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The effect of the cutoff wall conditions on the seepage characteristics of homogeneous earth-fill dams using SEEP/W

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Abstract: There are different methods to control the seepage flow and its problems in earth fill dams. Construction of cutoff wall is one of these methods. In this study, the influence of cutoff wall depth, position and permeability on two seepage characteristics were investigated using computer model of SEEP/W, in the homogeneous earth fill dams. These characteristics are total seepage discharge and outlet gradient. Extensive analyses were performed for different conditions of cutoff wall influencing the total seepage discharge and outlet gradient. Then, the results were presented by dimensionless curves. The effect of each parameter was evaluated on optimum state of cutoff wall. The results show that the best position of cutoff wall is about 0.4-0.6 of width of dam from heel. The best options of cutoff wall permeability for reduction in seepage characteristics are between 10^{-8} to 10^{-9} m/s. Investigation of Karkheh dam has been showed that the SEEP/W model results and Karkheh specification are almost the same. Also results showed that for Karkheh dam, the obtained depth of cutoff wall, as compared with the main constructed cutoff wall, is 3.5% more than actual depth. The reason of this difference is the heterogeneity of Karkheh dam foundation that ignored in this research.

Key words: *Seepage; Cutoff; Permeability; Homogenous; SEEP/W*

1. Introduction

Earth fill dams have low expense rather than concrete dams and can be established on partly weak foundation, therefore many researches have done at different fields of dam designing and accomplishment, around the world.

Since the dams are rarely built on quite impermeable lands, in most cases, there is a flow of water through the dam foundation. Lack of attention to this may result in increased drifted and hydraulic gradient, dam breach and the consequences of that. The importance of this issue to some extent is that the seepage is the second causes of dam's destruction in the world. Considering the foregoing, it is necessary to investigate dam seepage in order to reduce the damage. Generally, the control of earth fill dam's foundation seepage occurs for several reasons, including:

1. To Limit the amount of dam foundation seepage,
2. To Reduce the drift and lift forces ,
3. The outflow hydraulic gradient at downstream.

Cutoff wall is a common method for the seepage control. A lot of researches have been made on the impact of foundation and cutoff wall properties on the properties of seepage flow. Kalkani and Michali (1984) investigated the permanent seepage flow through earth fill dam - with impermeable core and homogenous non-isotropic foundation – under effect of cutoff wall depth variations and different ratios of foundation permeability. Goel and Patro (1987) and Goel Mandavia (1991) modeled the seepage flow of Kapur dam in Orisa state of India country, a roller compacted concrete dam with multilayered foundation, using an electrical method. They intended to achieve the optimal combination of the clay blanket length and depth of defective cutoff wall. They investigated the influence of upstream clay blanket on different cutoff wall depth (0-32) m and showed that, without using of clay blanket, the cutoff wall with depth ratio of 0.9, cutoff wall depth to foundation depth, can only decrease the seepage flow up to 50%. The optimal length of clay blanket obtained 5-7.5 times of reservoir's height. Griffiths and Fenton (1997) studied the two and three dimensional analysis of seepage problems based on different permeability, using finite element method. They found that the three dimensional seepage discharge is more than two dimensional one, but the difference isn't remarkable. Generally, the two dimensional analysis of seepage flow is a good approximation to its actual amount.

Feng et al. (2006) and Sayadzade and Zomorodian (2007) studied the flow properties of impermeable dams with variable bottom width, multilayer foundation and variables depth of the curtain shield, and the results are presented as curves of dimensionless Epsilon. Soleimanbeigi and Jafarzadeh (2006) performed seepage analysis of Chaco gravel dam, by SEEP3D software. Based on the

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results, the gradient of the three-dimensional analysis is greater than the amount of two-dimensional. Chen and Zhang (2006) performed three dimensional analysis of Gouhou rockfill dam's body water using saturated-unsaturated seepage theory. Yoromihi and Barzegari (2007) studied the cutoff wall and injection curtain of Chaparabad dam evaluating and choosing optimal sealing method. Afifi et al. (2007), investigate the height, width and position of cutoff wall at different models using SEEP/W. They illustrated the influence of each parameter on an anisotropic earth fill dam with three layered foundation. The results showed that cutoff wall height has tangible effect on seepage flow. The presented charts of Afifi et al. (2007) provide the designer engineer to be free of difficult solutions. Finally, proper dimensions of Dorodzan cutoff wall determined.

Malik et al., (2008) performed the multivariate sensitivity analysis combining different thicknesses of clay blanket, depth and position of cutoff wall, for determining the sealing method of Sath Para dam in Pakistan, and the size and conditions of the sealing obtained based on the results analysis. Haji Azizi and Shadbash (2008) studied the relation of cutoff wall length and thickness on foundation seepage flow and obtained the optimal thickness of wall, using SEEP/W. They resulted that, at the thicknesses larger than optimal thickness, addition of the thickness not only don't decrease the seepage flow, but also, will increase that. Shakir et al. (2009), also, examined the seepage through the dams with nonhomogeneous isotropic foundation. They stated that the most of existing studies have been conducted on impermeable dams, and there aren't the comprehensive and practical Memes to realize the effect of foundation and cutoff wall properties on seepage flow properties of earth fill dams, yet.

Therefore, the aim of this study is evaluating the effects of different conditions of cutoff wall on flow properties, by SEEP/W model. Therefore, the effect of cutoff wall main characteristics such as depth, impermeability and position on seepage flow properties will be investigated. Also, the optimal size and position of the seal wall will be determined.

2. Material and Methods

2.1. Governing equations

All kinds of water flows in media are three dimensional, physically. However, in many of issues flow is planar, which means that the flow combines of parallel planes having the same motion, so, one of the flow dimension can be neglected. For such systems, the flow is assumed to be two-dimensional and the complexity of the three-dimensional current is considerably reduced. If the fluid and flow environment be considered incompressible, and the environment be considered saturated, then the two-dimensional continuity equation is:

$$\frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} = 0 \qquad (1)$$

In equation 1, v_x is velocity along the flow (m/s) and v_y is the velocity perpendicular to the flow direction (m/s). Combining this equation with Darcy's law in the case of two-dimensional, two-dimensional Laplace equation for flow will be achieved.

2.2. SEEP/W model

This model is a 32-bit Windows graphics program which operates on the basis of finite element relationships, and has the capability of groundwater semi-saturated and saturated conditions modeling. This model, also, simulate the moisture content and pore water pressure as a continuous function of pore water pressure. Some of the SEEP/W model capabilities are followings:

- Calculation of hydraulic gradient and seepage flow of body and foundation of earth fill dams.
- Calculation of excess pore pressure after rapid depletion of the reservoir.
- Plots of velocity vectors, also, other plots such as potential lines, total water lines and etc.

In this study, the most striking capabilities of model, hydraulic gradient calculation and seepage rate, are used.

2.3. Specifications of hypothetical case study dam

The hypothetical case study dam's Specifications is a homogeneous earth fill dam with body permeability coefficient of 10 m/s, and the upstream and downstream water head, respectively, 75 and zero meter.

The upstream and downstream slope of dam was considered 1: 2.5. Media of dam foundation considered to be homogeneous with a maximum depth of 100 meters. In future charts, q_t and q_0 are, respectively, the total flow of the dam with and without cutoff wall, and I_e and I_0 are, respectively, exit gradient of the dam with and without cutoff wall. The used parameters are described in Fig. 1. The sensitivity analysis of model relative to the number of elements was performed before modeling.

To avoid the influence of the upper and lower boundary conditions on flow properties, the foundation prorogated along the upstream and downstream slopes 3 times of the water height behind the dam, i.e. 200 meters (Sayadzadeh and Zomorodian, 2007). The cutoff wall analyzed in depth, permeability and position aspects.

3. Results and discussion

3.1. The influence of the cutoff position (x) on total discharge (q_t) and outlet gradient (I_e)

In this section, the position of cutoff wall changed in stepwise from heel to toe of dam, and the seepage analysis was performed. In this status, the constant parameters are t=1m, $k_c=1\times10^{-10}$ m/s, $k_f=1.5\times10^{-5}$ m/s and d=100m. The range of S value is as 1-100 m. in the charts of this section, x is the distance of cutoff wall to heel, and L is dam bottom width. The results showed that in the case of incomplete cutoff wall (S/T<1), cutoff wall position change has no tangible effect on the rate of change of the total seepage flow, and seepage flow was almost constant with cutoff wall position changing (Fig. 2). In the case of Full cutoff wall (S/T=1), the total discharge is minimum at 0.4 < x/L < 0.6. With attention to the Figure 3, although there are fluctuations in output gradient, but relatively it can be said that; at 0.4 < x/L < 0.6 the output gradient is minimal, in both partial and Full cutoff wall. Therefore, based of seepage discharge and output gradient, the best position of cutoff wall is 0.4 < x/L < 0.6, which be selected based on the advice of the consultant and the contractor.

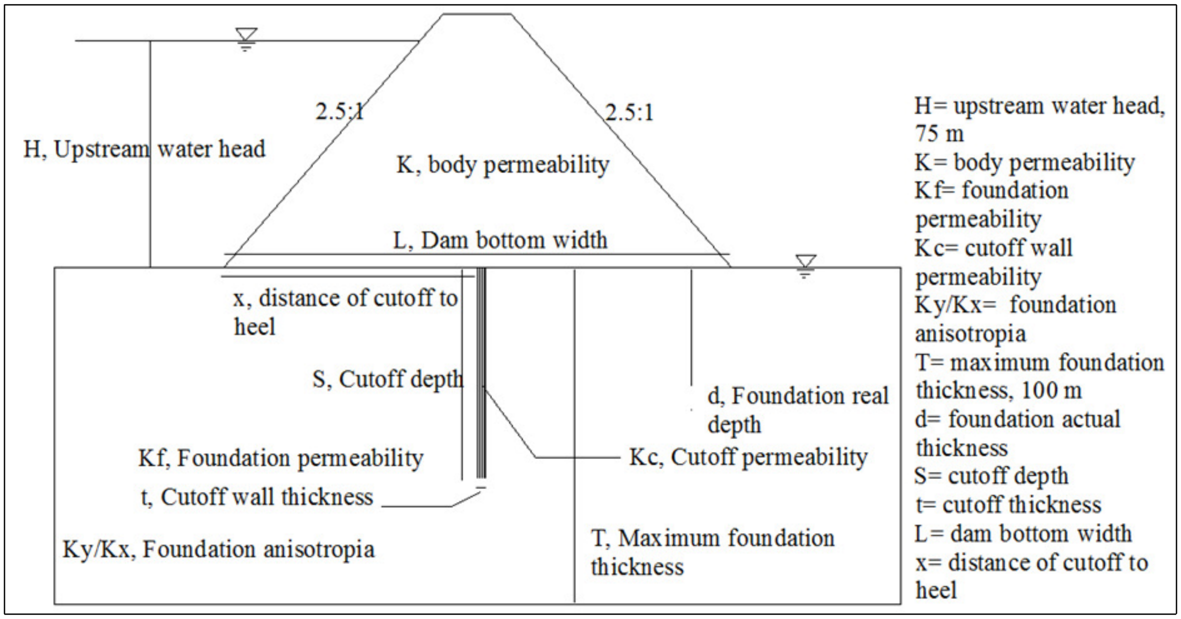

Fig. 1: The sketch of dam and parameters modeled is SEEP/W Software

Meanwhile, in the high permeability of foundation, due to the large difference between the cutoff wall and the foundation permeability, permeability has no impact on the output rate of the output gradient, practically and resulting the seepage properties tends toward a constant value at a constant depth of the cutoff wall.

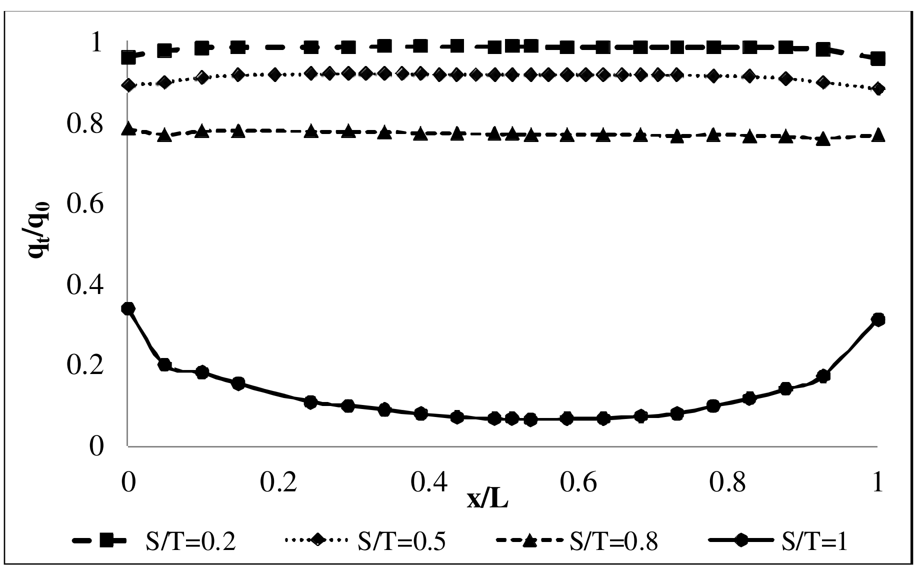

Fig. 2: The influence of cutoff position on total seepage discharge

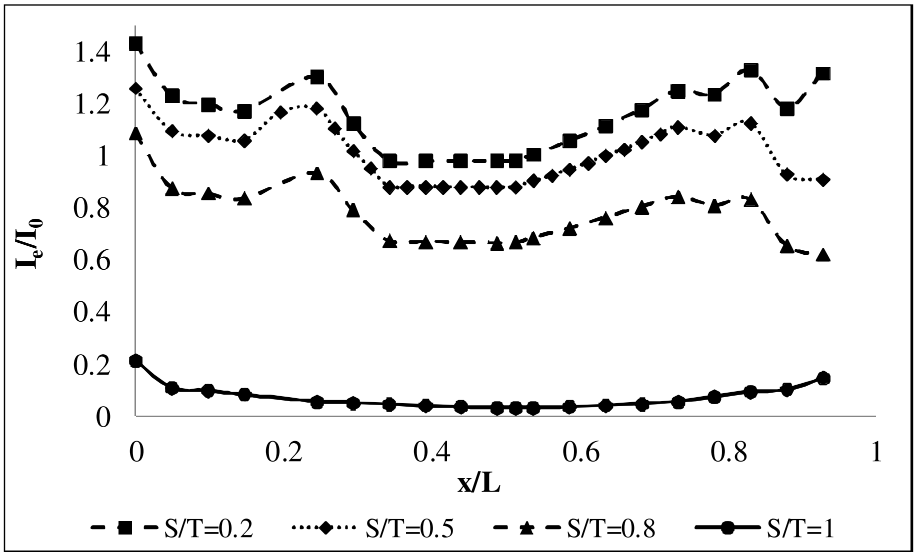

Fig. 3: The influence of cutoff position on outlet gradient

3.2. The influence of cutoff wall depth on total discharge (q_t) and outlet gradient (I_e)

In this status t=1 m, k_f=1.5×10^{-5} m/s and d=100m. The range of S value is as 1-100 m. The k_c Value is variable from 1×10^{-7} to 1×10^{-10}m/s, and in one case the cutoff wall was completely impermeable. The results were plotted based on flow characteristics relative to the cutoff wall and showed that, at the assumption of homogeneous dam, the total discharge reduces non-linearly by increasing the cutoff wall depth (Fig. 4).

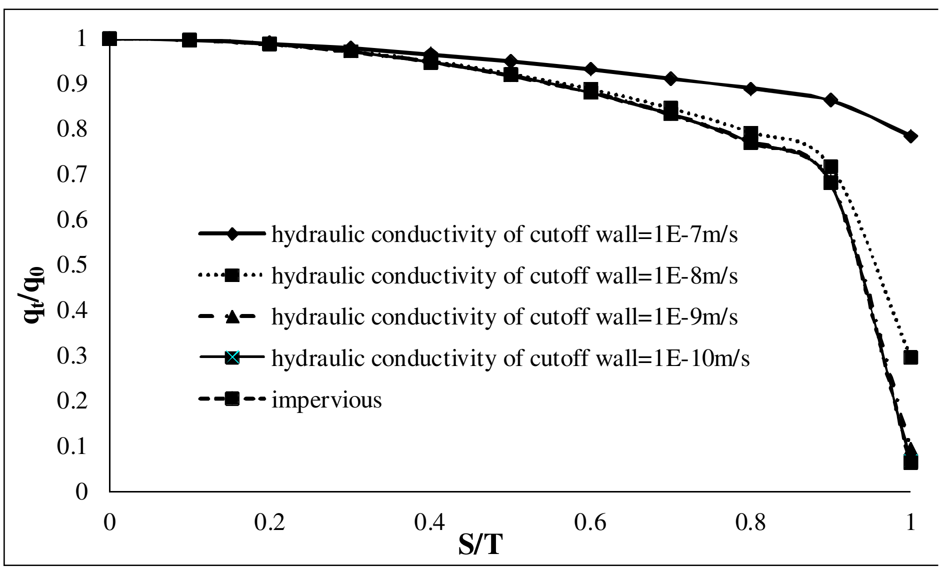

Fig. 4: The influence of cutoff wall on total discharge

As can be observed in the Figure 4, if the depth ratio of the cutoff wall and foundation is 90%, total flow rate decreases up to 30%. On the other hand, the output gradient decreases with increasing of cutoff wall depth. It seems logical because the water flow path is lengthened and $\Delta H / \Delta L$ B is reduced. The results indicate that incomplete cutoff wall has no significant effect on the output gradient, so that, with an increase in the depth of cutoff wall up to 90% of foundation depth, output gradient reduced maximally 70% (Fig. 5).

The influence of cutoff wall permeability coefficient (K_c) on total discharge (q_t) and outlet gradient(I_e)

In this status t=1 m, k_f=1.5×10^{-5} m/s and d=100m. The range of S value is as 1-100 m. The k_c value is variable from 1×10^{-7} to 1×10^{-10}m/s, and in one case the cutoff wall was completely impermeable. The results were plotted based on flow characteristics relative to the cutoff wall impermeability and showed that there is a non-linear relation between total discharge and cutoff wall impermeability (Fig. 6), and, only, the intensity of variations is more remarkable at higher depth of cutoff wall (Fig. 7). As shown in Figures 6 and 7, the total discharge values of cutoff wall with zero to 10^{-9} m/s impermeability and different depths is almost identical. Thus the impermeable cutoff wall or cutoff wall with permeability 10^{-10}m/s can be replaced with a cutoff wall with 10^{-9} m/s permeability, which are economically affordable.

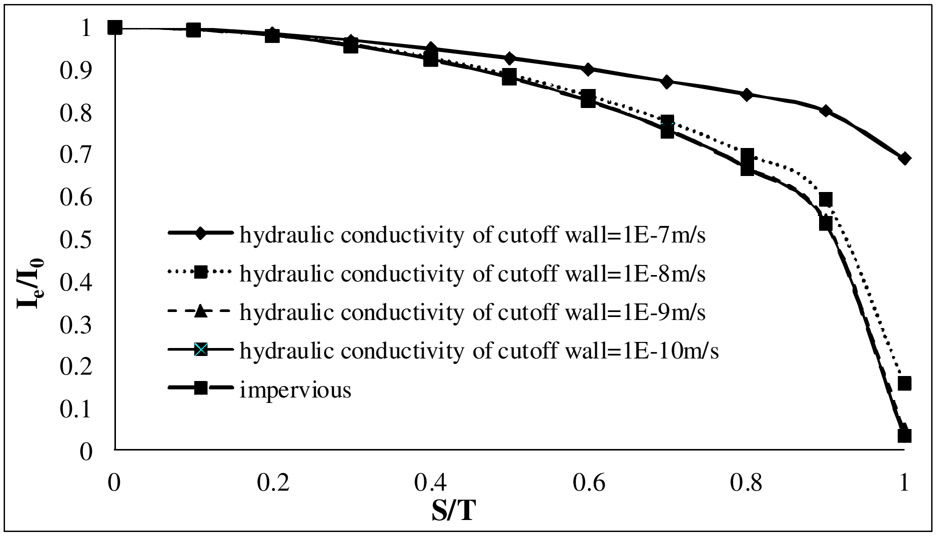

Fig. 5: The influence of cutoff wall depth on outlet gradient

Also, since the difference between the total flow rate and outlet gradient of cutoff wall with 10^{-7} m/s and 10^{-8} permeability is high, therefore, the cutoff wall with permeability 10^{-7} m/s and higher depth can be replaced with the cutoff wall with permeability 10^{-8} and less depth, which is economically affordable, too. In other words, the best options, in terms of cutoff wall permeability and the seepage and output gradient control, are the permeability coefficient between 10^{-8} and 10^{-9}m/s.

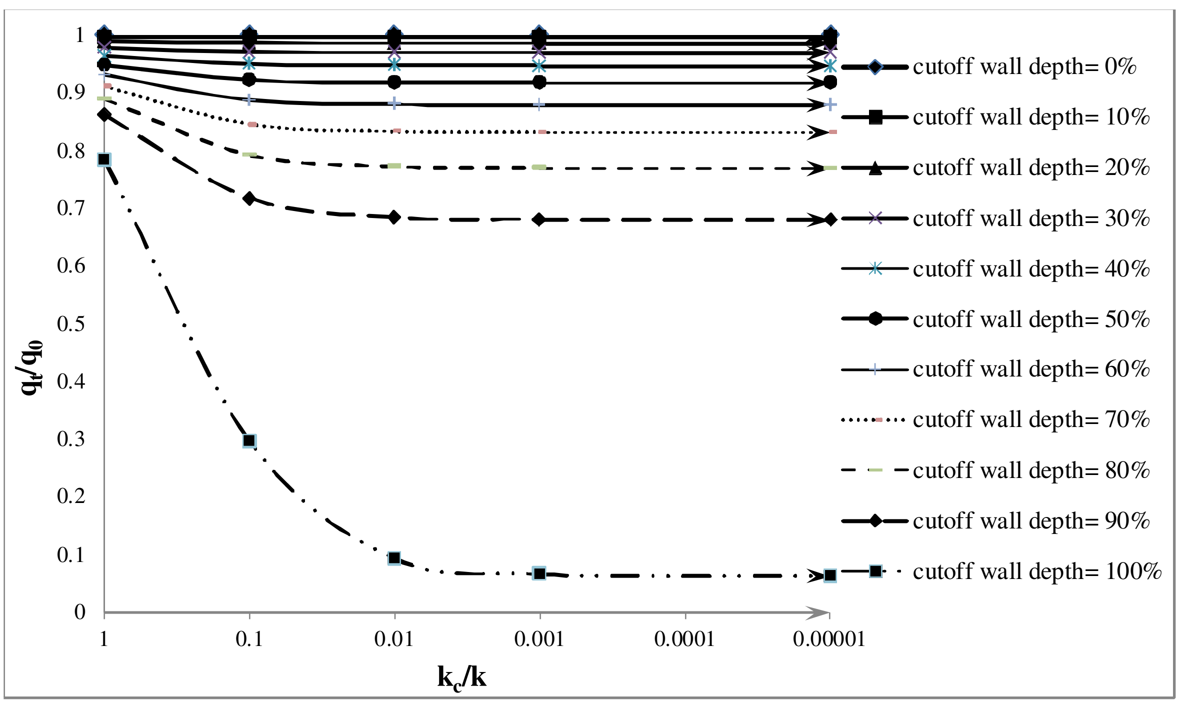

Fig. 6: The influence of cutoff permeability on total seepage discharge in different cutoff wall depth

3.3. Study of Karkhe Dam

The Karkheh dam is a clay core earth fill dam with that its dimensions are presented at Table 1. The input data to determine the optimal dimensions and position of Karkheh cutoff wall is showed in Table 1. After data processing and the use of non-dimensional curves, the optimal position of Karkheh cutoff wall obtained as Table 2 that the results can be compared with the results of the software.

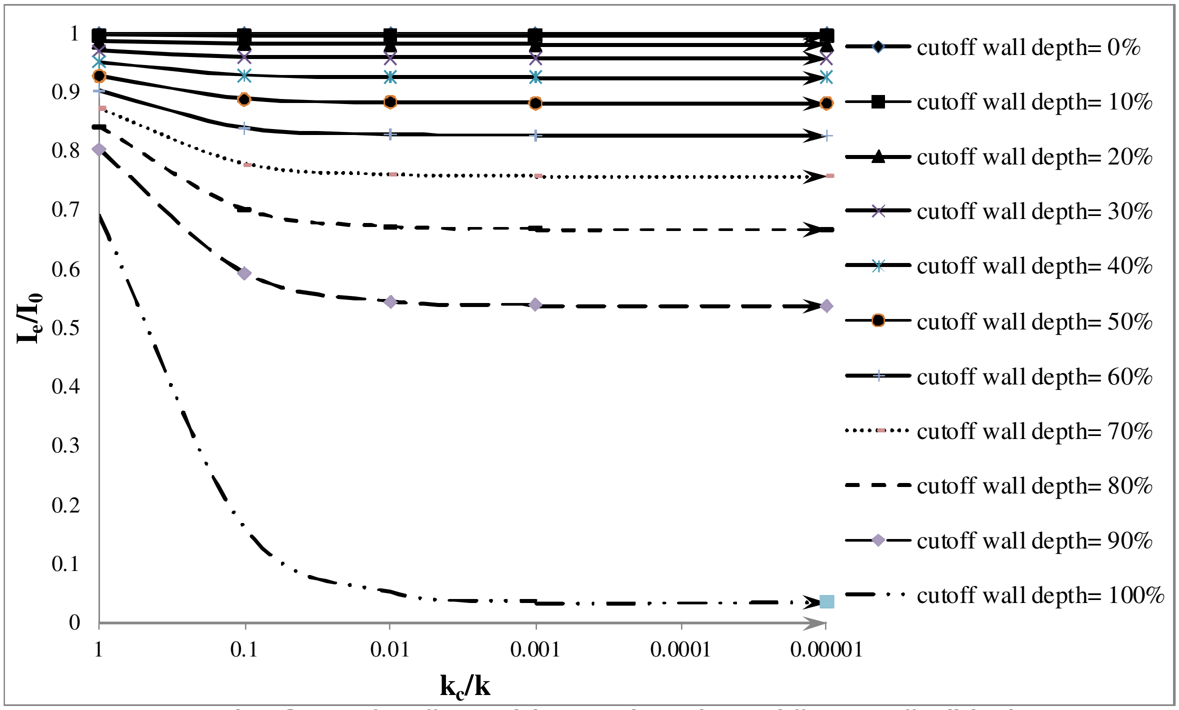

Fig. 7: The influence of cutoff permeability on outlet gradient in different cutoff wall depth

Based on Table 2 it is clear that the software results almost the same value as the real specifications of Karkheh dam. The cutoff thickness range of real condition is 0.8-1.2 m that the SEEP/W results 1 m for that (the average of 0.8-1.2 m). There is only a little difference between real and software values at cutoff wall depth, about 3.5%. The reason of this little difference can be due to the foundation heterogeneous of Karkheh dam that its effect didn't included in the proposed algorithm of this study.

Table 1: The dimensions of Karkheh dam

Property	Value
Height	127 m
Length	3030 m
Crest width	12 m
Maximum bottom width	110 m
Weir	gated Ogee
Weir capacity	18260 m³/s
Reservoir volume, at operation level	450 mcm
Reservoir area	47 km²

4. Conclusion

In this study, the effect of cutoff wall specifications on total discharge and outlet gradient of homogenous earth fill dam is investigated using SEEP/W. Based on the obtained results and analyzes in this study, it can be said briefly that the total flow rate and outlet gradient decreases by increasing the cutoff wall depth.

Table 2: The input data to determine the optimal dimensions and position of Karkheh cutoff wall

L(m)	T(m)	q_t/q_0	k (m/s)	k_f (m/s)	k_y/k_x	I_e/I_0	ΔP/H
1070	34.5	0.3	1×10^{-9}	3.115×10^{-5}	1	0.65	0.45

Based on the results, even if the ratio of cutoff wall depth is 90 percent of foundation depth, the seepage properties decrease up to 50 percent. The optimal option in terms of reducing the flow rate and output gradient is the cutoff wall with permeability of 10^{-8} to 10^{-9} m/s. Generally, in the cutoff wall properties, respectively, the cutoff wall depth and permeability and cutoff wall position has the greatest impact on seepage properties. With the case study analysis of Karkheh seepage flow using algorithm, the cutoff wall depth achieved 29 m that this depth is about 3.5 higher in comparison with the original Karkheh dam cutoff wall. This could be due to the foundation heterogeneous of Karkheh dam that it doesn't included in this research.

Table 3: The optimal position of Karkheh cutoff wall

	Real	Software
x/L	0.56	0.56
x (m)	600	600
S/T	0.84	0.87
S (m)	29	30
t (m)	0.8-1.2	1

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