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# THE OPTIMUM LOCATION OF CONCRETE SHEET PILES UNDER HYDRAULIC STRUCTURE AFFECTED THE SEEPAGE WATER PRESSURE USING ANSYS PROGRAM

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**Abstract**

The problem of water seeping through the earth dams or under concrete structure is regarded one of the main reasons of the structures' failure. This may be due to the failure in soil layer on which the hydraulic structure is constructed or due to the water pressure resulting from a difference in the level of the upstream and downstream. In previous studies have found that the use of concrete sheet piles under the dams is one of the effective solutions to control the seepage of water under structures, this study considers that control of this problem is by using sheet piles. The 2-D F.E. model ANYSIS Program, has been used to analyze the effect of the optimum location of concrete sheet piles affected on seepage water pressure underneath hydraulic structures, when the stability against seepage water pressure against piping were calculated in different cases. The results showed the water pressure reduce, when the sheet pile downstream is used at 60° and depth 6m.

**Keywords**: Anysis, Water Seeping, Sheet Piles, Water Pressure, Earth Dams.

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**Introduction**

Hydraulic structures are engineering structures, of which there are types, each according to the purpose and the desired benefit, usually used to reduce flow velocity, discharge measurement, flow control and maintain the design level of water. Therefore, the structures are constructed, according to engineering, geological, topographical studies, in addition to bearing the dam influence of water and other forces, including the self-weight of the structures, hydrostatic water pressure, the pressure of the current waves ... etc. One of the most important studies that considered the most interesting is that studying the causes of the failure in the base of hydraulic structures [1]. To avoid the problems in the design and to maintain the stability of structure, most of the dams in the world are constructed on a permeable soil. In addition, the difference in water levels between the upstream and downstream of the structures will cause a series of future problems that must be considered in the design. One of the important problems that must be taken into account is the problem of seepage of water either through the structure in the case of earth dams or through the soil under the concrete structure. Therefore, the materials of the concrete structures, stones or rocks, have to be selected correctly. Seepage, is usually defined as the flow of water through the soil under a hydraulic gradient, which expresses the pressure of seepage water, especially affecting the soil structure. It occurs when the soil thickness is not enough to resist the uplift pressure [4], resulting in the explosion of the floor and the occurrence of failure in the hydraulic structure.

The characteristics of the porous medium can be identified through water seepage. As the nature of sedimentary soil affected by the transfer and deposition of sediments that form horizontal layers, the hydraulic conductivity differs within the geological formation of the soil, and the characteristics are not similar in all directions. So they take the form of ellipse [1]. However, if the soil has a coefficient of permeability that depends on the velocity, it is called a homogeneous soil with variable properties where the permeability is not equal in all directions. Hence the flow is expressed by Laplace equation as follow:

$$k_x \frac{\partial^2 H}{\partial x^2} + k_y \frac{\partial^2 H}{\partial y^2} = 0 \qquad (1\text{-}1) \qquad \text{when} \quad k_x \neq k_y$$

The soil may have uniform properties and has the same coefficient of permeability at all points within the flow zone, in this case its properties are independent of the direction of velocity and called a homogeneous soil. The permeability characteristics of this type of soil in the direction of x-axis are equal to permeability characteristics the direction of y- axis and it is expressed by Laplace Equation [5]:

$$\frac{\partial^2 H}{\partial x^2} + \frac{\partial^2 H}{\partial y^2} = 0 \qquad (1\text{-}2) \qquad \text{when} \quad k_x = k_y$$

In order to ensure the safety of the structure against the failure by seepage water pressure and piping, protective measures that control the seepage are taken such as using the cutoff, sheet piles, filters and wells. These measures relieve the pressure, curtains of concrete [6]. In the past, clay walls or clay trenches were built underground to block the flow of groundwater. That was an affective low-cost method [7]. In general, sheet piles are made of different materials including; wood, concrete, steel, and aluminum [8]. So the research aimed studying the effect location of concrete sheet piles under hydraulic structure on seepage water pressure and exit gradient.Finding the best case to safety hydraulic structure against seepage water pressure and piping phenomenon.

## 2. Previous Studies on Seepage Analysis

When designing the hydraulic structures above the permeable soil, several problems are encountered. The most important problem is seepage under the foundations. In order to control the seepage, several methods were used such as sheet pile, protection works, inverted filter and pressure relief wells. As a result of the correlation of these problems in the design and analysis of hydraulic structures, various solutions have been developed to find the distribution of piezometric head under structures in various ways, including (laboratory an using advanced numerical analytical methods, computer programs ....etc) [1].

### 2.1 Numerical Studies

Numerical methods are characterized by giving high accuracy results compared to analytical solutions. It is characterized by the ease of boundary conditions for complicated situations in addition to the development of electronic computer science. Numerical methods are divided into several parts, such as the finite difference method, which is considered to be one of the oldest ways of analyzing the problems of flow in the porous medium. The second method is the finite element method, which is a numerical method to solve the differential equations while the third is the boundary element method [12]. Engineering and physical applications were the first of this method in the topics of structural engineering. Then they were followed by topics of heat transfer and directly by the application of fluid mechanics, especially flow through the porous media. Its benefits that it is easy to apply if the boundary is curve and can apply the method in the medium of heterogeneous, anisotropic. It can be varied in form and size to suit the boundaries and suitable for rapidly changing areas. So the application of boundary conditions can be easily compared with the finite difference method that requires special laws for each case [11]. Applications of those numerical methods for seepage flow through the porous medium under the hydraulic structures are as in the following studies.

Hillo [1] studied seepage below hydraulic structures on anisotropic soil foundation, and using finite element to obtain uplift pressure distribution under floor base and variation of exit gradient along downstream bed. Results are obtained for angle of inclination of the major axis of hydraulic

conductivity ellipse with horizontal axis, floor length, depth of sheet piles, different combinations of degree of anisotropy and depth of permeable stratum, as follows:

1- The maximum exit gradient at downstream of structure is independent on degree of anisotropy.

2- For all cases in this study, when ($\theta < 90°$), the distribution of the exit gradient is less than that for isotropic soil foundation and the difference increases as the ratio ($k_{max}/k_{min}$ ) increases.

3- For all structures basing on soil stratification with inclination angle of $90° < \theta < 180°$ with horizontal axis, the distribution of exit gradient along downstream bed is greater than that for isotropic case and the differences increase with ($k_{max}/k_{min}$).

4- The piezometric head distribution under the structure base is dependent on the angle of inclination, ($\theta$) with horizontal axes and type of structures.

5- The piezometeric head distribution behaves as reversed compared with that for structure with downstream sheet pile, when hydraulic structures with single sheet pile are constructed at upstream.

Senda [12] developed the finite element program SEEP2D. as she did Phanuwat and Pachern [13], developed a finite element program called SEEP/W.

Damluji and others. [14] Provide a solution to problems that an acceptable agreement can be obtained between the boundary element method and the finite element method or a closed model solution. Al-Adili and colleagues [15] analyzed the effect of leakage under Diala foundations, using a 2D FE (Geo slope) model. The result also showed that if the initial blanket is built, it will reduce the lift pressure and reduce the exit gradient, while simulating the downstream blanket will increase the lift pressure and reduce the exit gradient. The results showed that compacting the filter trench at a distance of 22.0 m from the beginning of the dam structure will reduce the lifting pressure by about 97.5% and reduce the exit slope by about 88%. Salih et al. [16] studied the distribution under the Diyala foundations using the SEEP/W finite element package. Abbas [17] obtained an analytical solution to leakage flow using derived equations to calculate the hydraulic gradient along the downstream bed and the pressure at key points.

## 3. NUMERICAL MODELING

Numerical prediction was performed using the FLUENT version (19.0) to determine water leakage under hydraulic structures. For the purpose of simulation, a number of assumptions were made; They are the three-dimensional, constant, laminar, incompressible, and Newtonian flow.

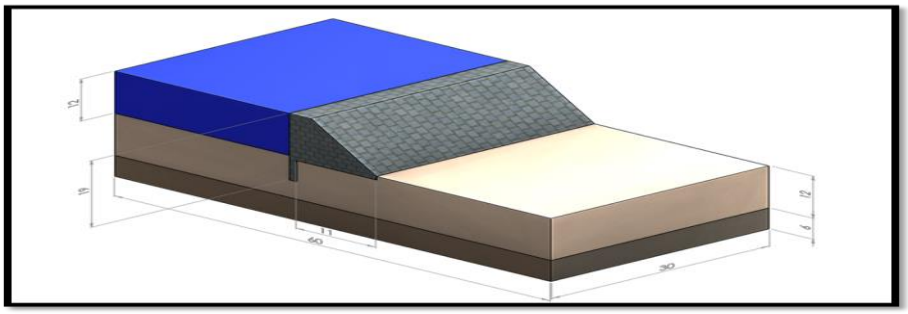

**Fig.3-1: Schematic of the considered geometry**.

### 3.2 Governing Equations

The compounds of seepage velocity through the porous media according to Darcy's law are:

$$\left.\begin{aligned} u &= -k_x \frac{\partial H}{\partial x} \\ v &= -k_y \frac{\partial H}{\partial y} \\ w &= -k_z \frac{\partial H}{\partial z} \end{aligned}\right\} \qquad (3\text{-}1)$$

where u, v, w represents the velocity in the directions of x, y and z, respectively.

Based on Bernoulli equation:

$$\frac{p}{\gamma\omega} + z + \frac{v^2}{2g} = H = \text{Constant} \qquad (3\text{-}2)$$

where, the flow in steady state, the velocity will be neglected and the piezometric head will be: -

$$H = \frac{P}{\gamma\omega} + z \qquad (3\text{-}3)$$

$P$: Hydrostatic pressure, $(N/m^2)$, $(F/L^2)$,

$\gamma\omega$: Unit weight of fluid, $(N/m^3)$, $(F/L^3)$, and

$Z$: Elevation head (m), (L).

The principle of fluid flow continuity through a given space produces the continuity equation of a three-dimensional flow of non-compressible fluid [11].

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \qquad (3\text{-}4)$$

To compensate Darcy's law (3-1) in an equation (3-4), the equation for the state of the soil becomes heterogeneous, anisotropic:

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(k_z \frac{\partial h}{\partial Z}\right) = 0 \qquad (3\text{-}5)$$

In the case of soil, which is homogeneous, anisotropic the Equation becomes as follows:

$$k_x\left(\frac{\partial^2 h}{\partial x^2}\right) + k_y\left(\frac{\partial^2 h}{\partial y^2}\right) + k_z\left(\frac{\partial^2 h}{\partial z^2}\right) = 0 \qquad (3\text{-}6)$$

As well as the state of homogenous soil, Equation (3-6) becomes:

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial Z^2} = 0 \qquad (3\text{-}7)$$

This equation is known as the Laplace Equation, which is similar to the Laplace Equation in terms of velocity potential for ideal flow or the flow of non- viscosity and the state of flow in two- dimensions shorten the Equation to becomes:

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} = 0 \qquad (3\text{-}8)$$

This Equation represents the Laplace Equation of the static laminar flow, which has different solutions [11].

### 3.3 Numerical Model

The numerical model is the mathematical model. The numerical model has the advantage of quick preparation of the model. In addition, it provides information and results for any place in the cross section.

#### 3.3.1 Hydraulic Structure Model

The model of hydraulic structure in this study is a flat floor structure with vertical sheet pile embedded in a porous anisotropic, non-homogeneous soil foundation as shown in a Fig. 3.1. Where S represents the depth of the sheet pile, T expresses the depth of the domain and B is the hydraulic structure floor length, so that the optimal length of the upstream and downstream to achieve the boundary conditions and applied in the solutions of the finite element in this research are as follows:

1- The value of the piezometric head is determined by $H=H_1$ on the surface of the soil in front of the ground of structure, and $H=H_2$ on the surface of the soil after the ground of structure or at the downstream of the structure.

2- The vertical slope of the piezometric head $\frac{\partial H}{\partial n}=0$ on the impermeable boundary and on both sides of the flow domain as shown in Fig. 3.1

Several attempts were made to estimate the dimensions and domain of the flow in the horizontal direction at the upstream and downstream. The ratio of horizontal distance along the length of the floor to the depth of the sheet pile is defined by the equation below:

$$\text{Error\%} = ((H_n - H_1) / H_1) \times 100 \qquad (3\text{-}9)$$

If the difference is less than 1%, the flow domain is sufficient and the distance has marginal effect on the distribution of the piezometric head [27]. Therefore, the distance 4S is sufficient for this purpose. There is no flow that crosses the boundary line, so the behavior is similar to the application of boundary conditions. At the same time, the results were given by increasing the uplift pressure on the sheet pile, which is part of the floor at the upstream and lower on the sheet pile when at the downstream, as well as a decrease in the exit gradient distributed along the floor at the downstream. The distance of the flow domain in the vertical direction of the impermeable layer T is greater than the length of the floor to have a small effect on the distribution of the piezometric head. To test several attempts, the ratio of T to B taken as 1.5, which achieves less flow domain on the distribution of the piezometric head. The ratio of the principle axis of permeability $K_{max}$ to the secondary axis $K_{min}$ , in this study, is taken 1 for all cases, but in lenses soil equal zero. This present study the effect of lenses under hydraulic structure on uplift pressure and exit gradient again in the porous media of non-homogeneous anisotropic soil depending on the permeability ratios.

### 3.3.2 Inhomogeneity and Anisotropy

The surface heterogeneity is a consequence of the way the latter has been formed and reshaped over millions of years through geological processes. The median is isotropic at that point. Similar considerations apply to the hydraulic conductivity, K, and to the permeability, T, of the aquifer: in the latter case, the directions considered are in the xy plane only. , flat-shaped mica particles which when deposited, the resulting porous medium have a higher permeability in one direction than it does in other directions. In carbonate rocks, flowing water may dissolve the rock, resulting in solution channels that begin as very thin cracks in the direction of the prevailing flow. In some soils, structural cracks develop more easily in one direction than others, and the soil will exhibit anisotropy. In some rocks, fractures produce very high permeability in the direction of the fractures. All of these conditions are anisotropic in permeability. In general, we can distinguish two types of heterogeneous aquifers: a) Type 1. A gradual change in permeability; Variable transmittance

may be expressed as a function of the space coordinates, T = T(x, y). b) Type 2. Abrupt changes across well-defined surfaces of discontinuity. An inhomogeneous material composed of alternating layers of different textures, say low permeability silt and high permeability sand, is equivalent in its overall behavior to a homogeneous anisotropic porous medium in which the permeability parallel to the layers is larger than that perpendicular to them (Bear, 1972, p. 155) .

Fig. 3-2, shows how a layered aquifer (Type 1 inhomogeneity) may be considered as an inhomogeneous aquifer with a gradually varying hydraulic conductivity.

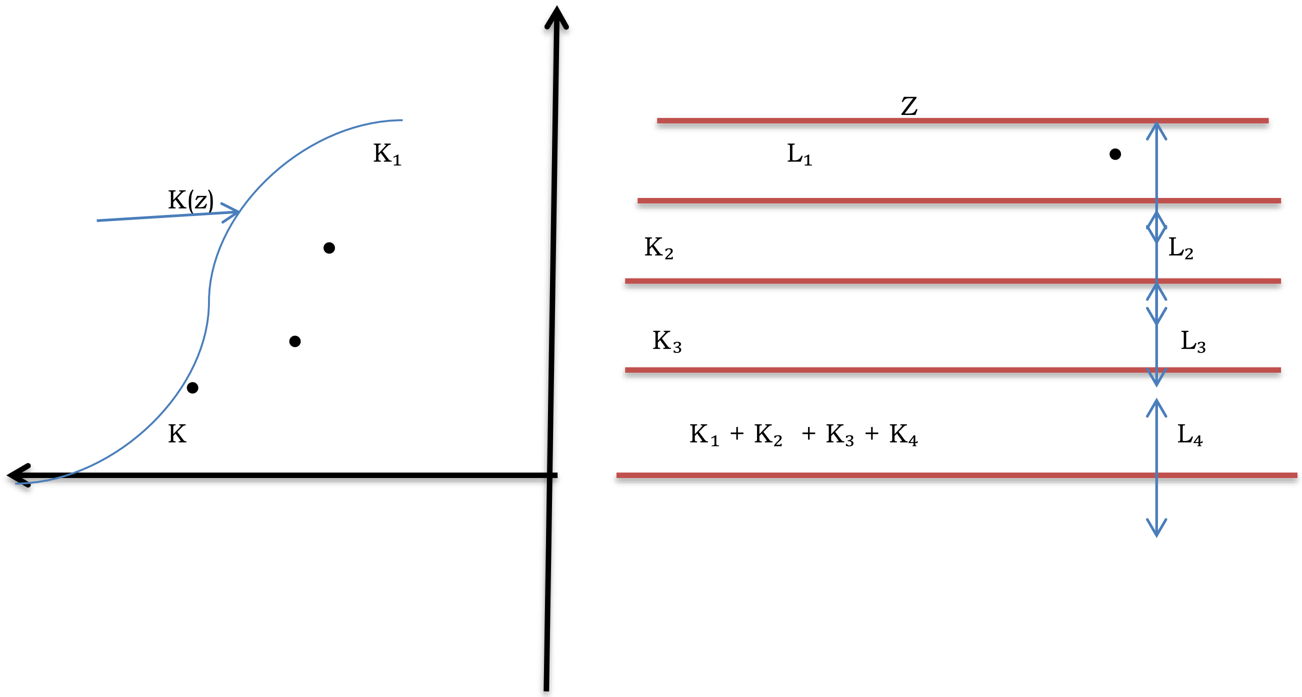


**Fig.3-2. A layered aquifer.**

### 3.3.2 .network generation

FLUENT Grids consisting of tetrahedrons or hexagons as shown in Figure 3-8 (or a combination of the two) in 3D. The choice of network type depends on the application. For problems involving complex geometries, creating networks that are structured or with a block structure (consisting of hexagonal cells) can be very time consuming. If not impossible, setup time is the main motive for using unstructured grids using tetrahedral cellsThis is the reason for this case in the current study of selected tetrahedral networks.

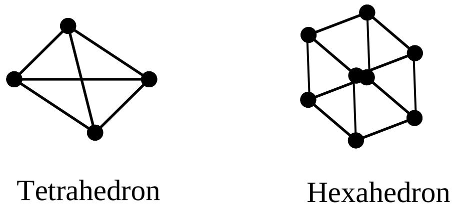


**Fig. 3-3: Tetrahedron and hexahedron grid. cells**

### 3.3.4 Solution of the governing equation

FLUENT solves the integral equations governing the conservation of mass, momentum, energy, and other quantities. There are two types of processors used to solve the equations of flow and heat transfer. The first wizard is the software architecture that creates the architecture and network using the Ansys workbench. The second processor is to solve the governing equations that include continuity, momentum, and energy.

### 3.3.5 Boundary Conditions

The conditions of the boundary of the general state of flow of two dimensions and steady state of the water flowing through the soil are as follows [**1**]:

1-In the impervious boundary, compound vertical velocity on surface equals zero $(\frac{\partial H}{\partial n}) = 0$ , means that water cannot penetrate in to this surface and does not leave gaps between it and the surface

$$k_x\left(\frac{\partial h}{\partial x}\right) i_x + k_y\left(\frac{\partial h}{\partial y}\right) i_y = 0 \qquad (3\text{-}10)$$

where the $i_x$ and $i_y$ represent the cosine direction of the vertical line on surface with the X and Y direction, respectively. The boundary of this type represents the stream line with constant value for the stream function.

2- Reservoir boundary, the height of water above these boundaries, that the pressure of any point on these boundaries is known.

$$H = H_o \qquad (3\text{-}11)$$

Thus, piezometric head along this boundary line shall be fixed so that all the boundary of the reservoirs shall be equal to the lines of the piezometric head **[1].**

### 3.5. Affinity Check

The method of checking the affinity of a solution is called residue monitoring. More than 5,500 iterations are needed to get a convergent result that takes about (2 to 4) hours on a computer array of eight nodes of 1.65 GHz. Processer Intel® CORE (TM) i7, memory 8 GB personal computer. Two computers were used in this study to ensure the rapid access to results.

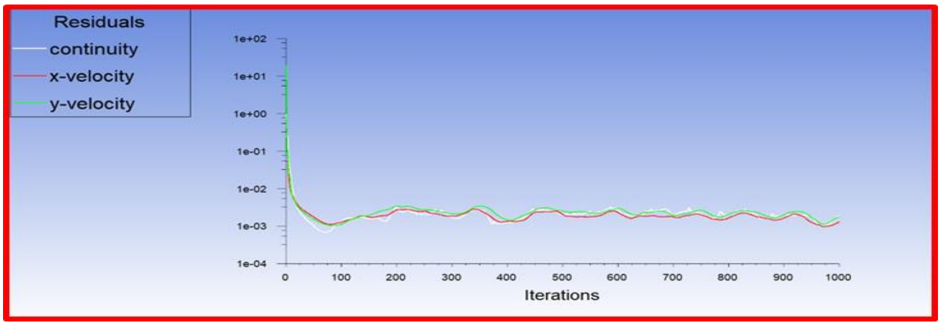


**Fig.3-3: Convergence history to solve discrete conservation equations.**

## 4. Results and discussion

The present chapter contains analysis and discussion of numerical model in finite element using Ansys fluent 19.0 program. The analysis is to study water seeping under hydraulic structures considering two typye layers. Therefore, the model is programed to determine the effect seepage water pressure under hydraulic structure for three cases as previously stated.

### 4.2. Results of the Numerical Study

#### 4.2.1. Velocity and Pressure Contours

Figures (4-1) to (4-11) are made to clarify the location of the lowest pressure for the hydraulic structures, as well as show the change in velocity and pressure along sheet pile at porous medium. These figures show the base pressure distribution and velocity contours for three at [(30°, 45°, 60°, and 90°). The contour of the velocity flow and the pressure were generated in a plane at the mid-height of the structures to study the flow characteristics of the system. Through contour, it is noticed that the lowest pressure, and the highest velocity in case 2 with 60° angle of inclination.

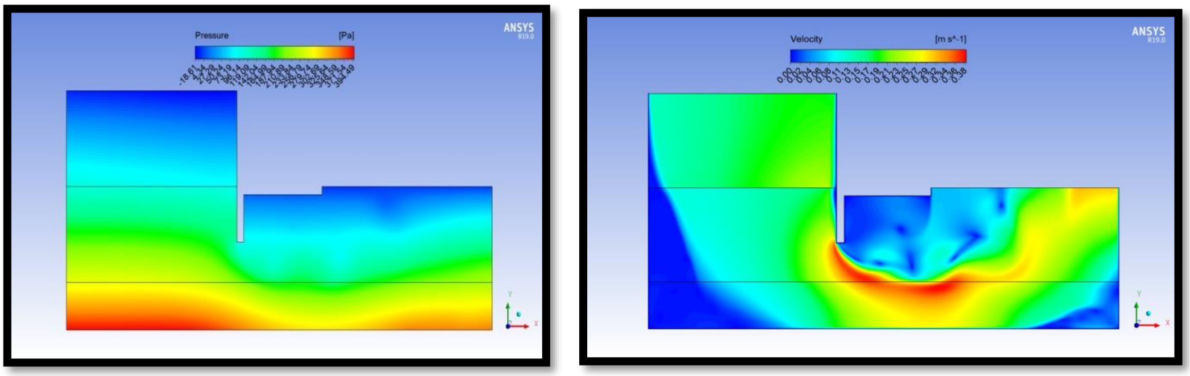


**Fig.4-1: case 1 pressure and velocity contour with angle 90 degree.**

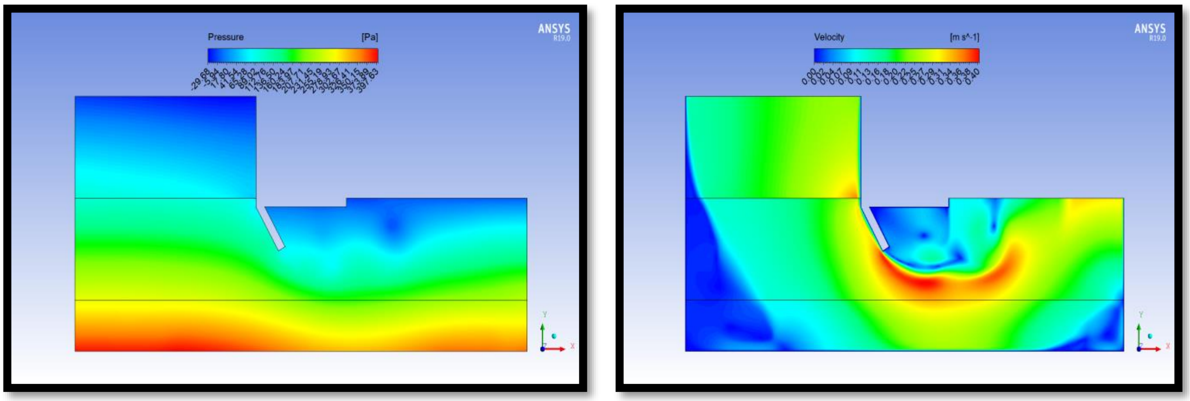


**Fig.4-2: case 1 pressure and velocity contour with angle 30 degree.**

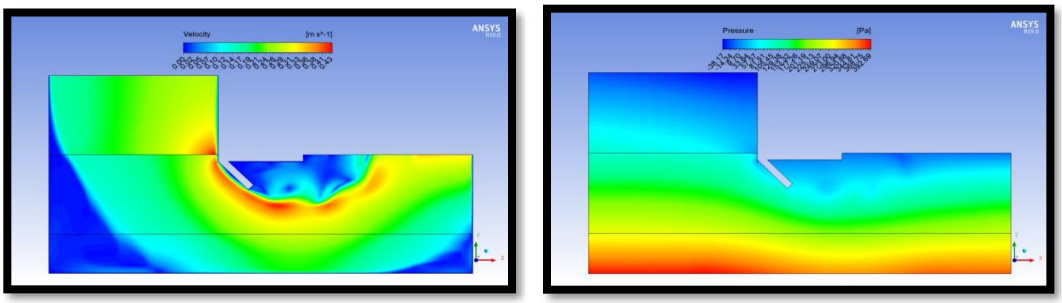

**Fig.4-3: case 1 pressure and velocity contour with angle 45 degree.**

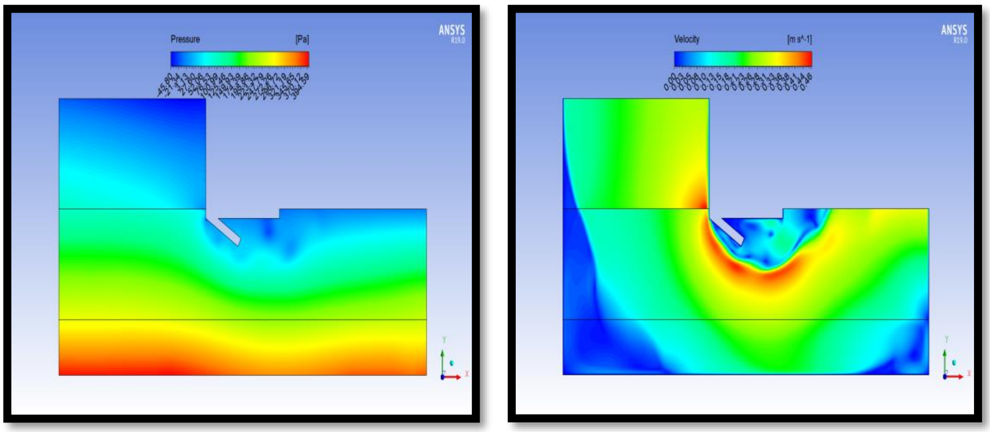


**Fig.4-4: case1 pressure and velocity contour with angle 60 degree.**

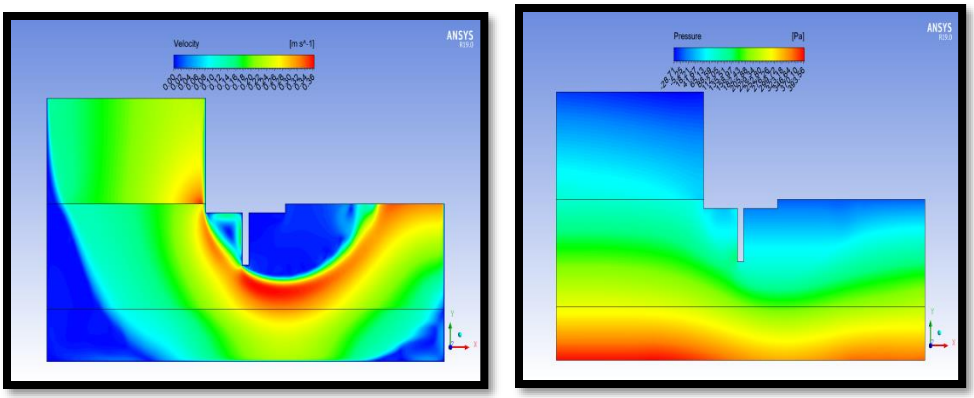


**Fig.4-5: case 2 pressure and velocity contour with angle 90 degree.**

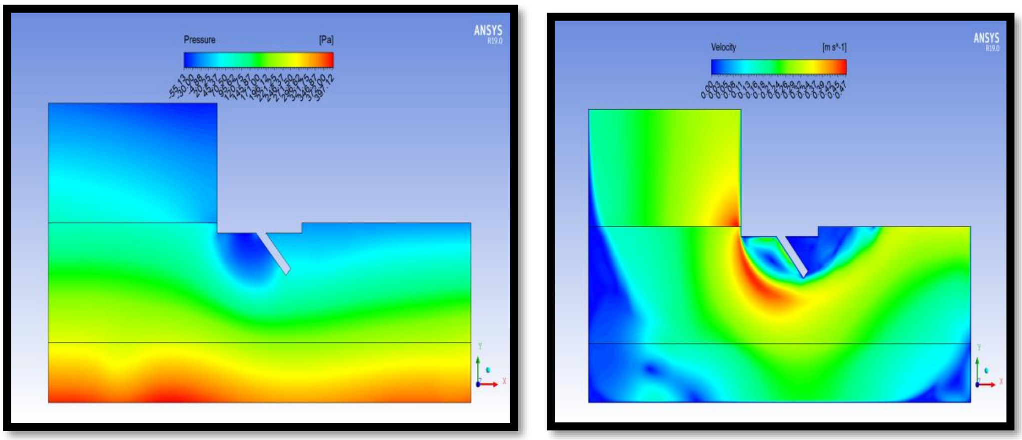


**Fig.4-6: case 2 pressure and velocity contour with angle 45 degree.**

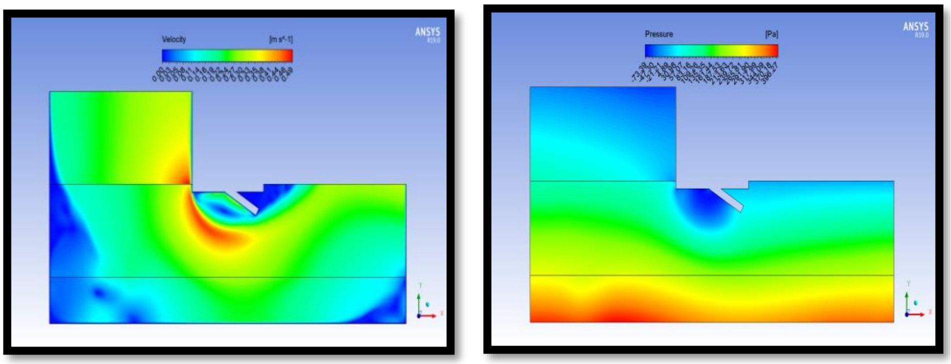


**Fig.4-7: case 2 pressure and velocity contour with angle 60 degree.**

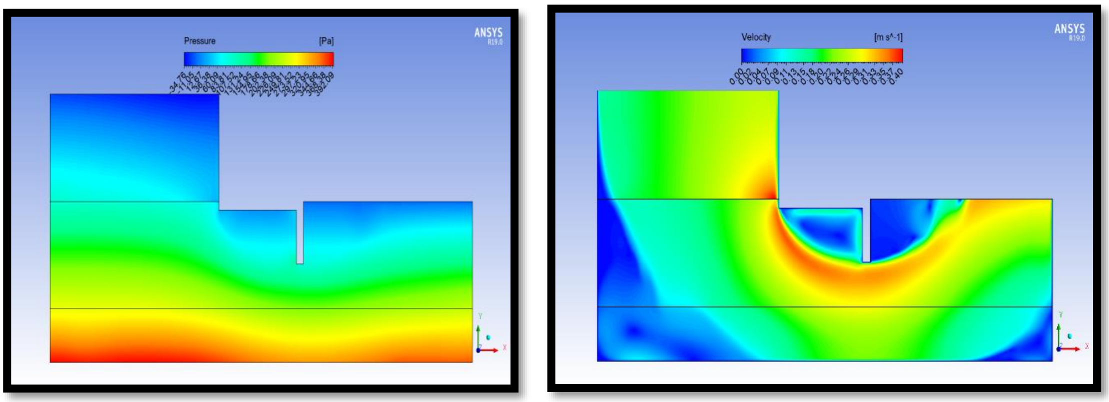


**Fig.4-8: case 3 pressure and velocity contour with angle 90 degree.**

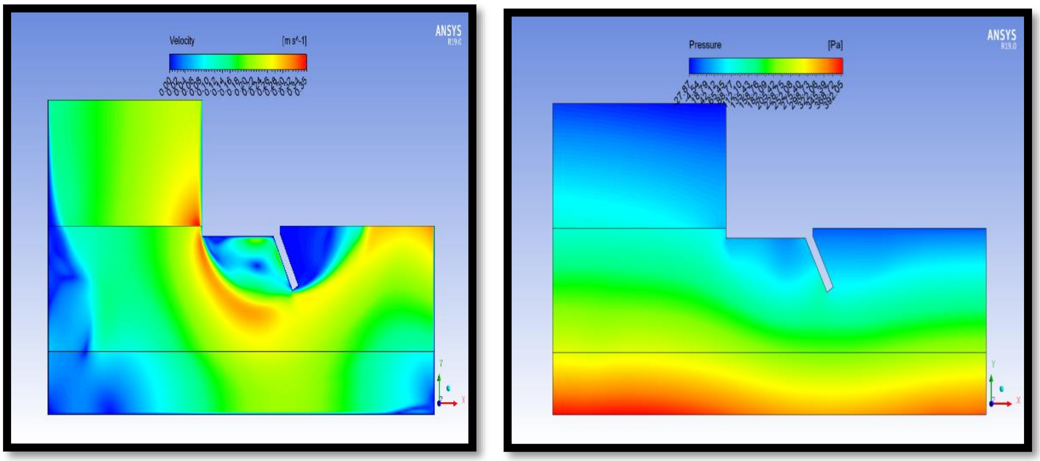


**Fig.4-9: case 3 pressure and velocity contour with angle 30 degree.**

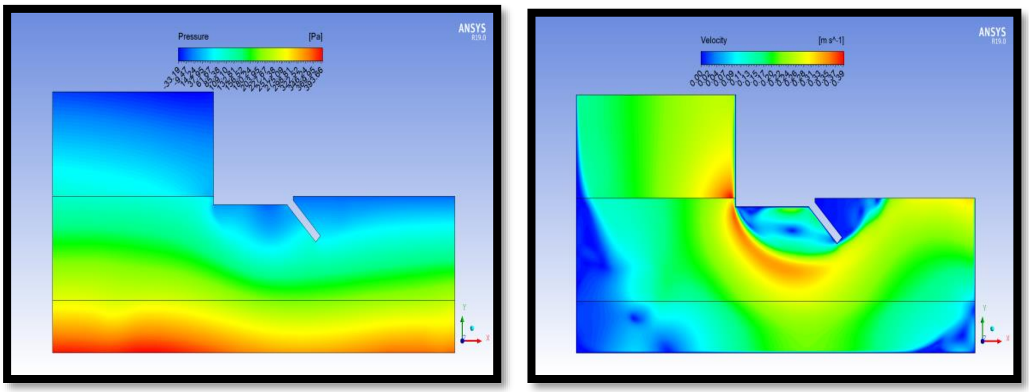


**Fig.4-10: case 3 pressure and velocity contour with angle 45 degree.**

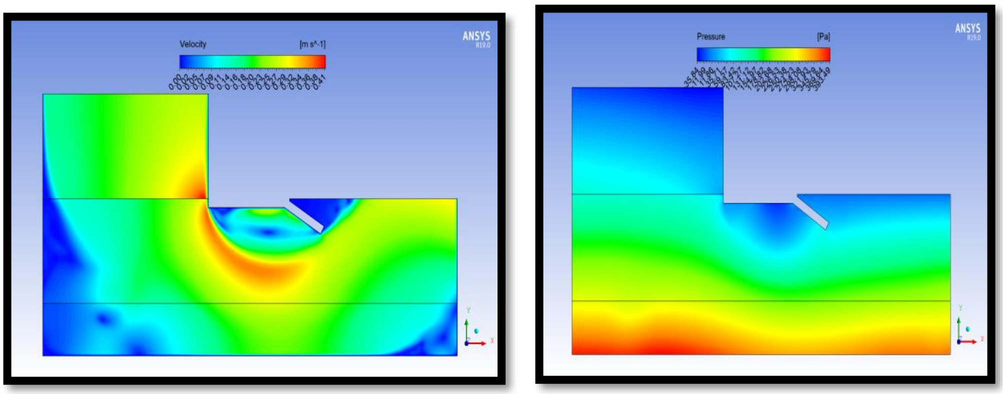


**Fig.4-11: case 3 pressure and velocity contour with angle 60 degree.**

#### *4.2.2. Effect of the orientation and arrangement on pressure and velocity*

In this section, the results are shown in order to display the best angle and direction of structures. Figure (4-12) to (4-14) show the effect of angle change and directions on the pressure drop.

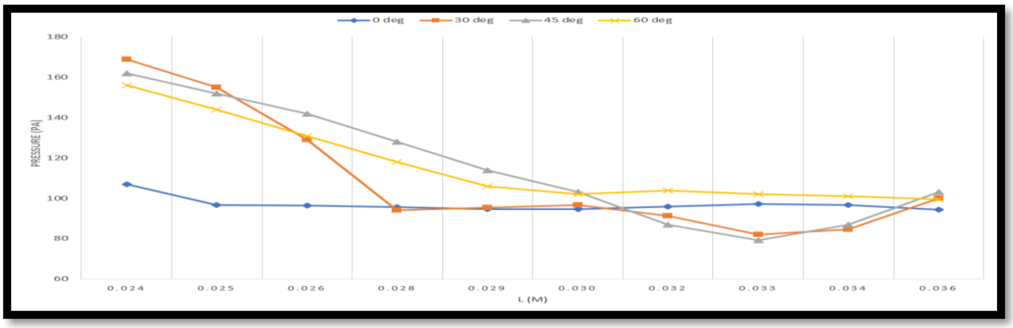


**Fig.4-12: the variation of pressure along the length (case 1).**

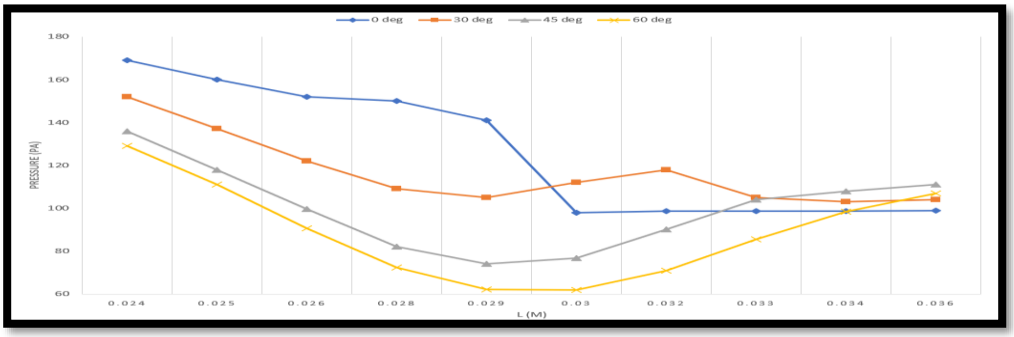


**Fig.4-13: the variation of pressure along the length (case 2).**

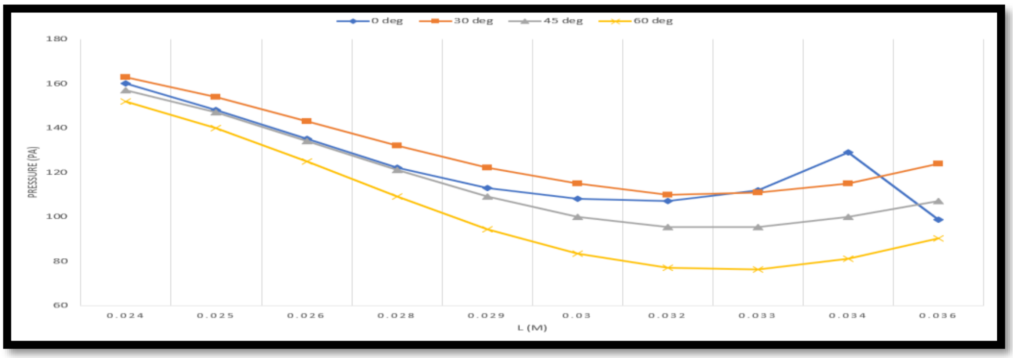


**Fig.4-13: the variation of pressure along the length (case 3).**

From these figures show that the lowest pressure in case 2 with angle 60 degree.

**Conclusion and recommendation**

Finite element method has been used in many researches for analyzing the seepage flow through the soil foundation, which is under the hydraulic structure as well as the seepage control. Using FLUENT version (19.0), the program based on the theoretical application of models, the following points could be concluded:

1- The safety of the structure against failure of piping and the safety factor against the piping phenomenon is increased and safety against seepage water pressure, when the location of the sheet piles are in the area of the downstream.

Through the conclusions made from experimental and numerical analysis, the following recommendations can be suggested:

- The flow domain for the seepage can be under any hydraulic structures as suggested in the present research.
- For safety of the hydraulic structures and to reduce the effect of the resulting pressure head from the seepage along sheet pile, it is suggested that the location of the sheet pile at upstream with effect lenses layer.
- Physical study in the case of the porous media anisotropic and to compare the results with the numerical model.

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