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Investigation of seepage, uplift forces and hydraulic gradient under hydraulic structures with different configurations of dual-cutoff walls

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ABSTRACT: In the design of hydraulic structures, cutoff walls are needed for the reduction of uplift force and exit hydraulic gradient. The upstream cutoff wall is used for the reduction of the uplift force and the downstream cutoff wall is used for the reduction of the exit hydraulic gradient. This study tends to numerically investigate the double-cutoff beneath the hydraulic structures with variation in their location, distance and depth. Governing equations with boundary conditions are solved using the finite element method (FEM). Results showed that if the downstream cutoff wall is deeper than the upstream cutoff wall, the resultant uplift force would be more than the uplift force without cutoff walls. With a constant value for hydraulic structures width (B), decreasing in the distance between two cutoffs (L), results in the reduction in uplift force. Increasing in impermeable depth (D) and reduction in B, yields lower uplift force. Increasing in downstream cutoff depth (d2) and L, results in reduction in exit hydraulic gradient (GR). When the two cutoffs are located in the end of the hydraulic structure, GR is lower than that when the downstream cutoff is located in L/B=0.33 and L/B=0.66 from the upstream cutoff. Comparison between the available analytical solutions for two equal ending cutoffs with FEM, showed that FEM could predict PC and GR with a maximum 5% error.

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1- Introduction

If the piping phenomenon or scouring under the foundation is not stopped, it may lead to the collapse of the structure. Although the construction of a cutoff wall is one of the methods to reduce seepage from under earth dams, but the study of its effect on the position of the phreatic line and the amount of seepage discharge is of particular importance. Because the phreatic line is the boundary separating the saturated and unsaturated zone and determining its position is important in the stability of earth dams. The use of cutoff walls is one of the most common methods to deal with seepage in water storage structures such as dams, reservoirs, embankments and irrigation canals [1]. Nourani et al. [2] investigated the performance of foundation drains in reducing the uplift force in gravity dams. The results showed that increasing the drain diameter has little effect compared to other parameters in reducing the uplift force. The effect of relief well downstream of the earth dam on the reduction of uplift pressure was investigated by Salmasi et al. [3]. In that study, the depth of wells, their distance and diameter were considered variable and diagrams were provided for the design of such wells. Salmasi et al. [4] investigated the effect of inclined clay core on the earthen dam stability by LEM and FEM methods. The results showed that the stability of the upstream slope of the earth dam with an inclined clay core is higher than the vertical clay core. A review of past researches has shown that most previous studies have been related to one cutoff wall under the structure and the effect of two cutoff walls of the structure has been done simultaneously at a limited level. Usually, in the design of hydraulic structures, two cutoff walls are required. The upstream cutoff wall is used to reduce seepage flow and uplift force, while the downstream cutoff wall is used to reduce the exit hydraulic gradient (piping phenomenon). Therefore, in the present study, the effect of the placement of the dual cutoff wall on the hydraulic structures in terms of position, distance and also the depth of their application in the amount of uplift force, seepage discharge from the structure and exit hydraulic gradient is investigated.

2- Methodology

In this study, SEEP/W software, which solves the differential equations along with boundary conditions using the finite element method (FEM), has been used for modeling flow in a porous medium. In order to investigate the effect of dual cutoff walls on the uplift force distribution, the resultant uplift force, exit hydraulic gradient and seepage discharge from hydraulic structures, 330 numerical models were simulated. The range of important parameters in this study is presented in Table 1.

In Table 1, d_1 is the upstream cutoff depth, d_2 is the

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Table 1. Dimensionless parameter values in this study

Dimensionless parameters	Values					
(B/D)	0.7	0.9	1.25	1.5	1.75	**2**
(B/d_2)	4	6	8	10	15	**20**
(L/B)	0.33	0.66	1	-	-	**-**
(d_2/d_1)	0.66	1	2	-	-	**-**

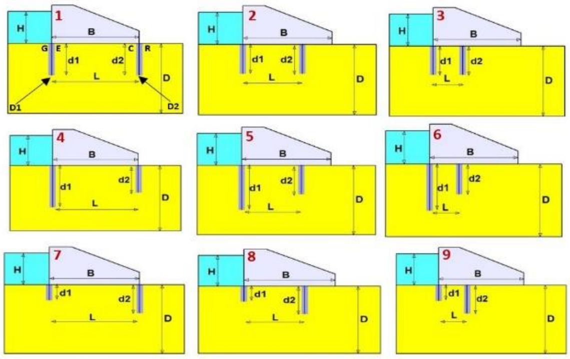

Fig. 1. Illustrations of different configurations of double cutoff walls under the hydraulic structure

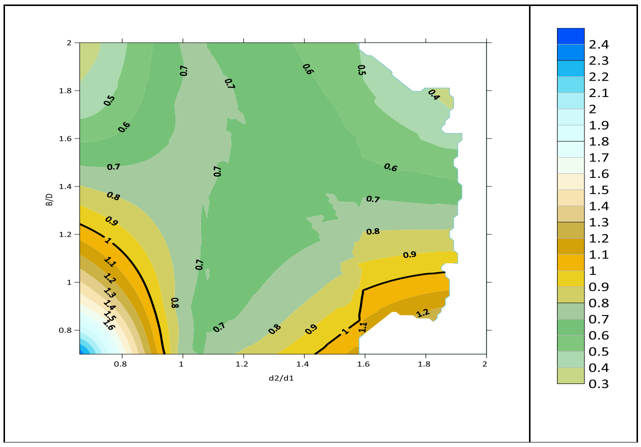

Fig. 2. Contours of U/Uo as a function of d2/d1 and B/D

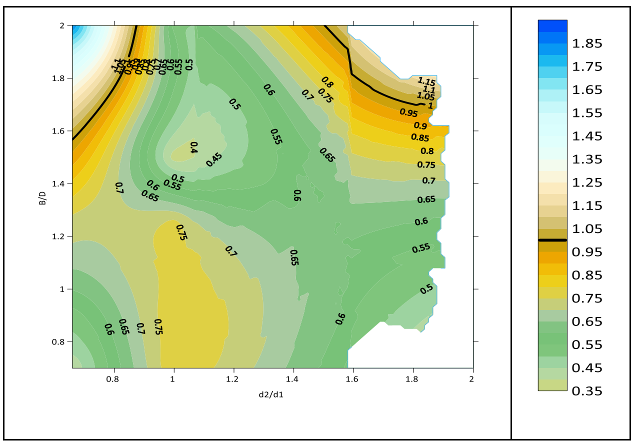

Fig. 3. Contours of GR/GRo as a function of d2/d1 and B/Dm

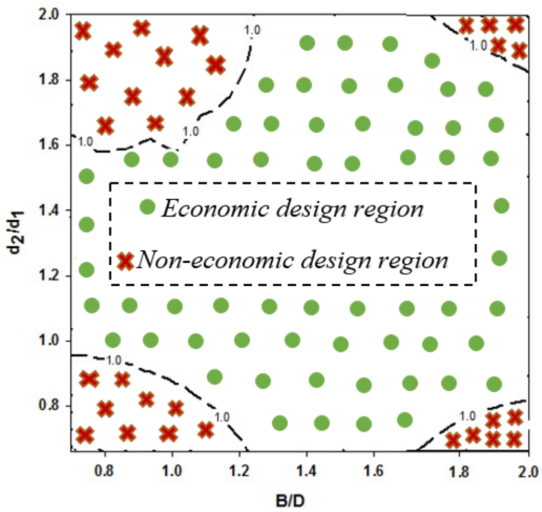

Fig. 4. The intersection of two Figures 2 and 3 to determine suitable and unsuitable areas for the design of two cutoff walls

downstream cutoff depth, L is the distance between the two cutoffs, D is the depth of permeable foundation, and B is the width of the apron. Figure 1 shows the position and location of cutoffs and the geometric parameters in the present study.

3- Results and discussion

Figure 2 shows the relative uplift force contours (U/U_o) against d_2/d_1 and B/D changes. Relative uplift force contours are highlighted to indicate the boundary between economic and non-economic design. This means that for a relative uplift force of less than one ($U/U_o<1$), the relative uplift force is reduced and therefore offers a cost-effective design. Figure 3 provides the exit hydraulic gradient (GR/G_{RO}) against d_2/d_1 and B/D variations. In this case, for a relative hydraulic gradient of less than one ($G_R/G_{RO}<1$), the relative hydraulic gradient decreases and therefore presents an economic plan. The intersection of Figures 2 and 3 refers the suitable and unsuitable ranges for the design of two cutoff walls (Figure

4- Conclusions

To the best knowledge of the authors, the effect of the combination of two cutoff walls under a hydraulic structure has not been fully studied until now. Most prior research comprises a single cutoff wall. Some existing studies have considered the two cutoff walls with equal depth and with fixed locations, one in the upstream portion and the other in the downstream region of a hydraulic structure. The present study has investigated the simultaneous effects of two cutoff walls under a hydraulic structure and their combined influence on uplift force (U) and exit hydraulic gradient (G_R). The main outcomes of the present study are summarized below:

-A comparison between the results of the analytical method presented by Jane and Reddy [5] and the numerical model of finite elements method (FEM) showed that the numerical method with an error of less than 5% could estimate the pore water pressure at the end of the structure and the exit hydraulic gradient.

-If the downstream cutoff wall is deeper than the upstream cutoff wall, it will increase the uplift force compared to the without cutoff wall state.

- For a fixed width for the structure, the uplift force decreases as the distance between the two cutoff walls decreases.

- By increasing the distance between the two cutoff walls and increasing the depth of the end cutoff wall, the exit hydraulic gradient decreases.

- By increasing the depth of the cutoff wall in downstream, the amount of seepage discharge through the structure decreases.

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