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SEEPAGE CHARACTERISTICS ANALYSIS THROUGH HOMOGENEOUS EARTH DAMS USING THEORETICAL MODEL OF SEEP/W PROGRAM

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ABSTRACT: Seepage is used to express water movement in soil whether the flow take place through saturated or unsaturated soils. The seepage through the soil depend on several factors, the most important of which is hydraulic conductivity. When the soil is saturated, the value of hydraulic conductivity is considered a constant for each type of soil but when the soil is unsaturated, it becomes variable. There are many important factors effect unsaturated seepage through earth dam such as method of prediction of soil water characteristic curve (SWCC) and curve fitting parameters. In this research, finite element method is used to analyze seepage characteristics through homogeneous earth dam in steady state condition; therefore, SEEP/W program is used to compute the quantity of seepage. The effect of head boubary condition, method of estimation of conductivity function, curve fitting parameter (a), residual water content on the quantity of seepage was studied. Al- Gaara dam in Iraq is used as a case study to analyze seepage through it in both steady state and transient condition throughout study the effect of change of dimensions of fine filter and construction the dam without fine filter on amount of seepage. Results showed that the value of seepage using Fredlund and Xing theory is larger than value when using van Gentian theory. The amount of seepage was found to increase with increasing value of parameter (a) and residual water content. Small effect on seepage was noted when reducing the high of fine filter and when construct the Al- Gaara dam without fine filter at different level of water in upstream.

KEYWORDS: homogeneous dams, Gaarah dam, seepage, SEEP/W, fine filter

I. INTRODUCTION

Earth dams can be defined as economical hydro-engineering structures that are used for many purposes; firstly, they are used for protecting people from natural disasters such as floods. Secondly they are used for storing water for irrigation. Thirdly they are used for water supply and energy generation. Earth dam are the oldest type of used dams. They are generally constructed with available soil having high compaction (Sazzad et al., 2015).

Many problems from seepage and failures of earth-fill dams have occur due to inadequate seepage control (Omofunmi et al., 2017); Therefore, many theories have been used for solution of seepage problems such as Dupuit's, Schaffernak-VanIterson, Casagrande's and other solutions to determine discharge quantity through two dimensional homogeneous earth fill dams when the bases is an impervious (Al.Jairry, 2010). Finite element method was found is the better tool to analyze seepage through study of flow and deformation in zoned earth dam (Majeed, 2015).

Seepage results in ANSYS were found to be 18% lower than results in Geo-Studio while the results of slope stability were similar in both programs when analysis stability and leakage through Maroon dam in Bahaman (Kamanbedast and Delvari, 2012).

Analysis of seepage used finite element method in homogenous earth dam with no filter showed that when compare the suggest equation with artificial neural network (ANN), the error is less than 3% and with SEEP/W results less than 2% error, Dupuit’s solution has more than 20% error whereas Casagrande’s solution has more than 15% error (Jamel, 2016).

In this research, finite element method (FEM) using SEEP/W program was used for seepage analysis through homogeneous earth dams by investigate the effect of head boundary condition, method of analysis, curve fitting parameter (a), and residual water content on seepage quantity. Seepage analysis through Al- Gaara dam with changing fine filter dimensions under different height of water in upstream also studied.

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II. SEEP/W PROGRAM

SEEP/W can be defined is a finite element program. It is a sub- program of Geo- Studio used to do seepage analyses through saturated and unsaturated soils, it is also a general numerical modelling techniques that used for highly nonlinear problem which affected by the element size and material properties. For geotechnical and other engineering projects, SEEP/W is suitable and can be applied confidently **(**Irzooki, 2016). The following equation used in SEEP/W program.

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial h}{\partial y}\right) + Q = \frac{\partial \theta}{\partial t} \qquad (1)$$

where:
h: total head
k_x: hydraulic conductivity in x direction.
k_y: hydraulic conductivity in y direction.
Q: applied boundary seepage.
θ: volumetric water content.
t: time.
In steady state condition, seepage entering element and leaving it at all time is same (Abbas, 2017). So Equation 1 is modified to Equation 2 for steady state situation.

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial h}{\partial y}\right) + Q = 0 \qquad (2)$$

III. CONDUCTIVITY FUNCTION ESTIMATION METHOD

Direct measure of the unsaturated hydraulic conductivity is often difficult; therefore, predicting it from measured or predicted volumetric water content function usually used. In SEEP/W program, there are two theories used to estimate unsaturated conductivity function depending on saturated hydraulic conductivity function (GEO-SLOPE International Ltd, 2015).

FREDLUND AND XING THEORY, 1994

Unsaturated hydraulic conductivity function in this method is developed by integrating along the curve of the volumetric water content. The predicted equation is (Fredlund and Xing, 1994).

$$k_w = k_s \frac{\sum_{i=j}^{N} \frac{\Theta(e^{y}) - \Theta(\Psi)}{e^{yi}} \Theta'(e^{y_i})}{\sum_{i=j}^{N} \frac{\Theta(e^{y}) - \Theta_s}{e^{y}} \Theta'(e^{y_i})} \qquad (3)$$

where:
k_w: hydraulic conductivity at specific water content, m/s.
k_s: saturated hydraulic conductivity, m/s.
Θ_s: saturated volumetric water content.
e: 2.71828.
y: integration dummy variable which is negative pore pressure logarithm.
i: interval between j to N.
j: minimum negative pore water pressure.
N: maximum negative pore water pressure.
Ψ: suction equivalent to j^{th} interval.
Θ': first derivative of the equation.

$$\Theta' = C(\Psi) \frac{\Theta_s}{\left\{In\left[e + \left(\frac{\Psi}{a}\right)^n\right]\right\}^m} \qquad (4)$$

where:
a: air entry value for the soil.

n: parameter controls slope of the volumetric water content function at inflection point.
m: parameter correlated to residual water content.
C (Ψ): correcting function determined from Equation 5 where C_r is a constant correlated to matric suction related to residual water content.

$$C(\Psi) = 1 - \frac{In\left(1+\frac{\Psi}{C_r}\right)}{In\left(1+\frac{1000000}{C_r}\right)} \qquad (5)$$

VAN GENUCHTEN THEORY, 1980

In this method, unsaturated conductivity is determined with respect to matric suction as (van Genuchten, 1980).

$$k_w = k_s \frac{\left[1-\{a\Psi^{n-1}\}(1+(a\Psi^{n})^{-m})\right]^2}{\left[\{(1+a\Psi)^{n}\}^{\frac{m}{2}}\right]} \qquad (6)$$

a, n, m represent parameters of curve fitting and Ψ is the required suction range (Bunsri et. al, 2009). van Genuchten suggest Equations 7 and 8 to predict parameter m for Sp ranged from 0 to 1and for Sp greater than 1 respectively where Sp is the function slope determined from Equation 9.

$$m = 1 - exp(-0.8\, S_P) \qquad (7)$$

$$m = 1 - \frac{0.5755}{S_p} + \frac{0.1}{S^2{}_P} \qquad (8)$$

$$S_P = \frac{1}{(\Theta_S - \Theta_r)} \left|\frac{d\Theta_p}{d(log\, \Psi_p)}\right| \qquad (9)$$

where:
Θ_r: residual volumetric water content.
Θ_P: volumetric water content at the point of halfway of the function of volumetric water content.
Ψ_p : matric suction corresponding to same point mentioned above.
For parameter a, the following formula was suggested by van Genuchten.

$$a = \frac{1}{\Psi}\left(2^{\frac{1}{m}} - 1\right)^{(1-m)} \qquad (10)$$

IV. PARAMETRIC STUDY FOR HOMOGENEOUS EARTH DAM

Homogeneous earth dam is composed from one type of material. SEEP/W program was used to study seepage when the soil in the saturated- unsaturated case. Fig. 1 shows the sample models of homogenous earth dam that considered in this study. The dimensions are same as the dimensions of Al- Gaara dam.

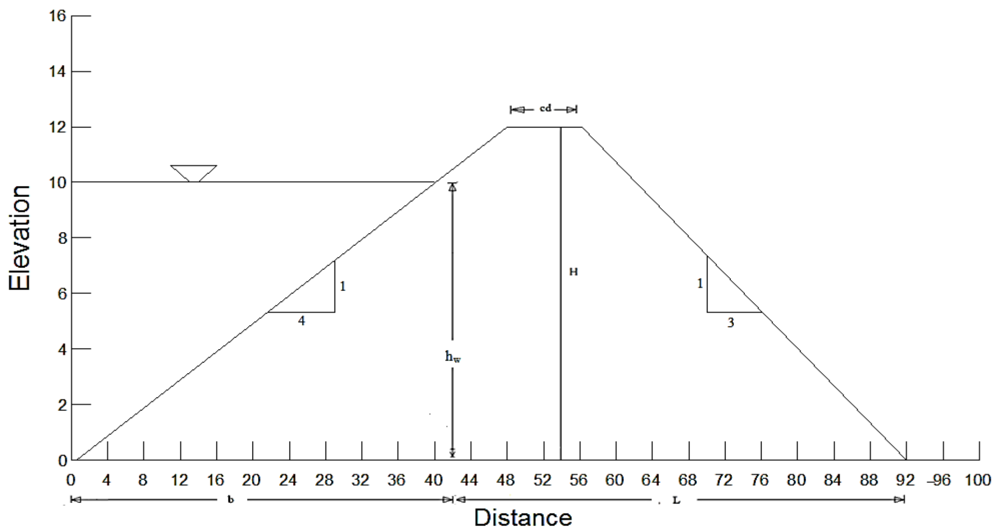

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Fig. 1: sample model of homogenous earth dam

H: Heigth of the earth dam (12 m).
h_w: Height of the water in the upstream , m.
L: Distance from the end of water height to end of dam, m.
Cd: Crest width of dam (8 m).
B: Distance from the front of the dam to the end of water height, m.
The relationship between the water content and the matric suction represent a curve called soil water characteristic curve (SWCC), the path of the curve can defined by curve fitting parameters (a, m, n) when values depend on the soil type. In this study, analysis of seepage through saturated-unsaturated soil was performed using the data according to values in fig. 2 (Ng and Menzies, 2017) which is illustrates the change in slope of the soil water characteristic curve (SWCC) with changing of the parameter (a) with constant (m and n) parameters. The effect of height of water in upstream (6, 8, 10) was studied to calculate amount of seepage through the dam with constant of both hydraulic conductivity (k_s= 0.00864 m/day) and residual water content (S_r = 0.1).

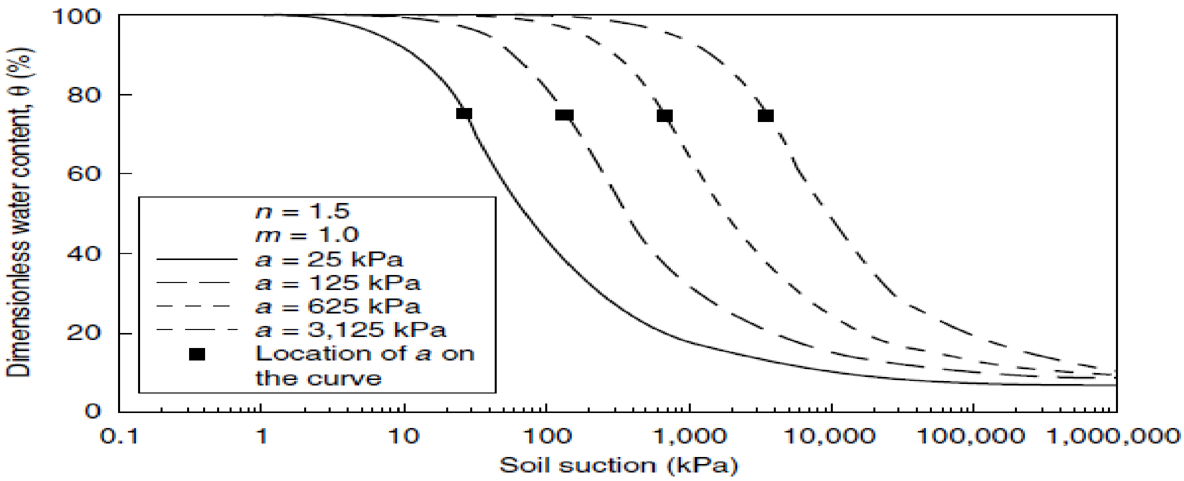

Fig. 2: Changing in SWCC curve with parameter (a) (After Ng and Menzies, 2007)

V. AL- GAARA DAM DESCRIPTION

The project of Al- Gaara dam is used for retention of floods and their seasonal regulation for the purpose of irrigation. The dam is located on Mlusi wadi, 5 km before its confluence with the other wadi in Al- Gaara depression, which is located 150 km north west of Rutba town. Fig. 3 shows the location of Al- Gaara dam. Table 1 shows the general properties for Al- Gaara dam.

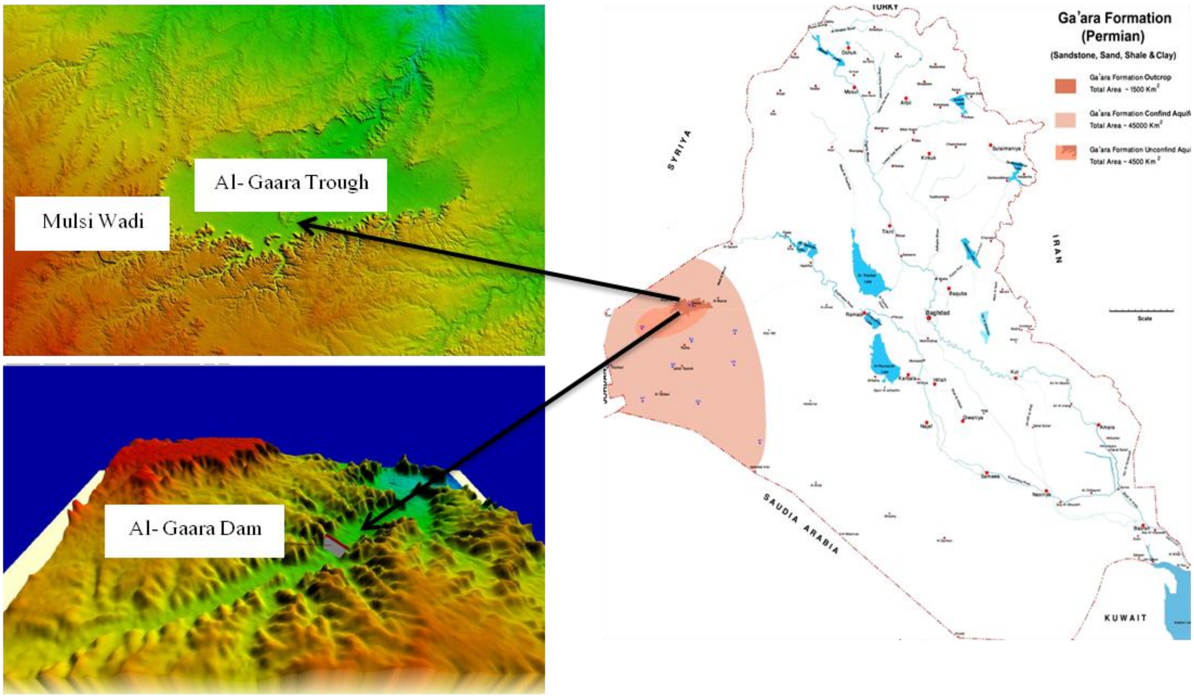

Fig. 3: location of Al- Gaara dam, Rutba city (After Sayl et. al, 2012)

Table 1: Properties of Al- Gaara dam

Properties	Value
Length of dam	700 (m)
Height of dam	13 (m)
Spillway length	350 (m)
Crest width	8 (m)
Total storage capacity	7750000 (m^3)
Excavation	51500 (m^3)
Works burial	280000 (m^3)
Maximum flood discharge	809 (m^3)

COMPONENTS OF AL- GAARA DAM

The dam consists of many regions. Volume of these regions changes according to location in dam. Fig. 4 illustrates the cross sectional the dam and Table 2 shows properties for material used in construction the of Al-Gaara dam.

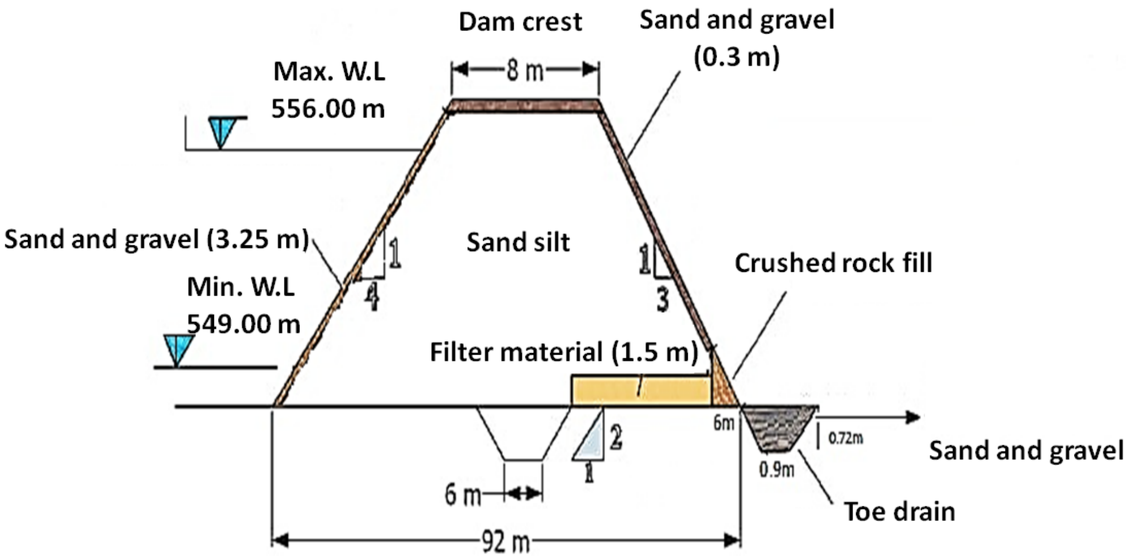

Fig. 4: Cross section of the Al- Gaara dam

Table 2: Hydraulic conductivity at different part of Al- Gaara dam

Type of material	Hydraulic conductivity [cm/s]	Volumetric water content	Residual water content
Sandy silt	1.15×10^{-4}	0.45	0.35
Fine sand	2×10^{-3}	0.4	0.35
Sand and gravel	0.1	0.5	0.3
crushed rock	10^{-3}	0.2	0.1

VI. RESULTS AND DISCUSSION

A) EFFECT OF HEED BOUNDARY CONDITION FOR TWO THEORIES OF ANALYSIS ON QUANTITY OF SEEPAGE

Figs. 5 and 6 illustrate change in seepage quantity with methods of analysis under different height of water at upstream (6, 8, 10) m when (L) is (40, 32, 24). It clearly shown that the seepage quantity decrease with decreasing height of water in upstream. Lee et al showed that the seepage flow through dams was found to be related with the reservoir water level (Lee et. Al, 2018). Also, it noted that Fredlund and Xing method give larger values of seepage than van Genuchten method due to differentiation in method of prediction of soil water characteristic curve, same result was observed by Jassam and Abdulrazzaq (2019).

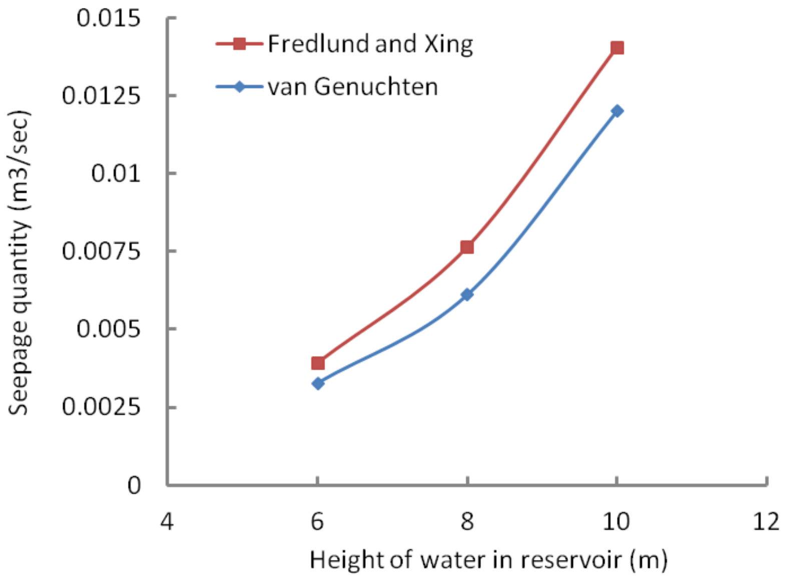

Fig. 5: Effect of methods of analysis on quantity of seepage at different height of water in upstream

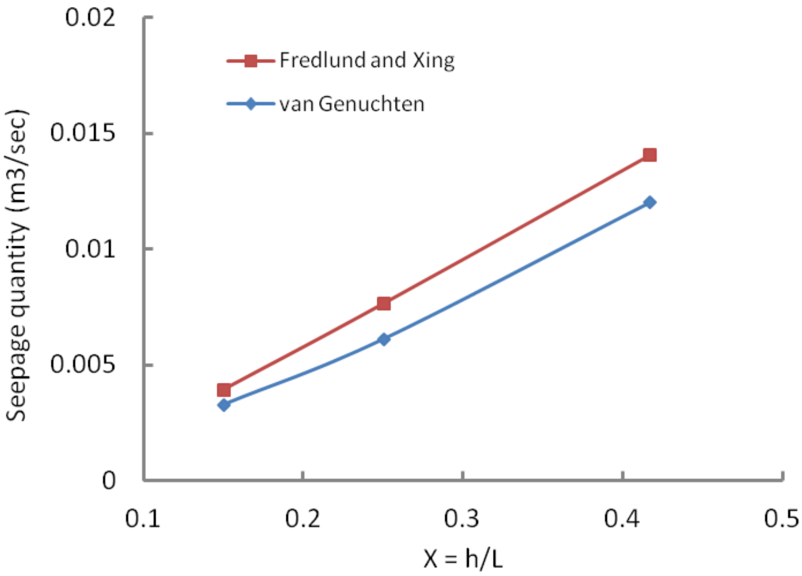

Fig. 6: Relationship between quantity of seepage and (h/L) at different height of water in upstream

EFFECT OF VALUE OF PARAMETER (A) ON QUANTITY OF SEEPAGE

Effect of change of value of parameter (a) with constant of n and m parameters and constant hydraulic conductivity on seepage quantity is show in fig. 7. It noted for Fredlund and Xing method that the quantity of seepage increase with increasing value of parameter (a) up to value of 125 kPa and then approximately constant whereas for van Genuchten method, the quantity of seepage increase with increasing value of parameter (a).

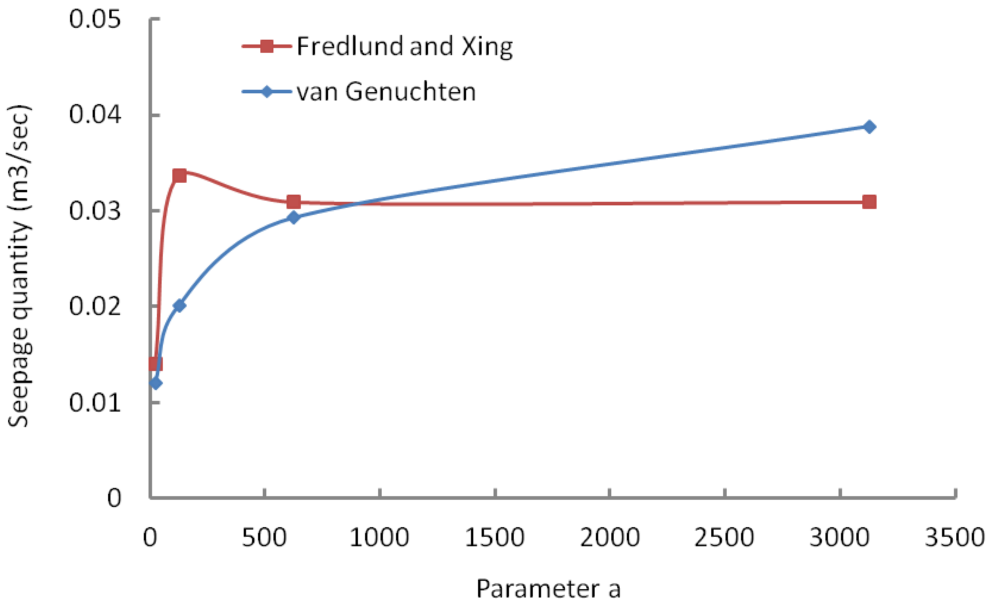

Fig. 7: Relationship between quantity of seepage and value of parameter (a)

EFFECT OF RESIDUAL WATER CONTENT ON QUANTITY OF SEEPAGE

Fig. 8 shows variation of quantity of seepage with different values of residual water content (0.1, 0.12, 0.14) with constant of (a, n, m) parameters. The values of (a, m, n) are (25, 1.5, 1) respectively and the value of hydraulic conductivity is (0.00864 m/days). It was noted that the quantity of seepage increase with increasing value of residual water content . This can be attributed to increase in unsaturated hydraulic conductivity with increasing residual water content and consequently increase in quantity of seepage. The amount of seepage for Fredlund and Xing method stay larger than that of van Genuchten method.

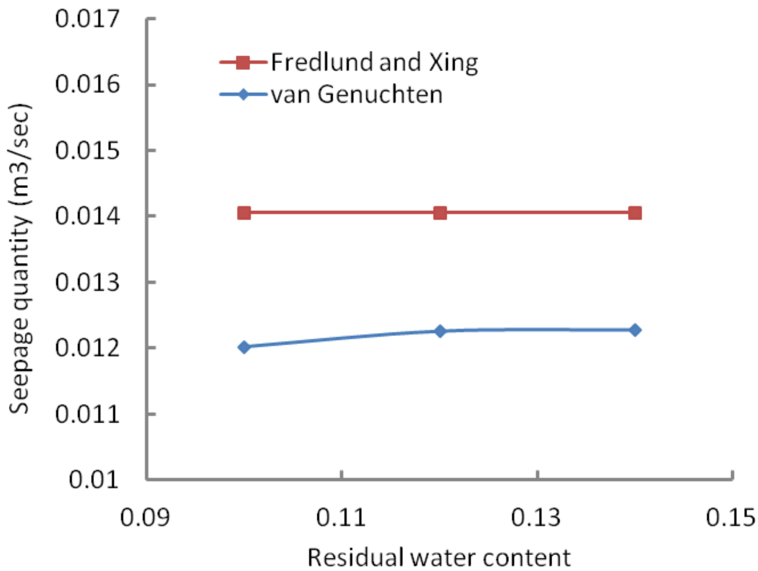

Fig. 8: Relationship between quantity of seepage and residual water content

B) SEEPAGE ANALYSIS FOR AL- GAARA DAM

The quantity of seepage that passing through cross-section area of Al- Gaara dam is calculated using SEEP/W program. The results for 8 m height of water at upstream are shown in fig. 9 using Fredlund and Xing theory and fig. 10 using van Genuchten theory. Fig.11 shows clearly that the seepage quantity decrease with decreasing height of water in upstream. Also, it was cleared noted that Fredlund and Xing method give large values of seepage than van Genuchten method. Al-Mansori et al. (2020), Abbas (2015), and Hammah et al. (2010) was found that the flow rate and exit gradient decreased with the decreases in the water height.

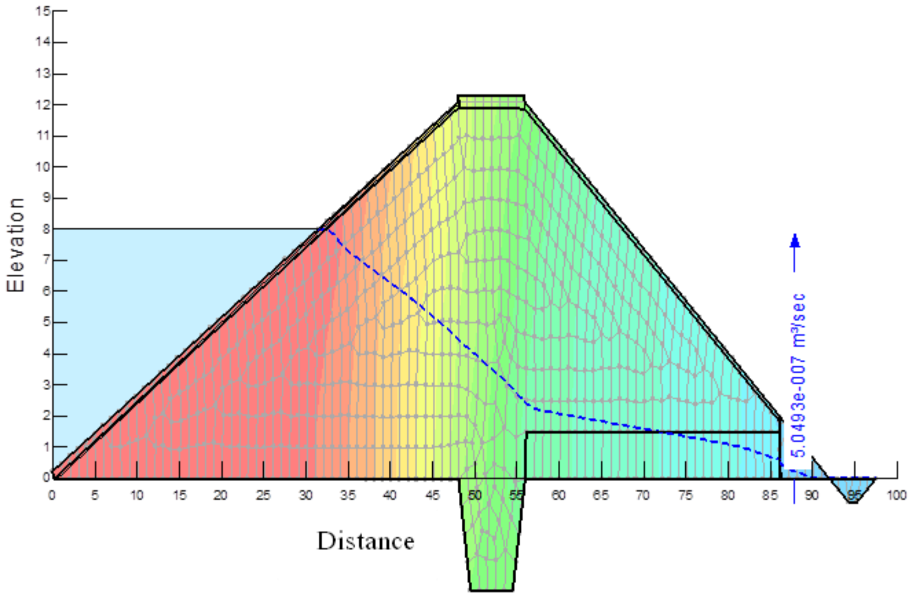

Fig. 9: Phreatic line and seepage quantity for Al- Gaara dam at 8 m head (Fredlund and Xing theory)

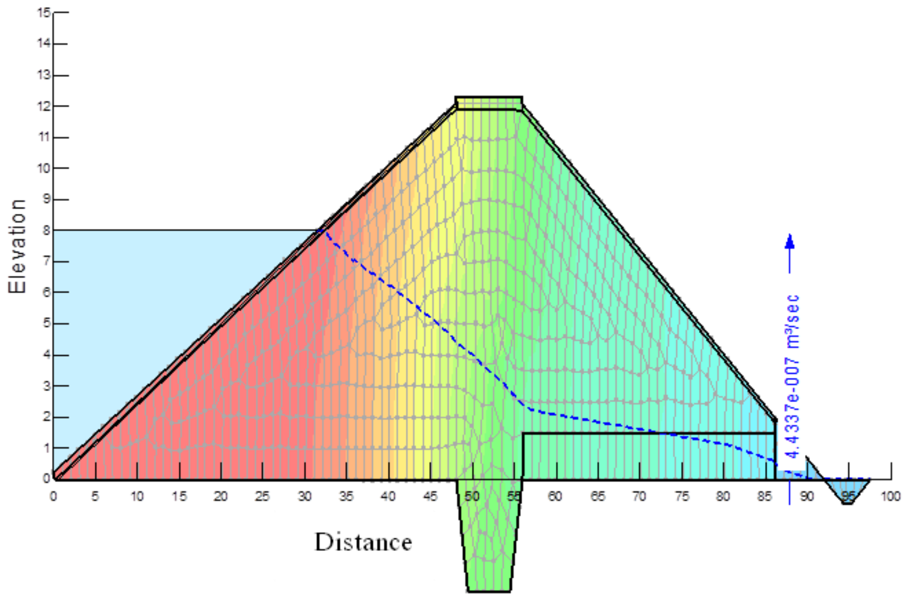

Fig. 10: Phreatic line and seepage quantity for Al- Gaara dam at 8 m head (van Genuchten theory)

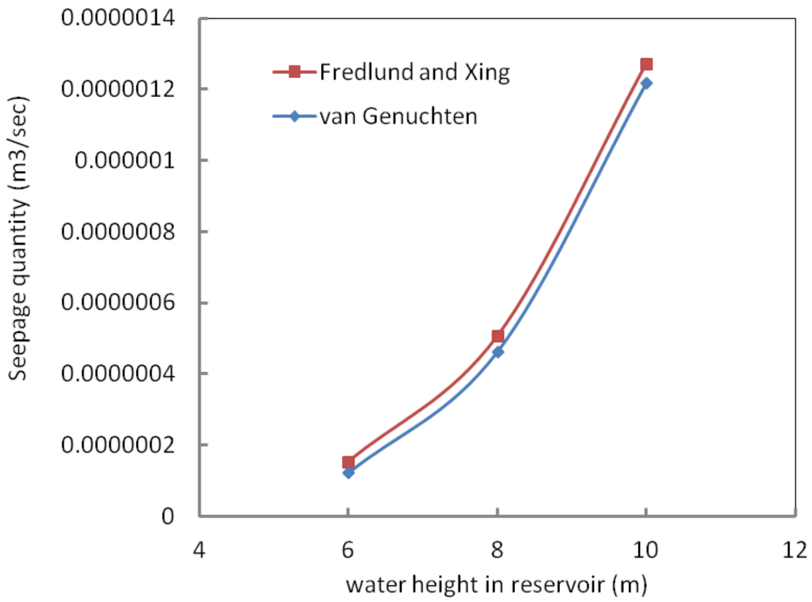

Fig. 11: Effect of method of analysis on quantity of seepage at different height of water for Al- Gaara dam

C) SEEPAGE CONTROL IN AL- GAARA DAM

REDUCE FINE FILTER THICKNESS

The effect of reduce of the thickness of fine filter on seepage through Al- Gaara dam using Fredlund and Xing theory is shown in fig. 12 for different height of water at upstream. It can be noted that the seepage quantity increased slightly when the filter thickness decrease. This can be attributed to that the filter in homogeneous dams represent part of dam body and any change in filter properties affect the seepage properties.

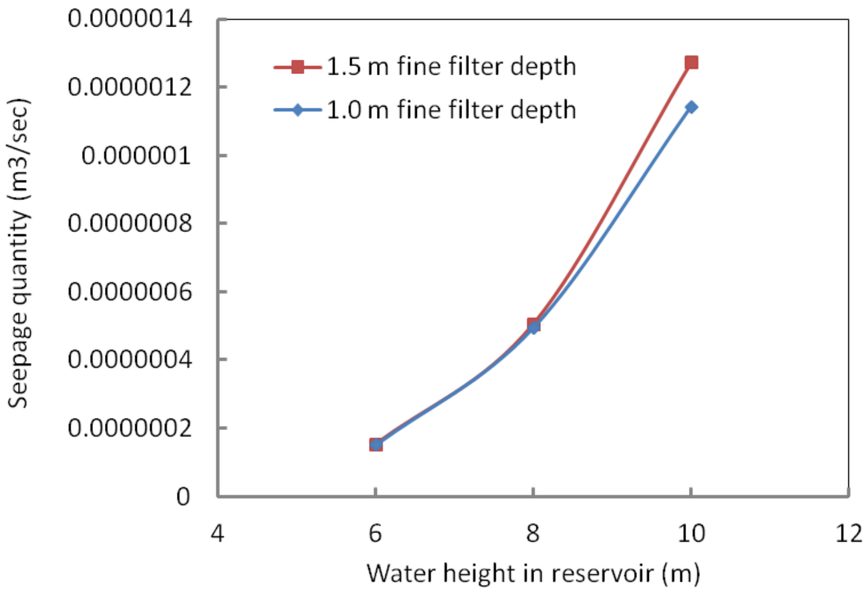

Fig. 12: Variation of seepage quantity with fine filter thickness at different water height in upstream

REPLACE FINE FILTER BY SHELL

The effect replacing fine filter by shell on seepage through Al- Gaara dam using Fredlund and Xing theory is shown in fig. 13 for 8 m height of water at upstream. Fig.14 shows clearly that the seepage quantity also slightly increased when the fine filter replaced by shell.

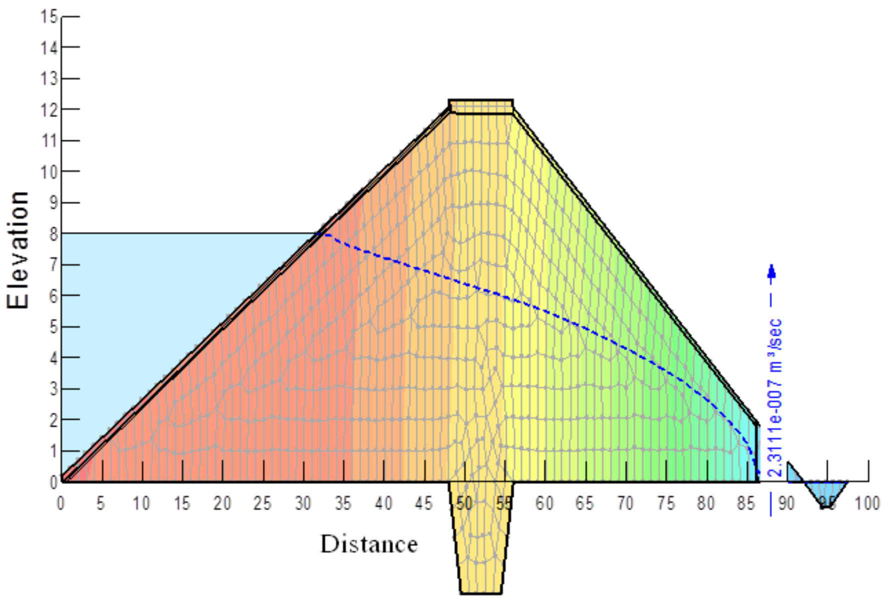

Fig. 13: Phreatic line and seepage quantity for Al- Gaara dam without fine filter at 8 m water head

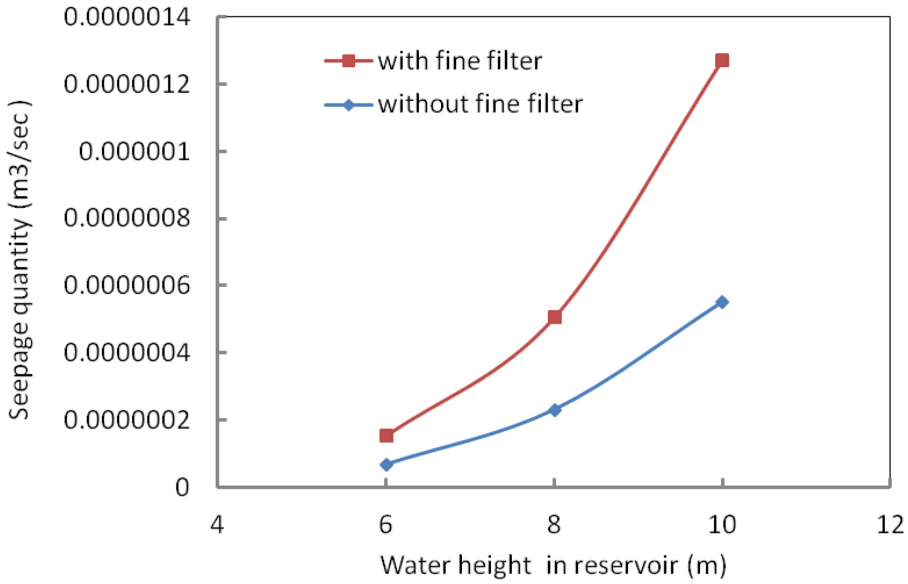

Fig. 14: Variation of seepage quantity with water height when the dam is with and without fine filter

EFFECT OF CHANGE OF TOTAL HEAD WITH TIME FOR TRANSIENT CASE

Fig. 15 shows the relationship between quantity of seepage with (h/ L) ratio through Al- Gaara dam using Fredlund and Xing theory at different times for transient case. It is noted that the relationship is nonlinear and the seepage increase when the value of (h/L) increase (i.e. water in upstream of earth dam is high and value of L is low).

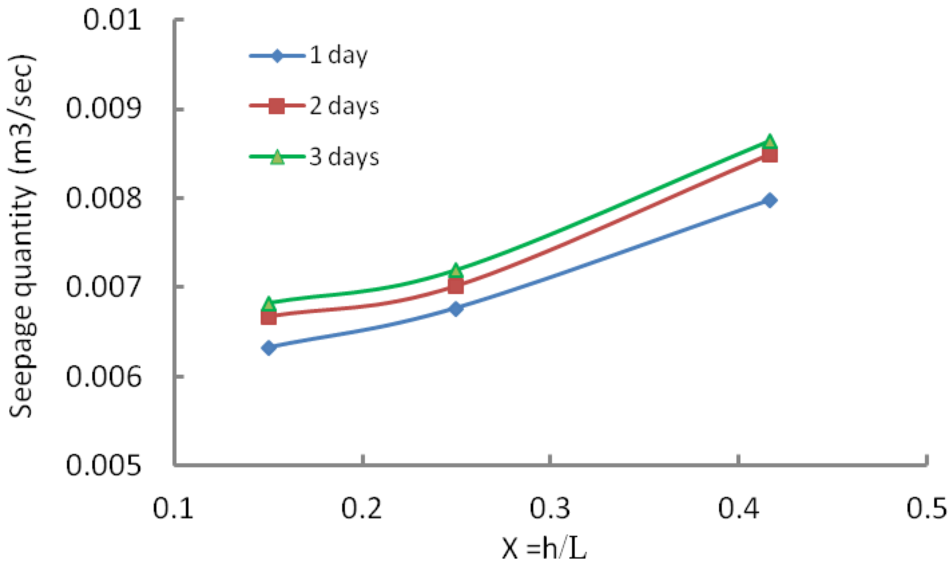

Fig. 15: Relationship between quantity of seepage and (h/L) in transient case for Al- Gaara dam

VII. CONCLUSIONS

Sub-program SEEP/W from Geo-Studio program was used to calculate quantity of seepage through homogeneous earth dam for steady state case and through Al- Gaara dam for steady state and transient cases at different water head in upstream. The following conclusions was found.

1- It is concluded that the quantity of seepage was affected by method of estimation of hydraulic conductivity, Fredlund and Xing method give large values of seepage than van Genuchten method**.**

2- The seepage quantity increased with increase of water height in upstream for both methods of analysis (Fredlund and Xing method and van Genuchten method).

3- Quantity of seepage increase with increasing curve fitting parameter (a) and residual water content.

4- Reducing height of fine filter increase slightly the quantity of seepage through Al- Gaara dam.

5- In general, the seepage quantity was small affected when reducing the height of fine filter or when replacing the fine filter by the shel I for Al- Gaara dam.

6- For transient case, the seepage quantity increase when the value of (h/L) increase.

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