EFFECT OF VARYING GEOMETRICAL CONFIGURATION OF SHEET PILES ON EXIT GRADIENT AND UPLIFT PRESSURE

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ABSTRACT: Seepage becomes an inevitable concern when dealt with earthen dams, as the impounded water seek paths of least resistance through the dam and its foundation. Seepage, if uncontrolled, can erode soil from the embankment or foundation causing progressive or rapid erosion and piping of the embankment or foundation soils. Out of the several approaches, increasing the length of the flow path by using sheet piles has proved to be effective in seepage reduction. This study examines the effect of using multiple sheet piles of varying length positioned at different distances from the upstream and downstream of a homogeneous earthen dam on the variation of exit gradient, uplift pressure, porewater pressure and flux along the toe of the dam. The analysis is done using a Finite Element modeling with the aid of SEEP/W module in Geo-Studio 2007 software. The results of the numerical analysis gives an insight about the effect of varying geometrical arrangement of the sheet piles on the reduction of exit gradient, uplift pressure, porewater pressure and flux along the downstream portion of the dam during the reservoir filling condition. The study highlights the arrangement of the sheet piles to obtain the maximum reduction of exit gradients and porewater pressures during the rise up condition.

Keywords: Earthen dam, Transient analysis, Finite Element modeling, Exit gradient, porewater pressure.

1 INTRODUCTION

Hydraulic structures such as dams, reservoirs, barrages, used for controlling the flow of water are subjected to seepage and the water seeping underneath the hydraulic structures endanger the safety of the structure resulting in its failure. Therefore, the seepage under hydraulic structures can be considered as one of the most important problems in the hydraulic structures safety. After the construction of dams, the water level rises from their initial position during the first reservoir filling, this condition is termed as 'Rise Up' – a state in which the rate of rising water level and the permeability of the associated earthen dam is vital, as during the initial rise up, the pore water pressure changes and volume changes may cause slope failure as well as piping failure. During the rise up condition the embankment dam is affected by the differential head formed between the upstream and downstream level and the seepage occurring may have detrimental effects at the downstream side of the dam. To prevent such hazards it is necessary to lengthen the seepage path and one of the methods of lengthening the seepage path is to introduce sheet piles as cutoff below the dam to reduce the exit gradient. The reduction of exit gradient plays a vital role because if the exit gradient is greater than the critical gradient for the foundation, piping may occur due to the progressive washing and removal of the fines of the subsoil. The exit gradient being the main design criterion in determining the safety of hydraulic structures against piping, this study is focused on a numerical method to investigate the performance of sheet piles against exit gradient.

Solutions for various problems of seepage under dams with embedded vertical cutoff wall were given using different approaches by (Terzaghi and Peck 1967). Failure mechanism during the reservoir filling condition have been studied by different research workers (Lawton *et.al.*, 1992) aiming to provide a better understanding of the phenomenon. Based on the previous studies, an attempt has been to conduct a parametric study to obtain the influence of the length of the sheet piles, their spacing and number of sheet piles under hydraulic structure on the exit gradient, uplift pressure and porewater pressure distribution.

2 MODEL FOR THE STUDY

For the present study the model dam is presented with its dimension and relevant soil parameters in Figure.1.

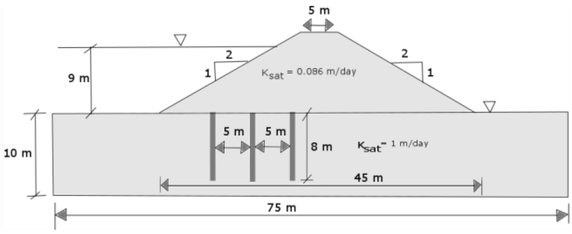

Fig.1 Model dam for the present study

The governing differential equations (Moharrami *et al.*, 2014) for the plane strain seepage can be expressed as:

$$\frac{\partial}{\partial x}[K_x \frac{\partial h}{\partial x}] + \frac{\partial}{\partial y}[K_y \frac{\partial h}{\partial y}] + Q = \frac{\partial \theta}{\partial t} \quad (1)$$

where, K_x and K_y are the hydraulic conductivity in the horizontal and vertical directions, respectively; h is the total head; θ is the volumetric water content; Q is the applied boundary flux; t is the elapsed time.

Under steady-state conditions, the flux entering and leaving an elemental volume is the same at all times. Therefore the equation reduces to the following form:

$$\frac{\partial}{\partial x}[K_x \frac{\partial h}{\partial x}] + \frac{\partial}{\partial y}[K_y \frac{\partial h}{\partial y}] + Q = 0 \quad (2)$$

3 NUMERICAL ANALYSIS

In this study, the analysis was done using the SEEP/W module of a finite element modeling software Geo-Studio. SEEP/W is used for analyzing water seepage and water pressure problems within porous materials for both steady-state and transient conditions in a plane strain configuration. For this study all the three material models i.e., saturated/unsaturated, saturated only and interface have been used for the embankment, foundation and the sheet piles respectively. The saturated permeability of the foundation and the sheet piles in foundation were taken to be 1m/day and impermeable, respectively. The permeability field was assumed to be isotropic (K_x=K_y=K) and a steady state seepage analysis to set up the initial conditions followed by a transient analysis during the rise up condition was performed for all the different sheet pile combinations. The rate of rise up in the transient analysis was taken to be 1.9m/day. Two boundary conditions in terms of total head were specified in the upstream and downstream level in the problem.

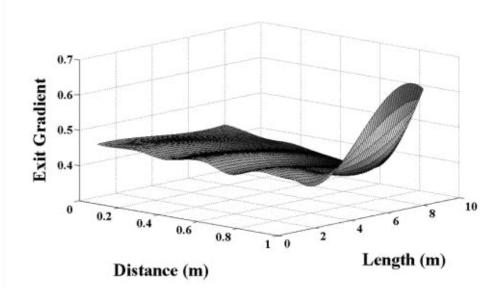

Fig. 2 Variation of exit gradient

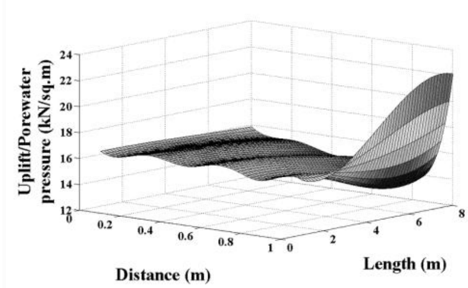

Fig. 3 Variation of uplift and toe pore-water pressure

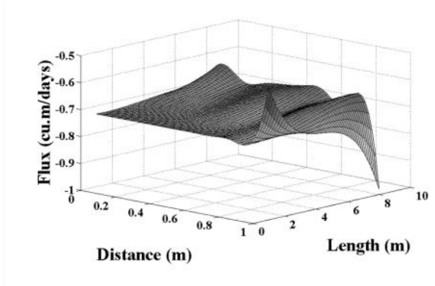

Fig. 4 Variation of flux

4 RESULTS AND DISCUSSIONS

The safety along the downstream end of the hydraulic structures can be ascertained with the decrease of the exit gradient and uplift pressures. The study carried out includes the variation of the length, position and number of sheet piles along the base of the embankment. The embankment width was considered as B, and the distance of the sheet piles from the upstream end was taken to be x thus, the various positions of the sheet piles were explained in $\frac{x}{B}$ ratio.

The total width of the embankment in the model was 45m and the position of the sheet piles i.e., x from the upstream end was varied starting from the toe followed by a spacing of 5m. The length of the sheet piles considered for this analysis was 8m, 4m, 2m and 1m. Moreover, the effect of the variation of the number of sheet piles has been studied.

The embankment when analysed without any sheet pile the value of the exit gradient, pore water pressure and flux were obtained to be 0.45, 16.23kPa, -0.73m^3/days respectively.

4.1 Effect of length and position for a single sheet pile

The variation of exit gradient, uplift pressure, porewater pressure and flux with respect to length and position for a single sheet pile has been plotted as shown from Figure 2 to Figure 4. From the figures, the maximum reduction of all the four parameters near the toe region was obtained for a length of 8m at a $\frac{x}{B}$ ratio of 0.78. The variation of the uplift pressure and porewater pressure are basically the same (as in Figure 3) since the uplift pressure below the hydraulic structure is due to the change in the porewater pressure which results in the reduction of effective stress of the soils.

4.2 Effect of length and position for multiple sheet piles

The same analysis was carried out by increasing the number of sheet piles to two and three with a spacing (S) of 5m between the sheet piles. Increasing the number of sheet piles decreases the value of the parameters, however, the length for which the maximum reduction of the parameters was obtained is the same as that obtained for one sheet pile i.e., 8m and the $\frac{x}{B}$ ratio for a combination of two and three sheet piles which results in the maximum reduction of the parameters also starts at 0.78 for the first sheet pile in the combination followed by a spacing of 5m between the remaining ones. The variation of the parameters for two and three number of sheet piles for varying lengths and positions is shown below in Table 1 and it is evident that irrespective of the position of the sheet piles, the increase in length of the sheet piles results in the decrease of the parameters.

Table1 Variation of parameters for different lengths

Number of sheet piles=2, $\frac{x}{B}$ ratio values = 0.78,0.67			
Length(m)	**Parameters**		
	Exit Gradient	**Porewater Pressure (kPa)**	**Flux (m^3/days)**
8	**0.35**	**12.63**	**-0.59**
4	**0.42**	**14.89**	**-0.69**
2	**0.44**	**15.74**	**-0.73**
1	**0.45**	**15.74**	**-0.73**
$\frac{x}{B}$ ratio values =0.11,0			
8	**0.41**	**14.91**	**-0.67**
4	**0.44**	**15.81**	**-0.72**
2	**0.45**	**16.11**	**-0.73**
1	**0.45**	**16.11**	**-0.73**
Number of sheet piles=3, $\frac{x}{B}$ ratio values = 0.78,0.67,0.56			
8	**0.32**	**11.66**	**-0.54**
4	**0.41**	**14.63**	**-0.68**
2	**0.40**	**14.91**	**-0.70**
1	**0.40**	**15.10**	**-0.70**
$\frac{x}{B}$ ratio values =0.22,0.11,0			
8	**0.38**	**14.32**	**-0.64**
4	**0.43**	**15.89**	**-0.71**
2	**0.45**	**16.41**	**-0.73**
1	**0.45**	**16.39**	**-0.73**

Similarly the effect of varying the position of the sheet piles has been presented in Table 2.

Table 2 Variation of parameters for different positions

	Number of Sheet Piles=2, Length of the sheet piles=8m		
$\frac{x}{B}$ ratio	**Parameters**		
Position	**Exit Gradient**	**Porewater Pressure (kPa)**	**Flux (m^3/days)**
1,0.89	**0.62**	**25.53**	**-0.85**
0.89,0.78	**0.41**	**18.72**	**-0.58**
0.78.0.67	**0.35**	**12.63**	**-0.59**
0.67,0.56	**0.36**	**13.23**	**-0.59**
0.56,0.44	**0.36**	**13.61**	**-0.60**
0.44,0.33	**0.37**	**13.48**	**-0.61**

0.33,0.22	**0.38**	**13.98**	**-0.63**
0.22,0.11	**0.39**	**14.54**	**-0.65**
0.11,0	**0.41**	**14.91**	**-0.67**
	Number of Sheet Piles=3		
1,0.89,0.78	**0.56**	**22.79**	**-0.80**
0.89,0.78,0.67	**0.37**	**17.27**	**-0.54**
0.78.0.67,0.56	**0.32**	**11.66**	**-0.53**
0.67,0.56,0.44	**0.33**	**12.29**	**-0.55**
0.56,0.44,0.33	**0.34**	**12.76**	**-0.57**
0.44,0.33,0.22	**0.34**	**12.78**	**-0.58**
0.33,0.22,0.11	**0.36**	**13.45**	**-0.61**
0.22,0.11,0	**0.38**	**14.32**	**-0.64**

The result of varying the position of the sheet piles in this analysis shows that the maximum reduction of the parameters takes place when the sheet piles are placed near the downstream end at some distance from the toe, thereafter reducing the $\frac{x}{B}$ values results in an increase of the parameters.

4.3 Effect of increasing the number of sheet piles

The effect of increasing the number of sheet piles on the rise up condition for different parameters has been obtained by plotting it's variation with time. The variation of one such parameter near the toe region has been shown below in Figure 5. The figure clearly indicates that the increasing number of sheet piles results in reduction of exit gradient. The rise up of water results in the increase of the exit gradient till 200 days after which it attains a steady state.

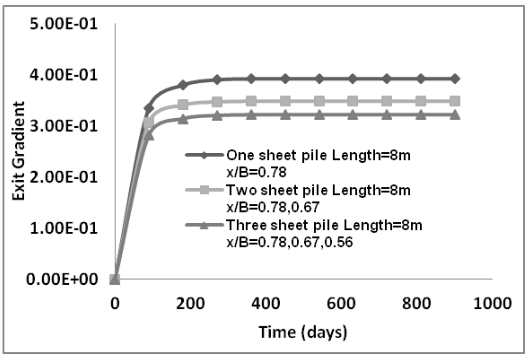

Fig.5 Variation of exit gradient with time

From the output of the analyses, though it can be stated that the length and position of the sheet piles plays an important role in reducing the exit gradient yet a proper sensitivity analysis will be required to conclude the most influential parameter resulting in the safety of the structure.

5 CONCLUSIONS

The following conclusions are drawn from the present study based on the results discussed above:

- Use of multiple sheet piles results in the reduction of exit gradient and uplift pressure as compared to the structure without sheet piles. The most beneficial number for this study is three.
- Increasing the length of the sheet piles results in the reduction of exit gradient and uplift pressure. For this study the most effective length has been 8m.
- The increase in distance of the sheet piles from the toe results in the reduction of the exit gradient and uplift pressure till a particular point but thereafter further increase in the distance results in the increase of the parameters. The best position of the sheet piles for this study is at $\frac{x}{B}$ of 0.78 for the first sheet pile in the combination of two and three sheet piles.
- The increase in spacing between the sheet piles results in the increase of the exit gradient and uplift pressure. The spacing which resulted in maximum reduction of the parameters was $\frac{B}{9}$ for this study.
- The lengths of the sheet piles were varied equally for this study, however further research can be made if unequal variation of sheet pile lengths can be made to guide the flow resulting in more safety of the hydraulic structures.
- Optimization of the length and position of the sheet piles will be very useful as merely increasing the number of sheet piles does not give the best results.

References

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