face. The dimensions of its width, length, and height are 100mm, 700mm, and 500mm, respectively. The model consists of three compartments; the middle is used for soil-sheet pile wall domain and the outside compartments are used for water control level at the upstream and as accumulated reservoir at the downstream; Figure 1 shows the testing model with dimensions.

Rectangular steel sheet pile wall model was manufactured with width of 100mm, height of 350mm, and thickness of 2mm; the embedded length within a soil was $L=150\text{mm}$. It should be mentioned here that the dimensions of sheet pile wall model with the embedment portion within soil domain were fixed for all tests undertaken.

The cavities were prepared by placing a piece of PVC-Pipe after perforating holes at 2mm in their bodies to allow the flow to seep through them. Three different diameters have been used to represent the size of cavity which is $D=75\text{mm}$, 50mm, and 30mm at constant length $T=100\text{mm}$. The cavities models are shown in Figure 2.

In all the models tests, the soil samples are prepared by mixing dry soil with water of 67.5% from optimum moisture content and then spreading the soil inside the middle part of the container in six layers. Each layer is compacted to a unit weight equal to 88% from maximum dry unit weight in the laboratory. The thickness of each layer is (50mm). After the compaction of all six layers to be finished the height of specimen becomes 300mm.

The cavity and sheet pile wall are placed in the required position during compaction process; the compaction continues until the final height is achieved. Each run consisted of supplying a fixed water level at the reservoir side of the physical model to achieve a constant head of water $H=150\text{mm}$ and at the opposite side the resulting water due to seepage is accumulated by graduated cylinder. Two horizontal locations of cavity measured from sheet pile are selected $X=100\text{mm}$ and 200mm to show the effect of doubling the distance horizontally on the seepage criteria. Whereas in three vertical locations Yu has been selected the first one located at the same level of mid of embedment depth, the second location at the level of end of sheet pile, and the last location, $Yu=400\text{mm}$, is selected to be far from the end nearly

FIGURE 1: Testing model feature and dimensions: (a) front view; (b) top view.

FIGURE 2: Shape and size of PVC-Pipe used to represent a cavity.

two-thirds of the embedment depth. Figure 3 illustrates a schematic diagram of the physical model with the symbolic abbreviations undertaken.

Eighteen model tests are conducted to study the effect of locations and diameters (size) of cavity when it is located at upstream side of the sheet pile wall on seepage problem. It should be emphasized that all models tests were conducted at steady state flow condition. Period of completing the test of every model ranged from four to seven days.

3. Results and Discussion

The start time of seepage from downstream, the steady time of seepage and the quantity of seepage are the criteria of present study. The variation of these criteria demonstrates the effect of presence of cavity. Three parametric variables related to the influence of cavity have been tested which are the diameter, D (which representing the size of cavity), the horizontal distance of cavity from sheet pile (X), and the vertical distance of cavity measured from the water level of the reservoir (Y_u). These influencing parameters are illustrated in Figure 3.

Figure 4 shows the effect of cavity size on the start time of seepage; this figure also illustrates the effect of the horizontal distance location. This location has a direct and appreciable influence on the start time of seepage; it is noted that there is delay at the start time as the cavity located close to the sheet pile, but this relationship becomes counter with the larger size. Generally, through Figure 4 it is worth noting that the size of cavity has a direct and significant impact on the start time of seepage and this time increases with the increase of the diameter of cavity. The trend of curves and the differences in the start time can be attributed to the fact that the seepage lines when entering the cavity need several times to fill the space occupied, thereby delaying the start time of seepage at the downstream. This effect increases with increase of the size and as the cavity becomes closer to the sheet pile, because it is being located within the short path of seepage.

The same effect of horizontal distance turns also through Figure 5; this figure is focused on showing effect of the vertical distance (Y_u) of a cavity on the start time. As seen from curves there is no specific tendency, where the start time of seepage tends to decrease with increasing of the vertical distance of cavity up to the end of sheet pile and then re-increase with farthest distance which equal two-thirds of embedment depth below the pile end.

From Figures 4 and 5 it could be concluded that the highest influence of cavity on delay of the start time of seepage was when it was closer to the sheet pile and farthest from its end and with $D=50\text{mm}$.

The time at which the seepage becomes steady is also important parameter that should be specified in seepage problem; the shorter the time needed for steadiness, the more appropriate the domain for seepage. The presence of cavity has the advantageous effect on steady time of seepage and this positive effect increases with increasing of the size of cavity. This feature is well illustrated through Figure 6. However, the horizontal location of cavity does not significantly affect the steady time. The vertical coordinate of cavity location Y_u seems to have a clear and direct influence on the steady time.

FIGURE 8: Effect of size on quantity of seepage.

FIGURE 9: Effect of Yu on quantity of seepage.

be far enough from the short way of seepage line especially when it is located at the same level of the mid-distance of the embedment depth or further below the end of the sheet pile. Accordingly, the steady seepage was achieved before completion the fill of a cavity.

For each run the quantity of seepage was accumulated by a graduated cylinder as shown in Figure 3. The beginning of accumulation is started with start time of seepage from a downstream and ending at time when the steady seepage achieved. Certainly the advantageous index measure in practice is through registering less amounts of seepage. On the same context as previously mentioned the increase in size of the cavity leads to a positive effect as illustrated in Figure 8. The significance of the closest horizontal location of a cavity is clearly demonstrated in this figure. The effect of the vertical location is noted at Figure 9 where the higher state of quantity was recorded when the cavity is located at the same level of an embedment depth of the sheet pile (i.e., at Yu=300mm) and then dramatically decreases with farthest location. Also,

FIGURE 10: Comparison observed of kt/D with that predicted by (1)

it seems through the tendency of the curves that there is no specific context for the horizontal location impact on the seepage quantity when it participated in the effect of a vertical location.

The statistical software (STATISTICA-10) was used to analyze the data for deriving a functional relationship between a steady time as dependent variable and the vertical and horizontal coordinates of a cavity location as independent variables via multiregression with $R^2=0.603$. The resulting relationship is presented based on dimensionless parameters as follows:

$$\frac{kt}{D} = 51.1069 \left(\frac{Y_u}{D} \right)^{0.7925} \left(\frac{X}{D} \right)^{0.2746} \quad (1)$$

The ordinate of Figure 10 shows the predicted values of kt/D based on (1), while the experimental data denoted as observed values are given at abscissa. Through the nature of the spread of points it could appropriately use (1) as a deterministic equation to find the steady time of seepage when it occurs with presence of single cavity at a specified location and size.

The same procedure has been used to process the experimental data statistically to derive a simple suitable deterministic equation by which the quantity of seepage can be determined. The following equation is formulated with $R^2=0.6011$.

$$\frac{q}{kD} = 0.4686 \left(\frac{Y_u}{D} \right)^{0.5904} \left(\frac{X}{D} \right)^{0.403} \quad (2)$$

Figure 11 shows the comparison between observed dimensionless parameter and predicted one when (2) is used for determination. The spreading manner of data points refers to that (2) at a reasonable reliability if it is used in practice.

4. Conclusion

With the limitations of this study the main conclusions can be drawn from the results that the cavity has a direct impact on seepage problem. The quantity of seepage, generally, increases with the smallest size of cavity and with the farthest

FIGURE 11: Comparison observed of q/kD with that predicted by (2).

horizontal distance from the sheet pile. It is noted that there is delay in the start time of seepage from the working site as the cavity is located close to the sheet pile, but this relationship becomes counter with the larger size. However, the start time of seepage tends to decrease with increasing the vertical distance of a cavity up to the end of sheet pile and then re-increase with farthest distance which is equal to two-thirds of the embedment depth below the pile end. Also the present study shows that the presence of a cavity has the advantageous effect on a steady time of seepage and this positive effect increases with increasing the size of cavity. The seepage was measured by a graduated cylinder to analyze the impact of a cavity on its quantity as an important step of the present study. Certainly the advantageous index measure in the practice is through recording less amounts of seepage at downstream. The results show that the increase in size, the closest cavity, and the farthest location vertically leads to a positive effect. Finally, two equations have been derived for determination of a steady time and the quantity of seepage.

Data Availability

The submitted manuscript is part of the M.Sc. thesis. The previously reported experimental data used to support this study are available at University of Kufa Thesis database. These prior studies (and datasets) are cited at relevant places within the references, Influence of Cavities on Seepage under Sheet Pile Wall for Hydraulic Structures.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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