# Analysis of Seepage Through Foundation of An Impervious Structure By Finite Element Method

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***Abstract-*** *Groundwater study has become an important branch of Civil Engineering. Groundwater problem normally pertains to the quantity of seepage, uplift pressure and exit gradients. The seepage analysis for the structures resting on heterogeneous pervious foundations is essential from viewpoint of their rational design. The "Method of Finite Elements" is used to develop the work, as the method has the capacity to accommodate anisotropic and nonhomogeneous soil character. In the present work, an attempt has been made to analyze the seepage characteristics below the impermeable structure resting on a pervious layer of finite depth underlain by an impervious stratum. The influence of embedment of a centrally located sheet pile is also studied. Some mathematical equations are derived to represent the Potential Values, Exit Gradients and Discharge through the foundations.*

***Keywords***- Discharge, Exit Gradient, Finite Element Method, Permeability, Potential Values, Sheet Pile.

## I. INTRODUCTION

The irrigation and hydraulic structures are often founded on pervious riverbeds. Due to the various factors playing a vital role in the process of the bed formation, the strata, in general, acquire heterogeneity in seepage characteristics. While dealing with such heterogeneity in the analysis, it is not easy to assign the variation of the coefficient of permeability (k) within the strata. Indeed thorough description of the heterogeneity appears to be an impossible task. Few attempts made in this direction, however, reveal the following features:

1. At any point within the strata the condition of anisotropy prevails; i.e. the 'k' along the bed is greater than that across it. Only a rough estimate of anisotropy is necessary to define the seepage flow pattern.
2. When the soil mass is uniformly graded, i.e. it has all the particles of approximately the same size, the permeability decreases with depth. This is due to the process of consolidation occurring under the self-weight during and after the deposition.
3. When the soil mass is well graded, i.e. it has particles of different sizes; during the process of deposition, the larger particles would settle first and then the finer ones. Thus, the void ratio and hence the 'k' would increase with the depth.
4. In the connection with (2) and (3) above, Siraskar and Patel (1967), recommends parabolic variation of 'k' across the depth of the strata.

## II. PROPOSED INVESTIGATION AND THE METHOD OF SOLUTION

In the Fig.1, a weir resting over pervious heterogeneous foundation is shown. The weir has an apron length 'B' and the depth of the pervious foundation strata is 'D'. A sheet pile of depth 'd' is located centrally to the weir as shown in Fig.1. The foundation is subjected to a differential head of water 'H'. It was proposed to investigate the uplift pressure over the base of the apron, the exit gradient at the toe of the apron and the leakage through the foundation. A parametric study with the following features was planned in this connection:

1. Five categories of aprons were considered. They were defined by:
   D/B = 0.25, 0.50, 1.00, 1.50 and 2.50.
2. For each category of D/B, the sheet pile depth variations are considered. They were defined by:
   d/D = 0.0, 0.2, 0.4, 0.6 and 0.8.
3. For the case of the 'k' increasing with the depth of the foundation strata, the parabolic variation of 'k' as shown in Fig.3 was adopted. In this '$k_T$' the value of 'k' at the top of the strata was kept unity, whereas '$k_B$' the value of 'k' at the base of the strata was represented by a ratio 'm' so that $k_B / k_T = m$, for each of the five sheet pile depth variation mentioned in (2) above. The analysis was performed with m = 2, 4, 10 and 100. Thus, in all 100 cases of the 'k' increasing with the depth was investigated.
4. For the case of the 'k' decreasing with the depth of the foundation strata, the parabolic variation of 'k' as shown in Fig.4 was adopted. Now '$k_B$' was kept unity and '$k_T$' was defined by a ratio 'n' so that $k_T / k_B = n$.

For each of the five sheet pile depth variation mentioned in (2) above the analysis was performed with n = 2, 4, 10 and 100. Thus, in all 100 cases of the ‘k’ decreasing with the depth was investigated. We should note that in this category of the variation in the ‘k’, n = 1 / m, viz n = 0.5, 0.25, 0.1 and 0.01.

5. The foundation stratum was assumed to be isotropic, i.e. the ‘k’ along and across the bed was assumed to be same. In case they are different, a standard geometrical scale transformation would convert anisotropic strata into isotropic one. This would naturally change the ratio ‘D/B’ as well. The modified value of ‘D/B’ however would make it fit into the range of investigations being covered.

## III. FINITE ELEMENT METHODOLOGY

The method of analysis is too well known to need any more detailed description, hence only the salient features governing the problem under consideration are discussed herein. The analysis involves the application of first-order isoparametric quadrilateral elements for simulation of the Geotechnical material. The investigations were carried out by employing two-dimensional finite element seepage analyses having the following features:

1. The differential head ‘H’ was considered to represent potential ‘ϕ’ equal to 100%.
2. As the line of symmetry passes through the center of the sheet pile, it was sufficient to analyze only a half section. Hence only the right half section with the geometrical boundaries and the potential boundaries were analyzed.
3. The finite element idealization as shown in Fig. 2 and as proposed in Table – 1 was employed for each case.
4. It may be noted that the pervious strata in the idealized section for individual cases consist of various layers, the ‘k’ at the top and bottom of the each layer were calculated by using the parabolic variation of the ‘k’ and the mean of these values were taken as the $k_x = k_y = k$, for the elements within the layer.

**Table – 1 Total Idealized Assembly (B = 50.0 m (Constant))**

| Case | Total no. of Elements | Number of Horizontal Divisions | Number of Vertical Divisions |
|---|---|---|---|
| D/B = 0.25 | 150 | 06 | 31 (Ref. Fig. 2) |
| D/B = 0.50 | 300 | 11 | 31 (Ref. Fig. 2) |
| D/B = 1.00 | 600 | 21 | 31 |
| D/B = 1.50 | 900 | 31 | 31 |
| D/B = 2.50 | 1500 | 51 | 31 |

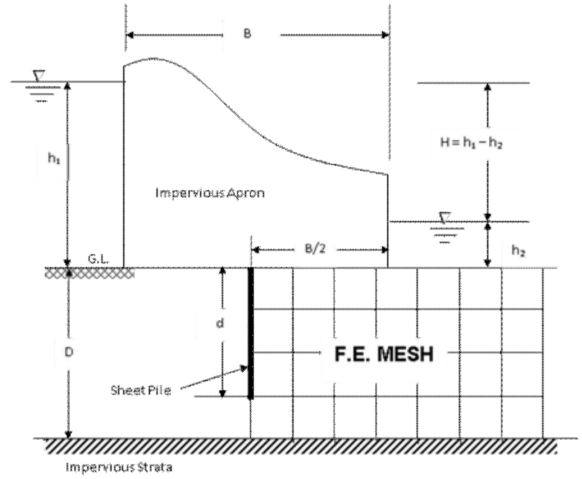


Fig. 1 : Problem considered for proposed investigation

Where,

B = Width of Dam,
h1 = Upstream Water level
h2 = Downstream Water level
H = Total head loss due to seepage

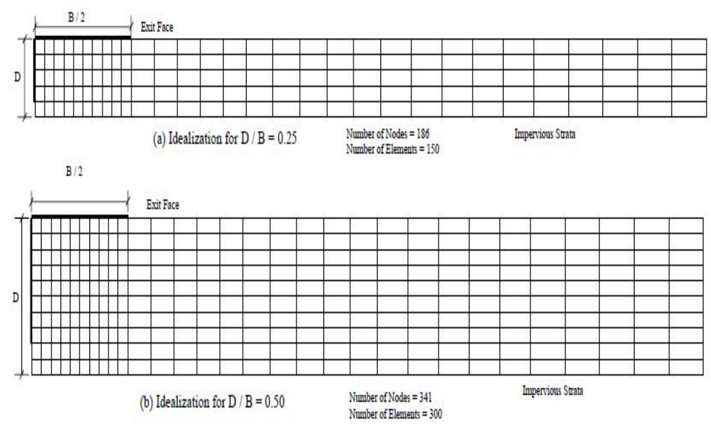


Fig. 2 Idealization for the Cases D / B = 0.25 and D / B = 0.50

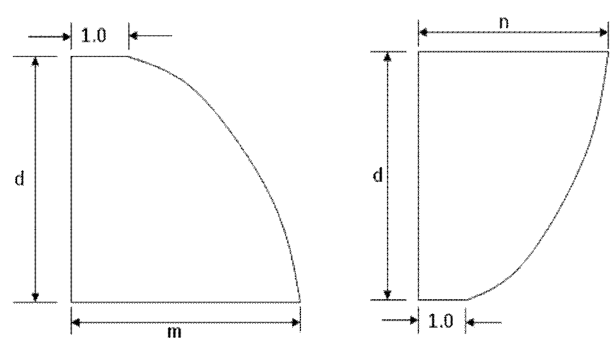


Fig.3: Permeability Increasing with Depth

Fig.4: Permeability Decreasing with Depth

(After Siraskar (1967))

## IV. PARAMETER CALCULATION

By considering the cases stated in Table –1 and both the permeability variations the required parameters like Uplift Pressure, Exit gradient and Seepage are calculated by using the computer program developed.

### 4.1 Uplift Pressure

From the cases stated in Table –1, the variation of uplift pressure over the apron is investigated. In the Fig. 5 and Fig. 6, the variation of uplift pressures over the aprons for the case D/B = 0.25 and d/D = 0.0 and 0.8, is presented. For clarity of presentation, however, the curves for m = 1, m = 100 and n = 100 are only presented.

### 4.2 Exit Gradients

In the Fig. 7 and Fig. 8, the curves showing respectively the variation of I (y) w.r.t. the various values of ‘m’ or ‘n’ for the various cases of sheet pile depth variation for the case of D/B = 0.25 variation are presented. Wherein, the I(y) represent the exit gradient in ‘y’ direction, at the point next to the apron. This variation is plotted for all the cases.

### 4.3 Discharge

In the Fig. 9 and Fig. 10, the graph shows the discharge variation along the various values of variation of permeability for various values of sheet pile depth variation for D/B = 0.25. There is linear variation of discharge for all the cases investigated

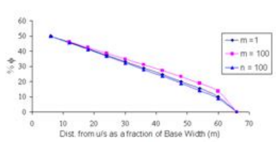


Fig. 5: Variation of Uplift Pressure for the Case D/B = 0.25 ; d/D = 0.0

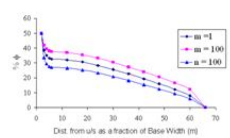


Fig. 6: Variation of Uplift Pressure for the Case D/B = 0.25 ; d/D = 0.8

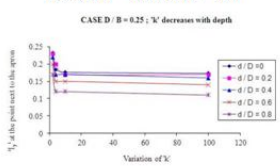


Fig. 7: Exit Gradient at the Point next to Apron for the Case D/B = 0.25 and Permeability Decreases with Depth

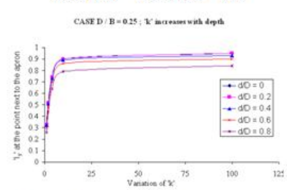


Fig. 8: Exit Gradient at the Point next to Apron for the Case D/B = 0.25 and Permeability Increases with Depth.

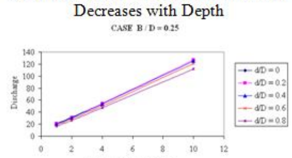


Fig. 9: Discharge For Case D/B = 0.25 ; ‘m’ Variation

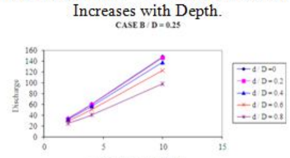


Fig. 10: Discharge For Case D/B = 0.25 ; ‘n’ Variation

## V. DISCUSSION AND CONCLUSION

From all cases stated in Table -1 the curves are plotted for each case (D/B = 0.25, 0.50, 1.00, 1.50 and 2.50) and also for each parameter (Potential values, Exit Gradient, and Discharge), stated above. From the curves plotted following inferences are drawn:

1. For the same value of ‘D/B’, the uplift pressure on the downstream of the apron reduces with the increase in the value of ‘m’ or ‘n’ as the case may be. By virtue of symmetry, this also means that for the same value of ‘D/B’ the uplift pressures on the upstream of the apron increases with the value of ‘m’ or ‘n’ as the case may be.
2. For the same values of ‘m’ or ‘n’ as the case may be, the uplift pressure on the downstream of the apron increases as ‘D/B’ gets increased.
3. For the same value of ‘D/B’ ratio and also for the same value of ‘m’ or ‘n’ as the case may be, the uplift pressure decreases as the ratio of ‘d/D’ increases.
4. For the same value of ‘D/B’ ratio and for the same value of ‘m’ or ‘n’ also for the same value of d/D ratio, as the distance from upstream increases towards downstream the uplift pressure decreases.
5. For the same value of ‘D/B’ ratio and the same value of ‘d/D’ ratio the exit gradient in the ‘y’ direction increases as the value of ‘m’ increases.
6. For the same value of ‘D/B’ ratio and the same value of ‘m’ or ‘n’ as the case may be the exit gradient in the ‘y’ direction decreases as the value of ‘d/D’ ratio increases.
7. For the same value of ‘d/D’ ratio and the same value of ‘m’ or ‘n’ as the case may be the exit gradient in the ‘y’ direction decreases as value of ‘D/B’ ratio increases.
8. For the same value of ‘D/B’ ratio and the same value of ‘d/D’ ratio the exit gradient in the ‘y’ direction increases as the value of ‘n’ increases.
9. For the same value of ‘D/B’ ratio and the same value of ‘m’ or ‘n’ as the case may be also for the same value of ‘d/D’ ratio as the distance from downstream toe increases the exit gradient decreases.
10. For the same value of ‘D/B’ ratio and also for the same value of ‘d/D’ ratio, the discharge increases as the value of ‘m’ or ‘n’ increases as the case may be.
11. For the same value of ‘d/D’ ratio and the same value of ‘m’ or ‘n’ value as the case may be, the discharge increases as the value of ‘D/B’ ratio increases.
12. For the same value of ‘D/B’ ratio and for the same value of ‘m’ or ‘n’ value as the case may be, the

discharge decreases as the value of 'd/D' ratio increases.

13. Though the above study conducted is only a parametric study, the computer program developed for the work can be used for any type of the actual seepage problem existed on the actual site.

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