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Mathematical Modeling of Seepage Flow 2D,3D Models Calibration Techniques

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Abstract - *Earth dams are structures used for water storage, energy production, flood control, and irrigation. One of the major causes of the embankment dam failure is seepage. Numerical analysis using computer programs is widely used to model various seepage flow circumstances in the dams. Numerical analysis of an embankment dam is an operation. The issue is represented as it appears in the actual condition of the real world and is interpreted in the abstract shape. Finite Difference (FDM), Finite Element (FEM), Boundary Component (BEM) methods are important for the numerical techniques commonly used in the computational mechanic's field. This paper presents the application of mathematical models of seepage in embankment dams. Ansys program used in dam analysis discusses the reported case studies. The program has its advantages and limitations, which are briefly discussed in the paper.*

Key Words: seepage, finite element, stability analyses, dams, mathematical models.

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1. INTRODUCTION

Seepages from the reservoir created by an earth dam may occur through the earth-fill abutment, through the ground, and through the dam abutments, see figure 1. The analysis of the seepage is a requirement for the assessment of the safety and operational utility of the dam because:

- Allows the assessment of the water loss from the reservoir and the efficiency of the water tightening provisions of the design.
- Defines the seepage forces that have to be included in the stability analysis of the dam slopes.
- Allows the quantitative valuation of the actual hydraulic gradients and the identification of potential piping risks [1].

The flow of water through soils except for the coarser ones like gravels and rockfill is of the laminar type and follows Darcy's law. This law states that the superficial velocity of flow is directly proportional to the pressure gradient through the soil. The primary objective of the seepage analysis is to determine the location of the seepage line (the interface between the saturated saturation zones of dams) and the flow net in the saturated zone. The steady-state seepage is usually considered. [1]. Typical flow net for an isotropic embankment on an impervious foundation.

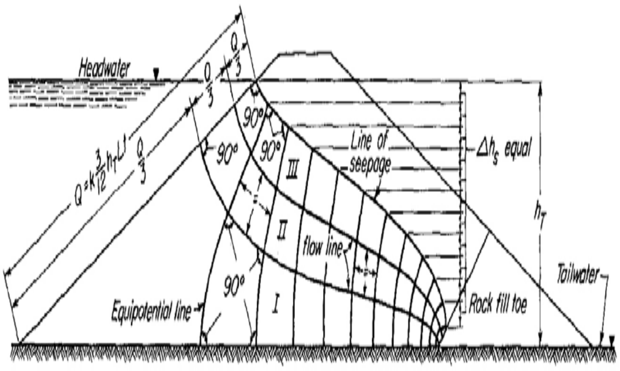

Fig. 1. Diagram of seepage analysis [1]

2. THE SEEPAGE THEORY IN EARTH DAM.

The Darcy's law can be applied to describe water flow through soils in both saturated and unsaturated conditions (Richards, 1931), which can be stated as follows. [2].

2.1. Coefficient of permeability

In soils, we are generally concerned about the water flow: the constant C is determined from tests in which the permeant is water. The specific value of the constant C obtained from these tests is the coefficient of permeable, given the symbol k. It is important to realize that this value only applies to the water when the soil is supposedly a particular factor of permeability (at 20°C). If heavier oil is used as the permeant, the value of C would be considerably less than K. High-temperature causes variation in k, but in most soils work, this is negligible. Provided that the hydraulic gradient is not more than 1.0, as is the case in most seepage issues, the flow of water through soil is linear, and Darcy's law applies, i.e., [2].

$$v = k * i \quad ...... (1)$$

$$Q = v \times A \quad ......(2)$$

Or using:

$$q = \frac{Q}{L} \quad .... (3)$$

$q = k * i$ ......(4)

Where:

q = discharge per unit area,
i = total head gradient, and
k = coefficient of permeability.

From this latter expression, the definition of k is obvious: the factor of permeability is the flow rate of water per unit area of soil when under a unit hydraulic gradient. BS 1377 specifies that the dimensions for k should be m/s. While suitable for coarse-grained soils, Swartzendruber (1961) showed that Darcy's law does not apply for solid soils due to departure from Newtonian flow (perfect fluid flow). Therefore, he proposed a modified flow equation for such soils. Many employees maintain that these variations from Darcy's law are related to the adsorbed water into the soil system, with its much higher viscosity than free water, and to soil structure, which can lead to small flows along the sides of the voids in the opposite direction to the main flow. Although these effects have not always been negligible, the unmodified form of Darcy's law is invariably used in seepage problems because it has the great advantage of simplicity. [2].

3. TYPES OF ANALYSIS

Patterns, which scale or simulate the flow of water in porous media, can provide a good sense for what is occurring during seepage and allow a physical feel for the reaction of the flow system to changes in the head, design geometry, and other assumptions. Processes that involve the movement of energy due to differences in energy potential operate by the same principles as the movement of confined groundwater. Such processes include electricity and heat flow, which has been used as seepage analogies. When a two-dimensional plan or section can characterize field conditions performing paper models could reasonably determine the effect of various configurations on the flow and pressures in the aquifer [3]. Sand models that may use prototype materials can provide information about flow paths and heads at specific points in the aquifer. The sand and porous material may be placed underwater to provide a homogeneous condition, or levels of different soil sizes may be used to study the effects of internal limits or layers. If the flow is unconfined and the same material is used for the model and prototype, the capillary rise will not be scaled and must be compensated for in the model. Flow can be traced by dye injection and heads determined by small piezometers.

3.1. Analytical Methods

Harr (1962) illustrates the use of transformations and mapping to transfer the geometry of a seepage problem from one complex plane to a different one. In this manner, the geometry of trouble can be taken from a plane where the solution is unfamiliar to a plane where the solution is Known. Although this method has been used to obtain solutions to general problems, it is not commonly used to solve site-specific seepage problems since it requires complex variable theory and the proper choice of transformation functions. Pavlovsky (1936, 1956) developed an approximate method for piecing flow net fragments to develop a flow net for the total seepage problem. This method, termed the Method of Fragments, allows rather complicated seepage problems to be resolved by breaking them into the parts, analyzing flow patterns for each, and reassembling the parts to provide an overall solution. Appendix B provides details of the Methods of Fragments based on Harr's (1962) explanation of Pavlovsky's work. [3].

3.2. Numerical and Computed Methods

The two primary methods of the numerical solution are finite differential and finite element. Both may be used in one-, two-, or three-dimensional modeling. [4].

3.3. Finite difference numerical method

The finite difference method solves the Laplace calculations by estimating them with a set of linear algebraic equations. Flow in the region is divided into a discrete rectangular grid with nodal points assigned head values (Known head values along fixed head boundaries or points, estimated heads for nodal points that do not initially know head values). Using Darcy's law and the assumption that the head at a given node has an average of ambient nodes, a set of N linear algebraic equations with N unknown head values are developed (N equals several nodes). Simple grids with few nodes could be solved by hand. Normally, N is large, and relaxation methods involving iterations and a computer must be applied.

3.4. Finite element numerical method

The finite element method is another way of the numerical solution. This method is also based on a grid pattern (not necessarily rectangular) which divides the flow region into discrete elements and provides N equations with N unknowns. Material properties, such as permeability, are fixed for each element, and boundary conditions (heads and flow rates) are set. The equation systems are solved to compute heads at nodes and flow in the elements [3].

- Intricate geometry, including sloping layers of material, can be easily accommodated.
- By modifying the size of elements, zones, where seepage gradients or velocity are high can be narrowly modeled. Pockets of material in layers can be modeled.

4. DESIGN ANALYSIS

Engineering analysis of mechanical systems has been addressed by deriving differential equations relating the variables through fundamental physical principles such as equilibrium, conservation of energy, conservation of mass, thermodynamics, Maxwell's equations, and Newton's laws of motion. However, solving the resulting mathematical models is often impossible once formulated, especially when the resulting models are nonlinear partial differential equations. Only simple problems of regular geometry, such as a rectangular circle with the simplest boundary conditions, were tractable [5] . The reaction of the mathematical model is then considered to be approximated by that of a separated model obtained through connecting or assembling the collection of all elements. The disconnection-assembly concept t happens naturally when examining many artificial and natural systems. For example, it is easy to portray an engine, bridge, building, airplane, or skeleton fabricated from more straightforward parts. Unlike finite difference models, the finite element does not overlap in the space.

4.1. Finite Element Analysis

A typical finite element analysis on the software system requires the following information:

1. Nodal point spatial locations (geometry)
2. Elements connecting the nodal points
3. Mass properties
4. Boundary conditions or restraints
5. Loading or forcing function details
6. Analysis choices [6]

I) FEM Solution Process.

- Procedures:

1. split structure into pieces (elements with nodes) (discretization/mesh) Attach (construct) the elements at the nodes to form an approximate system of equations for the whole structure (forming element in the matrix)
2. Solve the specified system of equations involving unknown quantities at the nodes (e.g., displacements)
3. Estimate required amounts (e.g., strains and stresses) at selected elements.

- Basic Theory

The finite element analysis obtains the temperatures, stresses, flows, or other desired unknown parameters in the finite element model by minimizing an energy function. An energy function consists of all the energies associated with the particular finite element model. Based on the act of conservation of energy, the finite element energy functional must equal zero. The finite element method gets the correct solution for any finite element model by minimizing the energy functional. The minimum of the function is found by setting the derivative of the function concerning the unknown grid point potential for zero [3]. Thus, the basic equation for the finite element is:

$$\frac{\partial_F}{\partial_P} = 0 \qquad (5)$$

Where F is an energy functional, and p is an unknown grid point possible (In mechanics, the potential is displacement.) should be calculated.

The finite element displacement method assumes that the displacement has unknown values only at the nodal points. Variations within the element are described in terms of the nodal values utilizing interpolation functions.

II) Discretization

1. Meshing

- Rough:

Faster calculation; not concerned about stress focus, singularities, or warping. Not near changes to the geometry or displacement constraints or changes in material, including thickness.

- Fine:

Best approximation but at the cost of calculation time. Look for disproportionate stress level changes between nodes or plate to plate and large adjacent node displacement differences to determine if the mesh needs to be refined. [3] Nodes should be defined in places where the changes of geometry or loading occur. Changes in geometry relate to thickness, substance, and/or curve. One simple check, if you can, is to decrease the mesh size by 50%, re-run the analysis, and then compare the change of magnitude of stresses and strains

- Degrees of Freedom

Constrain structure to prevent rigid abutment motion Restrict motion in non-desirable directions.

2. Applied Forces

- Static
- Static distributed
- Transient
- Harmonic vibratory

3. Element Types

PLANE55 can be used as a plane component or an axisymmetric ring element with a two-dimensional thermal conductivity Ability. Element has four nodes with a single degree of freedom at each node [7].
The element applies to two-dimensional, steady-state, or transient thermal analyses. The element may also compensate for mass transport heat flow from a constant velocity field. If the temperature element's model is also to be analyzed structurally, the element should be replaced by an equivalent structural element (such as PLANE42) [4].
A choice exists that allows the element to model nonlinear steady-state fluid flow through a porous medium. With this preference, the thermal parameters are interpreted as equivalent fluid flow parament.

5. CASE STUDY "AWA SPI" EARTH-FILL DAM

In this research, Awa Spi dam has been selected as a case study to determine and analyses seepage and relative value of stress.

5.1. General Description

Awa Spi dam, considered a hydrological Basin, is located in a large area of the Garmian district. The Awa Spi Dam is located on the Awa Spi River in the northern part of Khan Rustam village. The catchment area of the earth-fill dam is equal to 872 km^2. The dam reservoir area is about (2.23 km^2) at elevation level 472 MASL (Meters Above Sea Level), which is the elevation of the spillway crest level. This elevation gives live storage equal to 19,500,000 m^3, as shown in figure 3. The general purpose for developing the Awa Spi dam can be summarized in follows:

- Control and store water to irrigate about 970 hectares of agricultural area and supply water for the population living around this district and livestock at Awa Spi zone.
- Improve the environmental condition of the region around the reservoir and the tourism in the region.

The main function of this structure is diverting water from upstream to downstream to keep the construction site dry. The main dam can be classified as a moderate height clay core-shell filter earth-fill dam (Height about 27m) with a cofferdam.

5.2. Structure of Awa spi dam

The main structure of the Awa spi dam are:

1. Dam Embankments

The dam embankments are earth fill consisted of clay core with shell material, filter, and toe drain.

1. Diversion structure

The dam structure consists of two reinforced concrete box culvers of inner dimensions equal to 4×4 m at the inlet bed invert level of 453 MASL for the diversion structure, controlled by a cofferdam of crest level equal to 462 MASL. This structure is designed for three years to return peak discharge according to flood discharge calculations in the hydrology study, equal to 274 m^3/sec.

2. Concrete Weir Vertical Drop Type Spillway

The dam structure includes an impact basin used downstream to reduce the velocity and dissipate the flow's energy. Thus, uncontrolled free flow weir with 150 m waterway and crest level at 475 MASL, maximum water level during flood reaches 478 MASL for spillway location.

3. Bottom Outlet Design

The pipe of diameter 0.6 m has been used in the bottom outlet to draw water from the reservoir for water demand, and this pipe is extended to a dead storage elevation of 463 m.

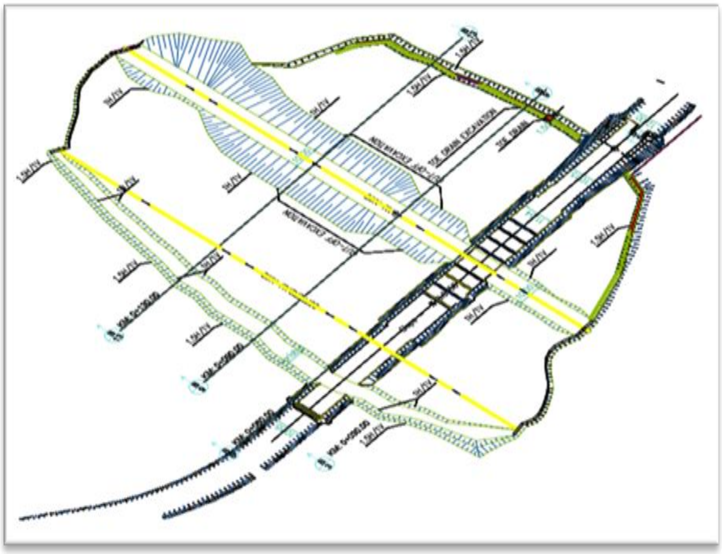

Fig. 3- Schematic of Awa spi earth-fill dam.

5.3. Material Properties

The material properties used in the dam's construction can be summarized in Table.1. Figure 4.

Table. 1.properties of Awa Spi dam materials.

Type	density kg/m^3	modules of elasticity mpa	Poisson ratio %	Permeability cm/sec
core	2.2	40000	0.3	1.00E-08
clay blanket	2.2	40000	0.3	1.00E-08
filter g	2	60000	0.25	2.70E-02
filter f	2	60000	0.25	1.00E-03
filter t	2	60000	0.25	1.00E-02
shell	2	60000	0.3	1.00E-01
sandstone	2	80000	0.35	3.75E-05
claystone	2.2	56000	0.36	2.30E-06
river deposits	1.5	20000	0.25	2.50E-02
toe drain	2	60000	0.25	2.50E-02
diaphragm	2.4	200000	0.2	5.00E-08

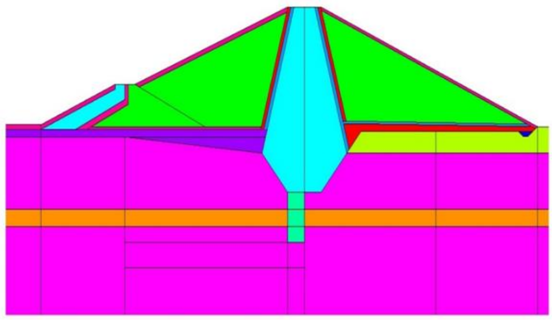

Fig. 4. diagram of Awa Spi dam materials according to properties.

5.4. Mathematical Model

This research is designed to analyze the seepage of a model from the "AWA SPI" dam by using a finite element approach.

In this study, the amount of seepage through and under the main dam's abutment is computed. The profile of the phreatic line is simulated for different scenarios and compared with the obtained data computed by the original situation used by the ANSYS program. Data about design parameters and dam geometry are given input to the program to compute an unknown parameter. At last, results are validated by comparing them with the obtained data in the original situation. This chapter comprises three major parts:

- Modeling of the dam (with different scenarios);
- Verification of the computed results.
- Comparison with obtained data by the current situation (scenario 1). Steps for Modeling Of "Awa Spi" Dam.

1. The following steps are adopted for modeling of Awa Spi dam.

- The dimensions of the dam were accurately determined by using AutoCAD program v.17, where the dam was divided into several regions, with various scenarios.
- These models have been imported by Ansys program v. 11. To realize the research objectives of the present study, a cross-section with different scenarios has been selected for the model.
- The ANSYS program is used to generate FEM mesh to carry out the seepage analysis.
- The nodes at the bottom and the sides of the dam foundation for each model are represented with the zero-flux condition.
- When the model is completely developed, it is verified by the ANSYS program, and after acceptance of the model by the program, it is ready for computation.
- Each model has been selected the same cross-section, where computation is carried out for different scenarios of clay blanket and diaphragm.
- Material characteristics for the materials used in the dam section are calibrated.
- Finally, simulated results obtained from the ANSYS program for each scenario are compared with the obtained data in the original situation.

2. ANSYS program v. 11.

ANSYS is simulation software (computer-aided engineering, or CAE). It is a general-purpose finite-element modeling package for numerically solving a wide variety of mechanical problems. These issues include static/ dynamic, structural analysis (both linear and nonlinear), heat transfer, and fluid problems, as well as acoustic and electromagnetic problems. Treatment of engineering problems contains three main parts: create a model, solve the problem, and analyze the results. Like many other FE programs, ANSYS is also divided into three main parts (processors): pre-processor, solution processor, and postprocessor.

5.5. Practical Applications

According to the comparison of the fundamental equations and boundary conditions, the ANSYS function of temperature field analysis is applied to that of the seepage flow field, the element birth or death mechanism with overlap method is adopted to estimate the saturation line site to compute the quantity of seepage on the vertical line through and under abutment of Awa Spi earth dam (in the north of Iraq), earth dam seepage flow stability [8]. Based on the result of the calculation, many reasonable suggestions are posed to help the management of Awa Spi earth dam. Thus, two scenarios' models have been suggested to compute the quantity of seepage and compared the results with
the status of the dam at the current situation that means scenario 1 also computed the total and relative value of stress, displacement, and shear with two sets of cases in the Optimum Scenario. These scenarios follow:

A. Scenario 1 "Current Situation"

The current situation represented the cross-section 0+130 without additions. To apply this mathematical model, preferences were selected from Ansys main menu, then selected thermal analysis. From element type was selected plane 55 2-D thermal solid, whereas the model composed of one type of element and the boundary condition set as:

III) Max water level in upstream (h=21m) at elevation 487.00 MASL and in downstream (h=0) at elevation 457.00.
IV) The nodes at each model's bottom and sides of the dam foundation are considered with the zero-flux condition.

Plane55 2-D thermal solid: can be used as a plane element or as an axisymmetric ring element with a 2-D thermal conduction capability. The element has four nodes with a single degree of freedom, temperature, at each node. The element applies to a 2-D, steady-state, or transient thermal analysis. Mesh of the model has been created so that the number of nodes is 2764 and the total number of elements 2764. The mesh formation is shown in figure 5.

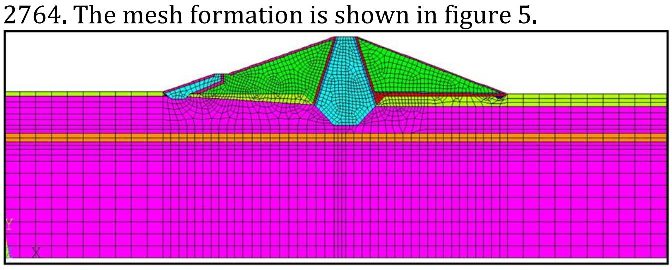

Fig. 5. Mesh Formation for Scenario 1 "Current Situation"

B. Scenario 2

In this scenario, the 5th h clay blanket at the cross-section 0+13 in the upstream of the dam and 10 m high of the plastic concrete diaphragm under the central of cat-off height have been added; thus, the number of elements in this scenario is 2752, and the total number of nodes is 2859, These mesh formations are shown in figure 6. Also, the seepage quantity has been computed by the same previous method in the scenarios above.

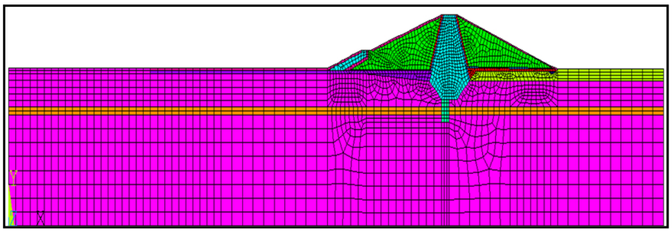

Fig. 6: Mesh Formation Scenario 2" add clay blanket 5h with plastic concrete diaphragm height 10 m"

6. RESULT AND DISCUSSION.

6.1. Scenario I

The current situation represented the cross-section 0+130 without additions. The results have been obtained: total seepage discharge on the vertical line in cross-section 0+130 equal 7.48×10-05 m3/sec maximum seepage velocity is 1.03×10-3 m/sec. Are shown in figure 7.8.9.10.

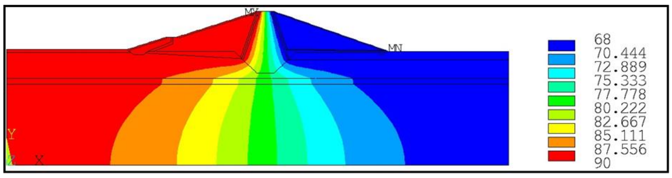

Fig.7. The distribution of water head (m) for Scenario 1.

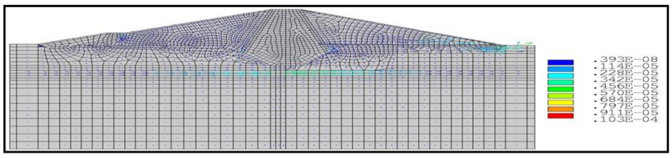

Fig.8. Seepage velocity in (m/sec) for Scenario 1.

Table 2 Computed seepage quantity.

TFX	L	q=V*L	TFX	L	q=V*L
3.35E-07	2.5283	8.48E-07	8.25E-09	1.3265	1.10E-08
3.37E-07	5.0565	1.70E-06	8.79E-09	1.3265	1.17E-08
3.43E-07	5.0567	1.73E-06	9.31E-09	1.327	1.24E-08
3.53E-07	5.0565	1.78E-06	9.84E-09	1.327	1.31E-08
3.67E-07	5.0565	1.86E-06	1.04E-08	1.3265	1.38E-08
3.87E-07	5.057	1.96E-06	1.09E-08	1.3265	1.45E-08
4.15E-07	5.0565	2.10E-06	1.15E-08	1.327	1.52E-08
4.52E-07	5.0565	2.28E-06	1.21E-08	1.3265	1.61E-08
5.01E-07	3.7785	1.89E-06	1.28E-08	1.3265	1.70E-08
5.32E-07	2.5	1.33E-06	1.35E-08	1.327	1.80E-08
5.68E-07	2.037	1.16E-06	1.42E-08	1.3265	1.89E-08
5.94E-07	1.5735	9.34E-07	1.49E-08	1.3265	1.98E-08
1.01E-05	1.6615	1.69E-05	1.56E-08	1.327	2.07E-08
1.02E-05	1.75	1.79E-05	1.65E-08	1.3265	2.19E-08
1.03E-05	1.7135	1.76E-05	1.76E-08	1.3265	2.34E-08
7.20E-07	1.6765	1.21E-06	1.90E-08	1.327	2.51E-08
7.82E-07	1.5015	1.17E-06	2.05E-08	1.3265	2.72E-08
4.40E-09	1.3265	5.84E-09	2.23E-08	1.3265	2.96E-08
5.22E-09	1.3265	6.92E-09	2.46E-08	1.327	3.27E-08
5.92E-09	1.327	7.85E-09	2.75E-08	1.327	3.65E-08
6.57E-09	1.3265	8.72E-09	3.02E-08	1.3265	4.00E-08
7.18E-09	1.3265	9.52E-09	3.14E-08	0.663	2.08E-08
7.73E-09	1.327	1.03E-08			
1.49E-08	1.3265	1.98E-08	$q = 7.48\times10^{-5}$ m^3/sec		

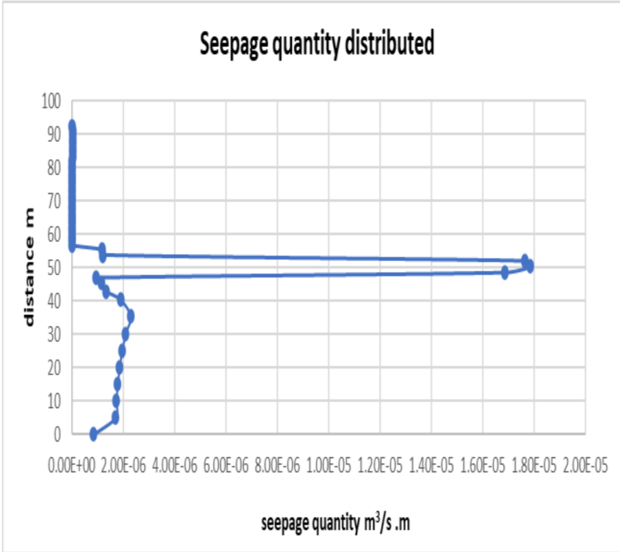

Fig. 9. The distribution of seepage quantity through vertical line for Scenario 1, (m^3/sec)

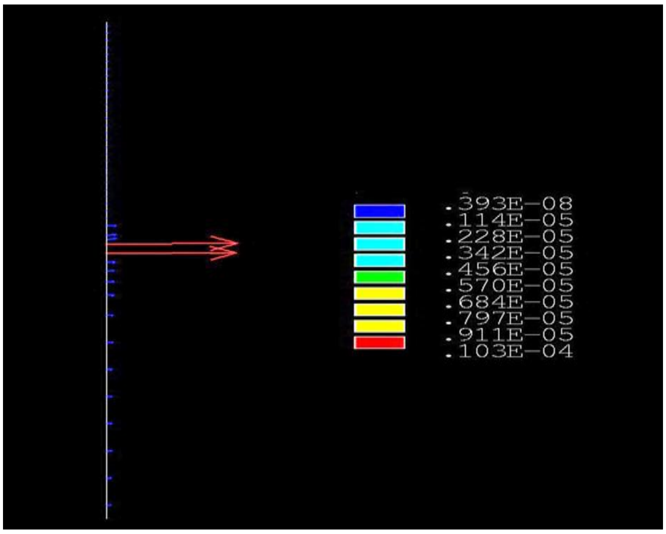

Fig. 10. Seepage velocity in (m/sec) for Scenario 1

6.2. Scenario II

This scenario used a clay blanket 5has long 116m and a diaphragm 10 m construct from plastic concrete. The seepage quantity is 2.35×10^{-5} m^3/sec, and the maximum velocity is 1.14×10^{-4} m/sec. The minimum value of seepage quantity and velocity obtained from previous scenarios is shown in figure 11.12.13.14.

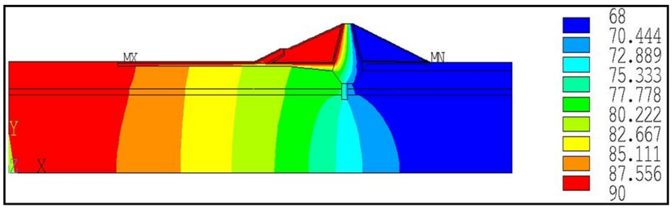

Fig. 11. The distribution of water head (m) for Scenario 6

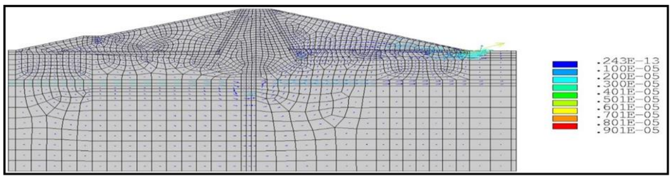

Fig. 12. Seepage velocity in (m/sec) for Scenario 2.

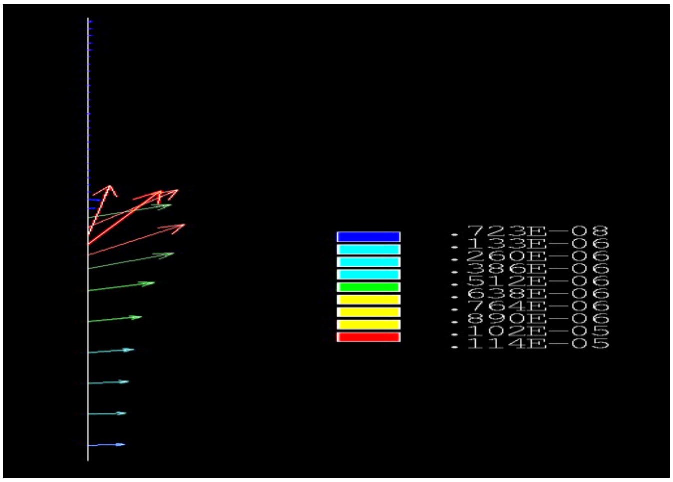

Fig. 13. Seepage velocity in (m/sec) for Scenario 6

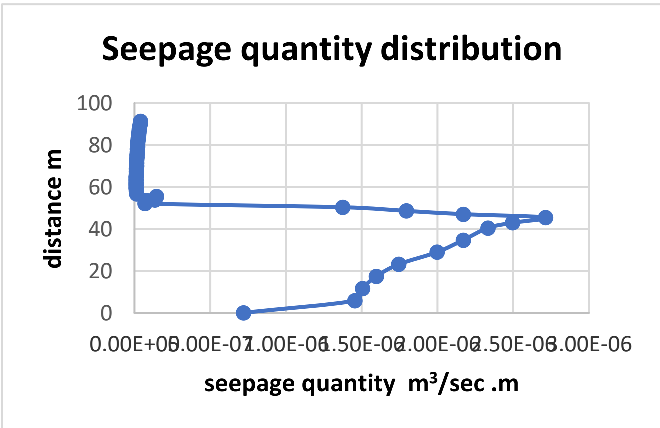

Fig. 14. The distribution of seepage quantity through vertical line for Scenario 2, (m^3/sec/.m)

Table 3 Computed seepage quantity scenario 2.

TFSUM	L	q=L*v	TFX	L	q=L*v ×10^{-8}
2.49E-07	2.8895	7.19E-07	8.78E-09	1.327	1.16×10^{-8}
2.52E-07	5.779	1.45E-06	9.30E-09	1.327	1.23×10^{-8}
2.60E-07	5.779	1.51E-06	9.88E-09	1.3265	1.31×10^{-8}
2.76E-07	5.779	1.60E-06	1.05E-08	1.3265	1.39×10^{-8}
3.02E-07	5.779	1.74E-06	1.11E-08	1.327	1.48×10^{-8}
3.46E-07	5.779	2.00E-06	1.18E-08	1.3265	1.57×10^{-8}
3.76E-07	5.779	2.17E-06	1.25E-08	1.3265	1.66×10^{-8}
5.64E-07	4.1395	2.33E-06	1.32E-08	1.327	1.76×10^{-8}
9.99E-07	2.5	2.50E-06	1.41E-08	1.3265	1.87×10^{-8}
1.33E-06	2.037	2.72E-06	1.50E-08	1.3265	1.99×10^{-8}
1.38E-06	1.5735	2.17E-06	1.60E-08	1.327	2.12×10^{-8}
1.08E-06	1.6615	1.79E-06	1.71E-08	1.3265	2.26×10^{-8}
7.85E-07	1.75	1.37E-06	1.83E-08	1.3265	2.43×10^{-8}
3.96E-08	1.7135	6.78E-08	1.95E-08	1.327	2.59×10^{-8}
7.97E-08	1.6765	1.34E-07	2.11E-08	1.3265	2.80×10^{-8}
9.62E-08	1.5015	1.44E-07	2.30E-08	1.3265	3.06×10^{-8}
1.09E-08	1.3265	1.45E-08	2.53E-08	1.327	3.36×10^{-8}
8.15E-09	1.3265	1.08E-08	2.76E-08	1.327	3.66×10^{-8}
7.48E-09	1.327	9.92E-09	3.01E-08	1.3265	4.00×10^{-8}
7.28E-09	1.3265	9.66E-09	3.14E-08	-45.637	2.08×10^{-8}
7.35E-09	1.3265	9.75E-09	3.96E-08	1.7135	6.78×10^{-8}
7.58E-09	1.327	1.01E-08	8.15E-09	1.3265	1.08×10^{-8}
7.92E-09	1.3265	1.05E-08			
8.33E-09	1.3265	1.10E-08	$q = 2.35\times10^{-05}$ m^3/sec		

Compared with the suggested Scenario, Scenario II was found to be the optimal scenario in the model. The minimum seepage exists compared to the other scenarios. It was 2.35×10^{-5} m^3/s, as shown in Table 4. Diagram 16 shows the variation in the quantity of seepage in the suggested scenario and the velocity of seepage. It was also found that the minimum seepage velocity is in Scenario II, which was 251m/sec, as shown in Table 4. Diagram 15. shows the variation of the seepage velocity value in the scenarios suggested.

Table 4. Computed seepage quantity

Nr.	Scenarios	∑q m^3/s	Reduction percentage seepage quantity %
I	0+130	7.48×10^{-05}	0
II	130(diaphragm 10 + Blanket 5h)	2.35×10^{-05}	68.55%

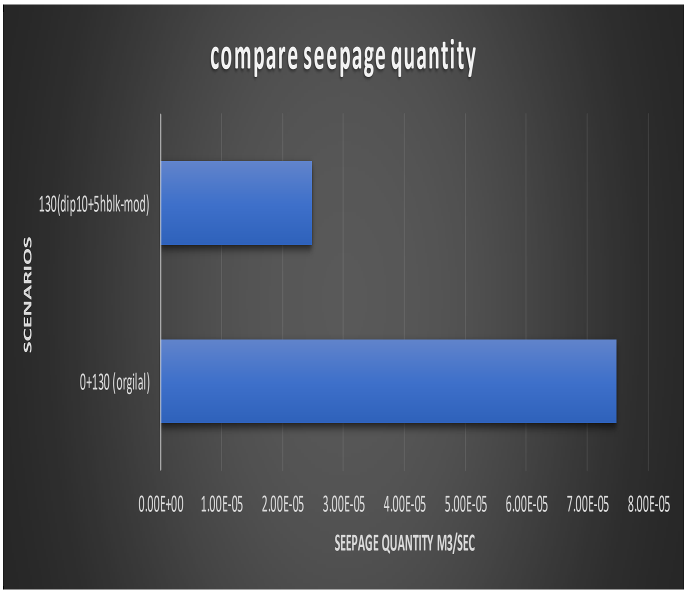

Fig. 15. Seepage quantity (m³/sec) for each scenario.

Table. 5Computed seepage velocity

No.	Scenarios	Velocity m/sec	Reduction percentage seepage quantity %
I	0+130	1.03×10-03	0
II	130(diaphragm 10 + Blanket 5h)	1.14×10-04	88.93%

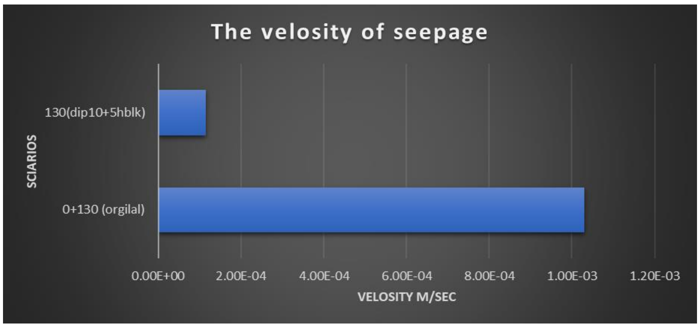

Fig. 16. Seepage velocity (m/sec) for each scenario.

Table 6.The seepage quantity per 1 year

No.	Cross-section	Σq m³/s per unit length ×10⁻⁵	Gross Discharge m³/s ×10⁻³	Gross Discharge m³/year ×10⁵
I	0+130	7.48	16.4	5.17
II	130(diaphragm 10 + Blanket 5h)	2.48	5.44	1.72

7. CONCLUSIONS

Earth-fill dams are considered widely constructed dams worldwide due to the availability of their construction materials and equipment. In this study, Awa Spi earth dam has been selected as a case study to analyze the seepage quantity permeated for a cross-section with different scenarios to compute the flow within the dam abutment and foundation by using ANSYS v.11 software program. Following are the main conclusion of this study:

I) Two Scenarios have been suggested to analyze the seepage quantity in the Awa Spi dam within the abutment and foundation by adding either a clay blanket upstream or a diaphragm at the central core or both of them.

II) The seepage flow is computed by using the ANSYS program at the cross-section 0+130 for two scenarios. The result of these quantities is shown in Table 5.1.

III) Scenario II was found the optimal scenario, where the seepage quantity is reduced by 68.55%, and the seepage velocity reduced by 88.93% from Scenario 1, see tables 4.7 and 4.8.

Table 7quantity of seepage in scenarios at cross-section 0+130.

No. of Scenario	Facilities Added	Seepage quantity m³/year
I	-	5.17E×10⁵
II	diaphragm 10m high with a blanket (5h)	1.72×10⁵

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