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SIMULATION OF A 2-D STEADY SEEPAGE FLOW AND TRANSPORTATION OF CONTAMINANTS THROUGH HARAWA DAM USING CFD MODULE AND GEO – SLOPE

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Abstract

In this study, the problem of transportation of contaminants through zoned earth dam due to seepage flow was studied and simulated using the computational fluid dynamic technique with the help of Comsol ver. 4.2 and Geo–slope programs. The paper also studies the prediction of future contaminants' levels in the specified dam. The study also discusses the effect of pool water level fluctuation from maximum to minimum on the seepage flow and the time of pollution transmission. For this purpose, Harawa Dam which was constructed in the Northern Iraq was considered as a case study. From the Geo- studio program, it is deduced that when the water level is at the maximum height (20m), it needs 70 days to reach the core zone while at a minimum height (8 m), it needs 6,800 days to reach the core zone. The results in Comsol program showed that the contaminant needs about 81 days until it reaches the core zone, while in Geo – Studio program the contaminant needs about 70 days until it reaches the core zone. Therefore, the results showed an acceptable consistency between the two computer programs.
Keywords: steady seepage flow; transportation of contaminates; Harawa Dam; CFD Module (Comsol 4.2); Geo–Slope (SEEP/W); (CTRAN/W).

Introduction

Earthen Dams have been constructed with the natural materials of soil, ranging from clays to boulder or quarried stone. Earth dams may be classified as "Homogeneous dams" which are comprised of a single type of material of impervious or semi- pervious soils. In terms of "Zoned type dams", these are the most common that are composed of a central impervious core and are enclosed by pervious zones called shells that support and protect the impervious core. From an engineering point of view, the preferable kind of soil for the core is "silty clay" soils while for the shells they may compose of sand or sandy loam soils.

Al-Jairry (2010) presented the finite element analysis (FEA) application with the use of Civil FEM/ANSYS (11). This application was used for analyzing an earth dam with two soil zones supported on an impervious base for predicting the 2D steady state water seepage. Seepage characteristics occurring downstream were tested against the ratio of permeability coefficient with changing the two zones of soil. The results of their study showed that changes in the permeability ratio of two zones of soil can affect seepage quantity and velocity downstream.

Noori and Ismaeel (2011) numerically studied surface seepage with the use of a Finite Element (FE) technique, SEEP2D. Their study was targeted on determining the following factors: free surface seepage line, the influence of anisotropy of core materials in the earth dam at Duhok, total head measurements, pore-water pressure distribution and the seepage quantity through the dam. They made use of STABIL2.3 for analyzing the stability of the investigated dam. The study concluded that a reasonable agreement was achieved with the program results and experimental results. Further, the permeability ratio and its effect on the horizontal direction to the vertical direction (Kx/Ky) was investigated on the seepage. The outcomes showed that when this ratio is increased, the seepage quantity also increases. In terms of the results achieved from the slope stability analysis, it was revealed that the safety factor reduces with increases in the ratio of Kx/Ky.

Wenli Wei *et al.* (2012) presented a method of solving the transformed equations for the mathematical model with boundary conditions of underground pressure seepage flow by using a technique of curvilinear boundary-fitted coordinate system. Comparison with FEM results showed that the proposed methodology was unable to resolve large-matrix equations. Also, the time as well as computing memory was found to be less for computing. Whereas, the mathematical model was found to be efficient for numerically solving the seepage flows in complex boundaries.

Chang Chun Wu (2012) demonstrated a seepage flow model based on the equation of seepage flow of earth dam and conditions adopted by Auto Bank software, to evaluate the seepage gradient, seepage quantity and the soakage line overflow points of the dam. The obtained results clearly mentioned that the method used can almost calculate and examine multi-media seepage flow field with complex boundaries.

Giglou *et al.* (2013) presented a simplified method with FE code to analyze the two-dimensional seepage rate. This was analysed with vertical drainage in a homogeneous earth dam. Also, the unsaturated and saturated flows subjected to steady state conditions are also considered with different heights of the dam; 5, 10, 20, 30, 40, and 50 m.

Zedan *et al.* (2017) investigated the seepage flow through KHASA-CHAI Dam by using the computer software SEEP/W. The actual design of the dam was tested with different heights of the water in the reservoir (half filled, minimum and maximum with water). Seepage control as well as the exit gradient in the dam was analyzed with understanding the influence of changes in the construction of the dam. The results showed that the dam's core had a significant impact on decreasing the quantity of the seepage through the body of the dam and the dam filters have slight impact on rising the quantity of seepage, but they have a significant impact on reducing exit gradient.

Van Genuchten and Alves (1982) developed some computer programs and mathematical models for solving the equation of solute transport. The equation includes equilibrium adsorption, dispersion, convection and diffusion. The first order decay and zero order production is also considered in some cases.

Zairi and Rouis (2000) implemented "advection-dispersion equation" in the numerical model and validation trials were compared with the semi-analytical as well as analytical solutions. A 2D FEM was proposed for transportation of contaminants. Cadmium and chloride transportation was tested experimentally using liner samples. Results were compares as well as discussed with the outcomes of the numerical solutions.

Rao, and Others (2006) introduced the product of a multiple domain algorithm. The two-dimensional dispersion equation was solved, and the results confirmed that the use multipurpose domain approach was successful and no loss was found in accuracies of the solution.

The aim of this paper is to examine and investigate the seepage flow and transportation of contaminants in a zoned type earth dam. The results were presented using CFD Module and Geo slope software (Charbeneau, 2006).

(A) Contaminates Transportation

The advection may be defined as the seepage of water flowing with suspended solute through porous media. The hydrodynamic dispersion and advection are the physical properties and control solute flux. The Darcy's law is applied on advection as seepage lines carry solute through the porous media.

Due to molecular diffusion and mechanical mixing the hydrodynamic dispersion takes place and it is a process where molecular and ionic constituents move in concentration gradient direction. The constituents also move from a higher to lower concentration. The intensity of gradient is responsible for diffusion.

On a contrary of advection, diffusion is a natural transport procedure which disregards the stream. Diffusion provides a haphazard movement and changes in concentration. Therefore, diffusion is governed by Partial Differential Equation (PDE) which can be referred to as an "advection diffusion time-dependent equation" (Charbeneau, 2006).

(B) CFD Module (Comsol Version 4.2)

COMSOL Multiphysics is an extension of the Computational Fluid Dynamics (CFD) module that can be used for the analysis of all types of fluid flow. The program using finite element tools for solving the governing equations of flow and transportation of contaminants through earth dam. It has ability for modelling laminar as well as turbulent flows in either single or multiple phases. Also, in a functional manner, it can treat fluid-structure interaction, porous media flow and free flow (Comsol).

(C) Geo - Studio Software

Based on "Geo-Slope International (Geo-Slope)", SEEP/W is a product of FE used for simulating the seepage in groundwater seepage. It allows users to examine simple steady state problems all the way to complicated problems. SEEP/W simulates the flow of water vapour and liquid water through unsaturated and saturated porous media. In this connection, the simulations of transient ground water flow or steady water flow are run with in a natural flow system, subjected to climate boundary condition (Geo-Slope).

CTRAN/W is a FE software product and is used to show the flow of rock and soil through porous material. CTRAN/W formulation makes it possible to examine tracking of simple particle problems and other complicated processes of radioactive decay and density dependencies, adsorption, dispersion and diffusion (Geo-Slope, 2012).

Materials and Methods

HARAWA DAM

(A) Location

Hawara village is located in the Northeast of Iraq, about 40 Km to the S 80° W of Sulaimaniyah City, and about 15 Km east of Chamchamal town. The dam site is located directly downstream of Harawa village at the longitude 44° 59' 35" and the latitude 35° 31' 37" (Figs. 1 and 2). This basin is located in semi-arid zone of Iraq with hot weathers in summer and cold in winter.

Fig. 1 : Map of Iraq

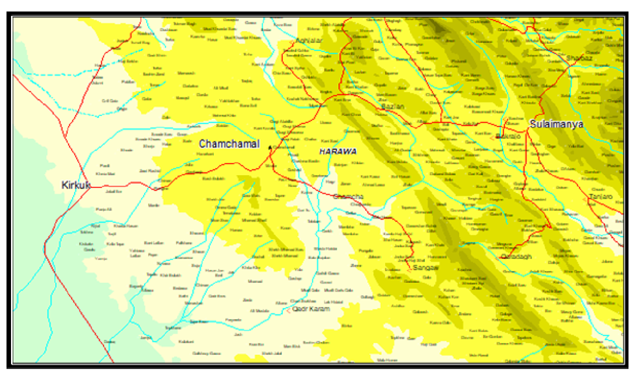


Fig.2: Location of Harawa Village in Sulaimaniyah Governorate

(B) *Characteristics of Harawa Dam*

Type of Dam

According to the material available and also from economical point of view, a zoned embankment type earth dam is chosen. The dam composed of a central impervious core flanked by zones of materials considerably more pervious. A suitable drainage system, of the form of toe drain is also provided. The outer shells are made of pervious, freely draining material. The shells give stability to the central impervious fill and at the same time distribute the load over a large area in the foundation. Moreover, the upstream pervious zone affords stability against rapid drawdown that is occurred annually in this site, while the downstream pervious zone acts as a drain to control the line of seepage. Since saturated soils are less stable than dry soil, therefore the upstream side of the embankment is flatter than the downstream side. For Harawa dam it is proposed to make the slope of upstream side of embankment as 2.5H: 1V, while the slope of downstream side as 2H: 1V.

The central impervious core is proposed to construct from silty clay or sandy clay with side slopes of 1:1 for both upstream and downstream sides. This core is taken down to, and bedded into, impervious clay stone layer so that there is no risk of seepage below it. Also, the core continued up to the apex of the embankment along the whole length of the wall and at both ends. The material was properly placed and compacted such that to act as an impermeable layer. Top width of the embankment is proposed to be 6m wide such that to be enough for both construction equipment and for any traffic since it can be used as a bridge.

Technical Specifications

Table1: below indicate the technical specifications of the embankment:

Table I The technical specifications of the embankment

Type of Dam	**Zoned Embankment Earth dam**
Crest	Elevation: 697.5m (m.a.s.l.); Length: 115m; Width: 6m.
Height of Dam	22.5 m
Freeboard	2.5 m
Max. Thickness at Base	107.25 m
Shell: Type of Material	Alluvial Soil
Angle of Friction	33°
Volume (m^3)	40000
Core: Type of Material	Silty Clay loam, PI < 20%, Low permeability
Angle of Friction	26°
Volume (m^3)	62000
Bottom Elevation of Cutoff Trench	672 m
Slope of the Shell	Upstream: 2.5:1; Downstream: 2:1
Slope of the Core	1:1 Both for Upstream and Downstream Sides
Thickness of Filter	1m
Volume of the Filter	1700m^3

Theoretical Analysis

(A) CFD Module

Comsol was used for studying two states: the first state involves studies and interpretation of the flow net through porous media (the stream lines and equipotential lines through an earth dam). It depends on Continuity, Navier – Stokes equations, and the modified Navier–Stokes equation for a fixed bed porous medium; in addition to Forhcheimer correction equation. These equations are as follows:

$$\rho\nabla.u = 0 \tag{1}$$

$$\rho(u.\nabla)u = \nabla.[-\mathrm{pl} + \mu(\nabla u + (\nabla u)^T)] + F \tag{2}$$

$$\frac{\rho}{\varepsilon_p}\left(\frac{(u.\nabla)u}{\varepsilon_p}\right) = \nabla.\begin{bmatrix} -\mathrm{pl} + \frac{\mu}{\varepsilon_p}(\nabla u + (\nabla u)^T) - \frac{2\mu}{3\varepsilon_p}(\nabla.u)\mathrm{l} \\ -\left(\frac{\mu}{\mathrm{K}} + \beta_\mathrm{F}|u| + \frac{Q_{br}}{{\varepsilon_p}^2}\right)u \end{bmatrix} + F \tag{3}$$

$$C_f = \frac{1.75}{\sqrt{150\,\varepsilon_P{}^3}} \tag{4}$$

Where:

μ = the dynamic viscosity (Pa· s)

u = velocity of water (m/s)

ρ = the fluid's density (kg/m^3)

p = the pressure (Pa.).

k = permeability of the porous medium (m^2)

ε_p = the porosity (dimensionless)

C_f = the dimensionless friction coefficient.

The second state studies the species flow through porous media. It depends on Advection – Dispersion equation, and the Retardation equation:

$$R\frac{\partial c}{\partial t} + \frac{\partial}{\partial x}(\boldsymbol{uc}) + \frac{\partial}{\partial y}(\boldsymbol{vc}) = \boldsymbol{D_x}\frac{\partial^2 c}{\partial x^2} + \boldsymbol{D_y}\frac{\partial^2 c}{\partial y^2} \tag{5}$$

$$R = \mathbf{1} + \frac{\rho_b}{e}\boldsymbol{k_d} \tag{6}$$

Where:

c = concentration of contaminants (mole/m^3),

u = Velocity field in the x- direction (m/s),

v = Velocity field in the y- direction (m/s),

D_x= coefficient of dispersion in the x- Direction (m^2/s),

D_y= coefficient of dispersion in the y- Direction (m2/s),

R = retardation which is caused by adsorption,

t = time,

e = porosity,

K_d = adsorption coefficient (m^3/kg)

ρ_b = the bulk density of the soil (kg/m^3)

Boundary Conditions

The boundary conditions are satisfied by the following points:

1- At inlet

$P = \gamma H$; $P = 196200$ Pa.,

$C = Co = 0.0083$ mol/m^3

2- At outlet

$P = 9810$ Pa.,

3- At ($t = 0$)

$C(x, y) = 0$

(A) Geo – Studio:

Seepage water (SEEP / W) and concentration of contaminants and its transportation through the soil (CTRAN/ W) studies 2 states as follows.

(1) Seepage Flow: The first state studies seepage flow (stream lines and equipotential lines) through earth dam. SEEP/W is devised depending on the fundamentals that the water flow thru both, unsaturated as well as saturated soil supports Darcy's Law, which mentioned that:

$$q = kiA \qquad ...(7)$$

Where:

q = the specific discharge,

k = the hydraulic conductivity,

i= the gradient of total hydraulic head, and

A= area of cross section

Darcy's Law was originally derived for saturated soil, but later researches had shown that it is applicable to water flow thru unsaturated soil. However, it must be noted that the hydraulic conductivity is not constant any longer under unsaturated flow conditions. This is the main difference where the mentioned conductivity differs with water content changes. However, it varies indirectly pore water pressure changes.

Darcy's Law is usually given by:

$$v = ki \qquad ...(7a)$$

Where:

v = the Darcian velocity.

It must also be noted that the real averaged velocity for the movement of water thru the soil is a linear one. This corresponds to the "Darcian velocity divided by the porosity of the soil. In unsaturated soil, it is equal to Darcian velocity divided by the volumetric water content of the soil". Therefore, SEEP/W calculates and demonstrates the Darcian velocity only.

(2) Solute Transfer:

The second state studies the transportation of contaminant through an earth dam (CTRAN/W).

The contaminant is transported by groundwater through: (i) retardation, caused by sorption; (ii) dispersion, caused by molecular diffusion and mechanical mixing; and (iii) advection, caused by the groundwater flow (Patil and Chore, 2014).

Advection refers to the transport of dissolved solute with groundwater flowing in porous media at the seepage velocity that follows Darcy's law as:

$$Q = KIA; \text{ or } V = KI \qquad ...(8)$$

Dispersion occurs due to 2 procedures; mechanical mixing and molecular diffusion.

Fick's law can be used for expressing molecular diffusion as:

$$F = -D_f\, dc/dx \qquad ...(9)$$

Where:

"F = mass flux per unit area per unit time,

D_f = diffusion coefficient,

C = contaminant concentration,

dc/dx = concentration gradient".

Molecular diffusion D* represented by:

$$D^* = \omega D_f \qquad ...(10)$$

Where

ω = the empirical coefficient with the value of less than 1, which considers the influence of the porous media's solid phase on the diffusion. The range of ω is from 0.5 to 0.01.

The coefficient of hydrodynamic dispersion is given by:

$$D_L = \alpha_L V + D^* \qquad ...(11)$$

Where:

DL = longitudinal mechanical mixing component of dispersion

α_L = longitudinal dispersivity = 0.1 L, where L is the length of the flow path.

Advection-dispersion transport

In saturated zone, dispersion as well as advection is prevalent. The relation that controls this process is:

$$D_x \frac{\partial^2 c}{\partial x^2} - \tilde{V}\frac{\partial c}{\partial x} = \frac{\partial c}{\partial t} \qquad ...(12)$$

Sorption refers to the molecular and ionic trade between liquid and solid phases. This includes desorption as well as adsorption. For calculating the retardation coefficient, the adsorption or distribution coefficients can be used for the contaminant while the attributes of the porous medium are:

$$R = [1 + K_d * \rho_b/e] \qquad ...(13)$$

The distribution coefficient (K_d) was calculated by taking the ratio of adsorption concentration in soil (C_s) and equilibrium concentration in solution (Ce). Thus, the distribution coefficient (K_d) was calculated using the equation:

$$K_d = C_s / C_e \qquad ...(14)$$

For calculating the groundwater contaminant's velocity, the following correlation can be utilized:

$$V_c = V / R \qquad ...(15)$$

Where

"V_C Is the velocity of the contaminant movement in groundwater, V is the groundwater velocity, and R is the retardation factor". High adsorption coefficient is represented by a high value of retardation factor, which substantially impedes the passage of groundwater contaminants.

Boundary Conditions

The boundary conditions are satisfied by the following points:

1- At inlet

H = 20m, and C = 2 (g/m^3)

2- At outlet

H=1m, Mass rate of dispersive contaminant ($\dot{m}$)= 0 (g/day).

1) Partial differential water flow equations: The governing equations used in flow formulation are from "Seepage Modeling with SEEP/W" (Geo-Slope)

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial H}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial H}{\partial y}\right) + Q = \frac{\partial \Theta}{\partial t} \quad ...(16)$$

Where:

H = total head,

k_x = hydraulic conductivity in the x-direction,

k_y = hydraulic conductivity in the y-direction,

Q = applied boundary flux (per unit volume).

Θ = volumetric water content, and

t = time (t).

The equation states that the change in volumetric water content is same as the difference between the flow of incoming and outgoing of an elemental volume at a point in time (flux). Basically, the volumetric water content's rate of change is equal to the summation of rate of flow changes in 2 dimensions and the externally applied flux. The flux stays same at all times under steady-state conditions. Thus, this eliminates the equation's right side thus reducing it to:

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial H}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial H}{\partial y}\right) + Q = 0 \quad ...(17)$$

Moreover, variations in soil properties and stress states result in changes in the volumetric water content.

SEEP/W is devised for constant total stress conditions. To elaborate, this signifies that no loading or unloading of the mass of soil takes place.

Changes in pore water pressure can be associated to changes in volumetric water content through the following correlation:

$$\partial \theta = m_w * \partial u_w \quad ...(18)$$

Where:

u_w = the pore-water pressure,

m_w = slope of the storage curve,

H, total hydraulic head, is given by:

$$H = \frac{u_w}{\gamma_w} + y \quad ...(19)$$

Where:

"y_w = the unit weight of water, and

y = the elevation (L)".

Rearranging Equation (19) gives:

$$u_w = \gamma_w (H - y) \quad ...(20)$$

Substituting equation (20) into (18) gives the following equation:

$$\partial \theta = m_w\, \gamma_w\, \partial (H - y) \quad ...(21)$$

Substituting into equation (17) results in:

$$\frac{\partial}{\partial x}\left(K_x \frac{\partial H}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial h}{\partial y}\right) + Q = m_w\, \gamma_w\, \frac{\partial (H-y)}{\partial t} \quad ...(22)$$

The (y) derivative respecting time disappears since the elevation is constant. This results in the below-mentioned governing differential equation:

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial H}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial H}{\partial y}\right) + Q = m_w\, \gamma_w\, \frac{\partial H}{\partial t} \quad ...(23)$$

2) Contaminant transport equations for CTRAN / W

Software differential water flow equations:

The governing equation for contaminant transport was taken from "Contaminant Modeling with CTRAN/W" (Geo-Slope).

With taking into consideration the mass flux, q, in an elemental volume of porous material, the equation for solute transport can be derived. This is also demonstrated in Figure (3). Across the element, the absolute net mass flux is given as:

$$\text{Net mass flux} = \frac{\partial q}{\partial x} dx \quad ...(24)$$

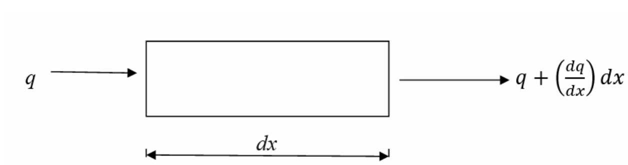


Fig. 3: Mass balance in a 1D element.

For mass conservation, "the rate of change of the total mass M in the element must be equal to the net mass flux". As a correlation, this is given as:

$$\frac{\partial M}{\partial t} dx = -\frac{\partial q}{\partial x}\, dx \quad ...(25)$$

By explanation, "the concentration C is the mass M of dissolved solute in a unit volume of water (solution)". As a correlation, this is given as:

$$C = \frac{M}{V_w} \quad \text{Or, } M = CV_w \quad ...(26)$$

The volumetric water content Θ is denoted by the volume of water in unit volume of the element. The resulting mass, M, in unit volume is:

$$M = C\,\theta$$

Substitution for M in Equation (26) followed by dividing by (dx) results in:

$$\theta \frac{\partial C}{\partial t} = -\frac{\partial q}{\partial x} \quad ...(27)$$

The mass flux through the element arises from both advection and dispersion processes. In equation form, these two mechanisms are:

Advection = v Θ C =U

And, dispersion = - Θ D $\frac{\partial C}{\partial x}$

Where:

"v = average linear velocity,
Θ = volumetric water content,
C = concentration,
D = hydrodynamic dispersion coefficient, and
U = Darcy velocity (specific discharge)".

In the dispersion term, the negative sign shows the mass flow direction is from an increased concentration to a decreased concentration. Thus, the fundamental transport equation can be derived by the substitution of the previous two terms into Equation (28):

$$\Theta \frac{\partial C}{\partial t} = -\frac{\partial}{\partial x}\left[-\Theta D \frac{\partial C}{\partial x} + U\, C\right] = \Theta D \frac{\partial^2 c}{\partial x^2} + U \frac{\partial C}{\partial x} \quad ...(28)$$

Dividing this equation by Θ results in:

$$\frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial x^2} - v \frac{\partial C}{\partial x} \quad ...(29)$$

Diffusion coefficient D*, average linear velocity and dispersivity are all related to the hydrodynamic dispersion coefficient, D by:

$$D = \alpha\, v + D* \quad ...(30)$$

Equation (30) represents advection – dispersion equation, the fundamental transport equation of a non-reactive substance. To elaborate, this means that adsorption does not result in any loss of mass.

In terms of the movement of reactive substances, the mass transfer is influenced by the soil particles adsorption of the solute. Mass amount adsorbed can be described by referring to the soil particles' bulk mass density. Therefore, the adsorbed mass, Ms, is:

$$M_s = S\rho_d \quad ...(31)$$

Where

"Ms = the amount of mass attached to a unit
Mass of soil particles",

S = the adsorption, and

ρd = the bulk density.

The adsorbed mass's rate of change can be given by:

$$\frac{\partial M_s}{\partial t} = \rho_d \frac{\partial S}{\partial t} \quad ...(32)$$

Where "the adsorption S is a function of concentration C". Usually, experimental results are plotted as S versus C and the gradient of this plot is (∂S /∂C). Such a gradient is often knowns the distribution coefficient K_d, when the relationship is linear. This leads to the rearrangement of previous equation as:

$$\frac{\partial M_s}{\partial t} = \rho_d \frac{\partial S}{\partial C} \frac{\partial C}{\partial t} \quad ...(33)$$

Equation 29, the transport equation, can then be altered for including adsorption. This results in:

$$\Theta \frac{\partial C}{\partial t} + \rho_d \frac{\partial S}{\partial C} \frac{\partial C}{\partial t} = \Theta D \frac{\partial^2 C}{\partial x^2} - U \frac{\partial C}{\partial x} \quad ...(34)$$

Or,

$$\left[\Theta + \rho_d \frac{\partial S}{\partial C}\right] \frac{\partial C}{\partial t} = \Theta D \frac{\partial^2 C}{\partial x^2} - U \frac{\partial C}{\partial x} \quad ...(35)$$

Results and Discussions

In zoned earth dam, the upstream pervious shell practically has no effect on the position of the seepage line while the downstream pervious shell acts as a drain. For this case, the seepage line is usually drawn only for the core section. As such, the reservoir is assumed to be extended up to the central core and treating the core as a homogeneous dam.

The contaminants transportation models indicates the following results:

A. (A) Geo - Studio

The following results are presented by using Geo - Studio software. Figure (4) indicates a schematic diagram of zoned earth dam. The finite element mesh which used for the analysis is shown in figure (5). The mesh type (Quads and Triangles) includes elements for whole body of dam, and the global element size is 2 m. The numbers of elements for all boundaries are 351 elements and the numbers of nodes are 391 nodes.

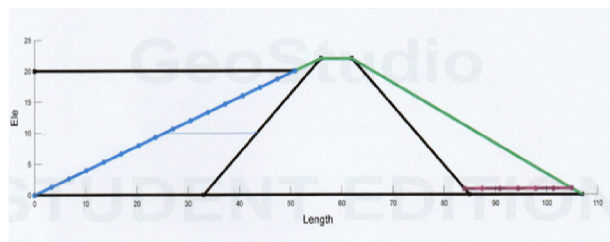


Fig. 4: Cross section of zoned earth dam.

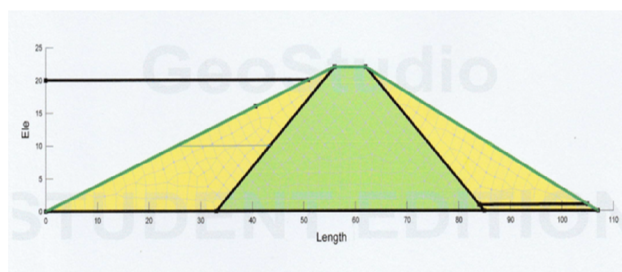


Fig. 5: Finite Element Mesh.

The location of seepage line at steady state seepage flow through earth dam at 20m upstream water level using Geo – Studio software is indicated in figure (6). A dotted blue line represents the phreatic line in the dam. The colored area represents a drop-in pressure head from (20 m) to (1 m) as shown in figure (6).

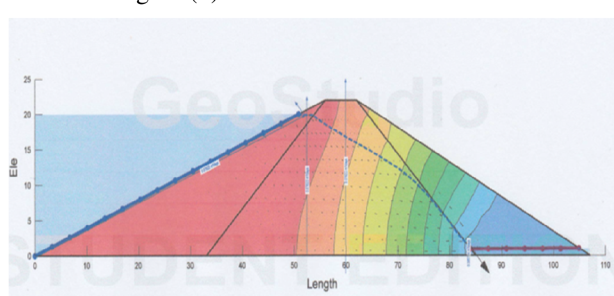


Fig. 6: Location of seepage line and equipotential lines by Geo-Studio program.

Unsteady state (time dependent) contaminates transportation through the dam is indicated in figure (7). The colored area represents the transmission of contaminates from the upstream or the source of the contaminants down through the earth dam. It is shown that the contaminate needs 70 days until reach the core zone as shown in figure (7).

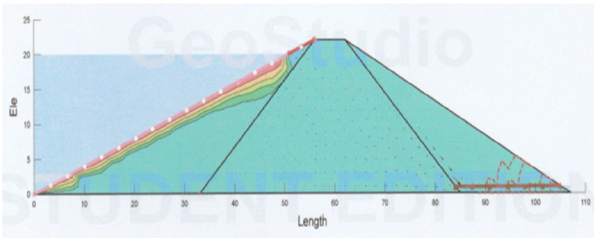


Fig. 7 : Computed transportation of contaminates until reach core zone.

Table 2: and figure (8) illustrate the effect of water level on the time rate of change of contaminates transportation and discharge through the earth dam till reaching the core zone.

Table 2 : Effect of reservoir water level on the rate of the time of contaminates transportation and discharge through the dam.

Head (m)	Time (day)	Discharge (m^3/day)
8	6800	0.01
10	4100	0.016
13	1000	0.027
16	780	0.044
18	350	0.058
20	70	0.076

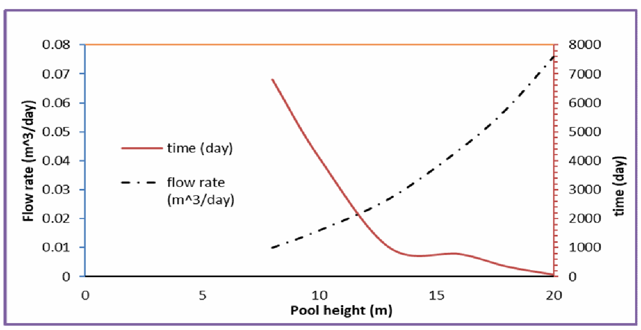


Fig. 8: Variation of water level in the U/S with the contaminant transportation and discharge.

(B) Comsol

Schematic diagram of the dam using COMSOL software is shown in figure (9). The finite element mesh that used for the analysis is shown in figure (10). The mesh type is triangular which cover the whole body of the dam. Number of elements is 365, minimum element size is 0.0322m, and maximum element size is 7.19 m.

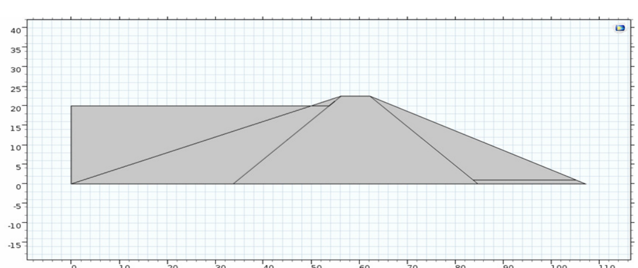


Fig. 9: Cross section of zoned earth dam.

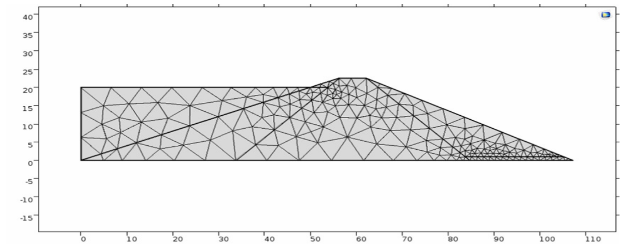


Fig. 10: Finite Element Mesh.

The flow net using COMSOL software is drawn and shown in figure (11). The colored bar line on the side represents a drop in the water pressure from (196200Pa) to (9810 Pa.) as shown in figure (11).

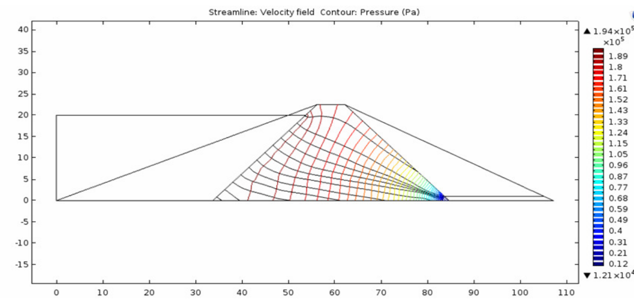


Fig. 11: Computed Seepage Flow, Streamlines and Equipotential lines.

Unsteady state (time dependent) contaminants transportation through the dam is indicated in figure (12); the colored area represents the transmission of contaminates from the upstream side or the source of the contaminants in the reservoir to the downstream side through the dam. It is shown that the contaminants need about 81 days until reaching the core as shown in figure (12) and about 4490 days to reach the D/S shell at maximum water level (20m) as shown in figure (13).

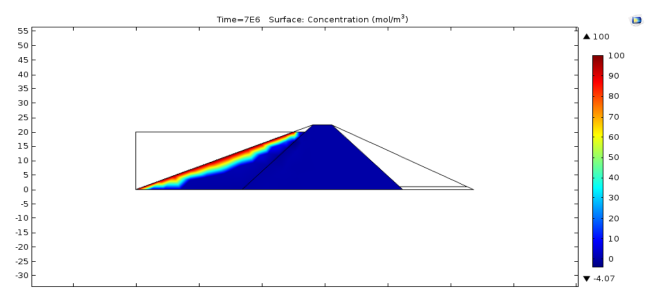


Fig. 12: Transportation of contaminants through the dam.

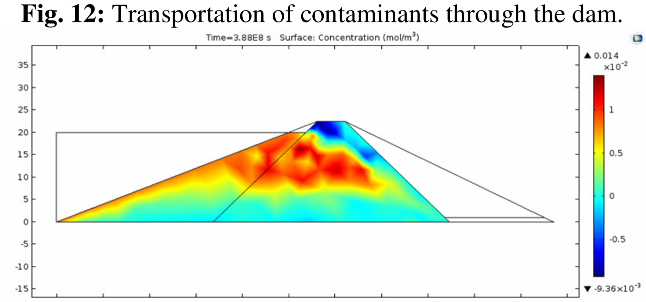


Fig. 13: Transportation of contaminants through shell and core zone.

Figure 14: illustrated the relationship between the concentration of contaminant and the time for 3 points selected randomly in the core of the dam. The location of the points is shown in figure (15).

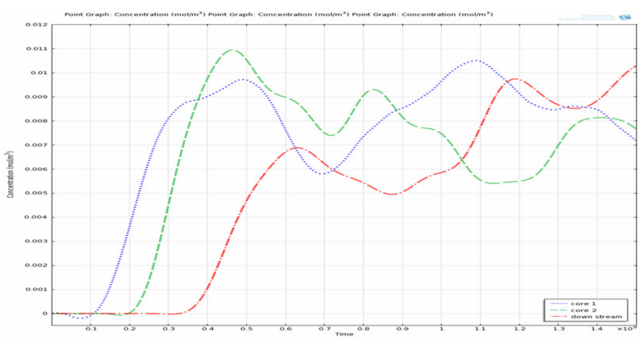
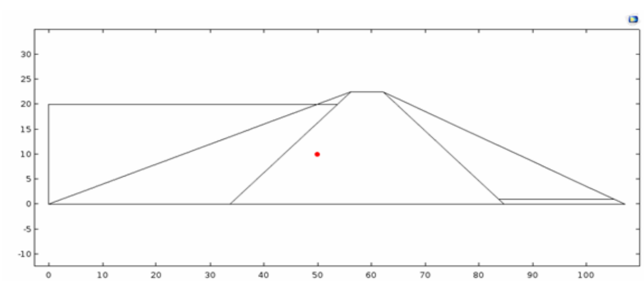


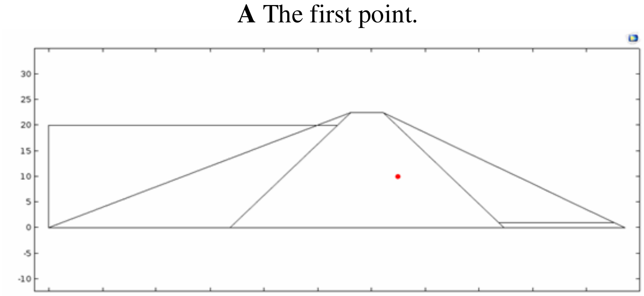
Fig. 14: Relationship between time and concentration for three points distributed in the body of the dam.

Fig. 14 indicates a relationship between the transportation of the contaminants with the time. In general, the contaminants start from the reservoir to the downstream shell.

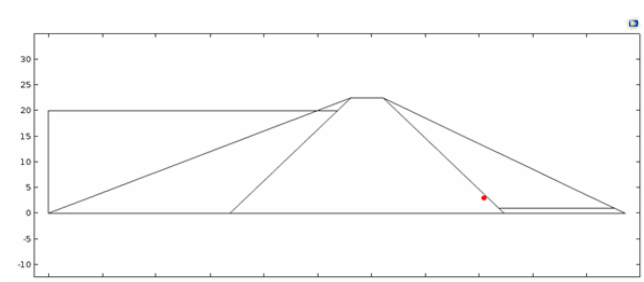
Moreover, the contaminants took about 0.1×10^9 sec to reach the first point, and took 0.2×10^9 sec to reach the second point, while it took about 0.35×10^9 sec to reach the third point in the core. Also, from the figure, it is shown that the three curves converge at about 1.35×10^9 sec.



A The first point.



B The second point.



C The third point.

Fig. 15 : Location of the points in the dam.

Conclusions

The following conclusions can be drawn from this research:

1. Flow through porous media and transportation of the contaminants are simulated by a 2D FE seepage flow model, which bases on the fundamental steady seepage flow equations for the zoned earth dam and definite conditions by using the COMSOL and Geo – Studio (SEEP/W sub program) programs. The program is applied on Harawa zoned earth dam to specify the quantity of seepage through the dam,, the location of the free surface seepage line and the total head measurements.
2. From using COMSOL software (CFD Module), it shows that the contaminate needs about 81 days to reach the core zone; while it needs about 4490 days to reach the D/S shell at 20m head of water level.
3. Geo- studio program indicates that the contaminate needs (70) days until it reaches the core zone and needs more than (3000) days for reaching the drain in D/S at 20m height of water level.
4. From the application of the two programs, it is shown that there is an acceptable correspondence between the programs in terms of contaminant transport.
5. There is an inverse relation between the effect of water level on the rate of change of contaminates transport; while the discharge through the earth dam varies as the water level changes.

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