EFFECT OF LOCATION OF A SCOUR HOLE ON THE SEEPAGE CHARACTERISTICS BENEATH A BARRAGE

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ABSTRACT

In this paper a study is made on one of the largest barrages on the River Nile, Nag Hammadi barrage. The actual dimensions of a big scour hole that had been formed downstream from the barrages are considered. The effect of the location of the scour hole on both the uplift pressure distribution and the maximum exit gradient is investigated. The finite element method is used in getting the numerical results which are non-dimensionally presented. The flow pattern is sketched for two locations of the scour hole to illustrate the change in the divergence characteristics of the streamline at exit.

NOMENCLATURE

K the hydraulic conductivity of soil;
L creep length = length of the base plus the total length of sheet piles;
n direction normal to ϕ;
x horizontal Cartesian coordinate;
y vertical Cartesian coordinate;
ϕ velocity potential; and
ψ stream function.

1. INTRODUCTION

Nag Hammadi barrage is one of the most important barrages on the river Nile in Egypt. It was constructed in 1930 near Nag Hammady City, about 588 km south from Cairo to provide higher water levels necessary to satisfy irrigation demands in both Gerga and Assiut provinces [3]. The barrage has 100 vents, each 6.0 m wide with piers about 2.2 m thick and main piers 4.0 m thick separating each ten vents. The barrage was designed to withstand a maximum differential head of 4.5 m. To improve the seepage characteristics and reduce the maximum exit gradient a system of sheet piles as well as upstream and downstream graded filters were provided. Figure (1) shows a longitudinal section of Nag Hammadi barrage. Among the problems arose after the construction of the barrage was the formation of a big scour hole near the downstream end of the graded filter. This hole could subject the filter and downstream apron to damage or failure [5, 10]. As temporary remedy, the hole was filled with boulders and stones [8,9]. However, some trials were made to construct sills of different design on the downstream apron to move any expected scour hole further downstream from the barrage.

It is known that excessive and uncontrolled seepage can lead to piping formation leading to undermining of a hydraulic structure. Usually such a piping process commences from the exit end and due to a high exit gradient there [5]. On the other hand the uplift pressure has a direct effect on the stability of a hydraulic structure. For the above mentioned reasons the effect of location of the scour hole with respect to the downstream apron on both the uplift pressure distribution beneath the barrage and the maximum exit gradient is studied in this paper. Though the scour hole varied in size across the river, yet the maximum recorded dimensions, shown in Figure (2), were considered.

2. MATHEMATICAL MODEL

The problem of seepage beneath hydraulic structures has been investigated on different lines of approach [1,2,4]. In this paper the case of a barrage with downstream scour hole is considered. The soil is assumed to be homogeneous and isotropic. It is also assumed that the dimensions of the scour hole remain unchanged at the different locations of the hole.

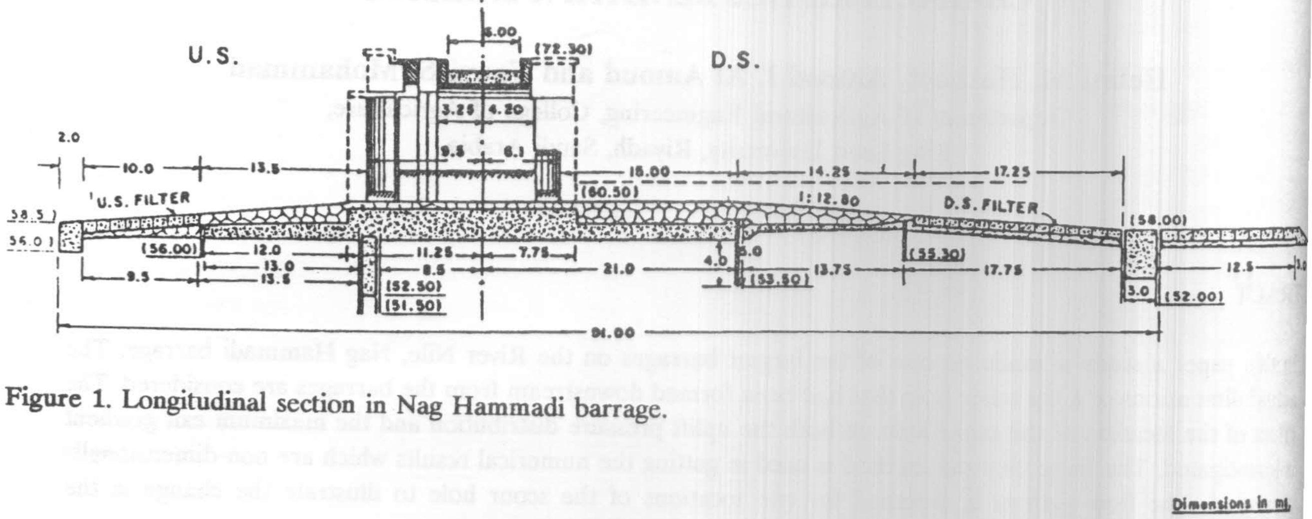

Figure 1. Longitudinal section in Nag Hammadi barrage.

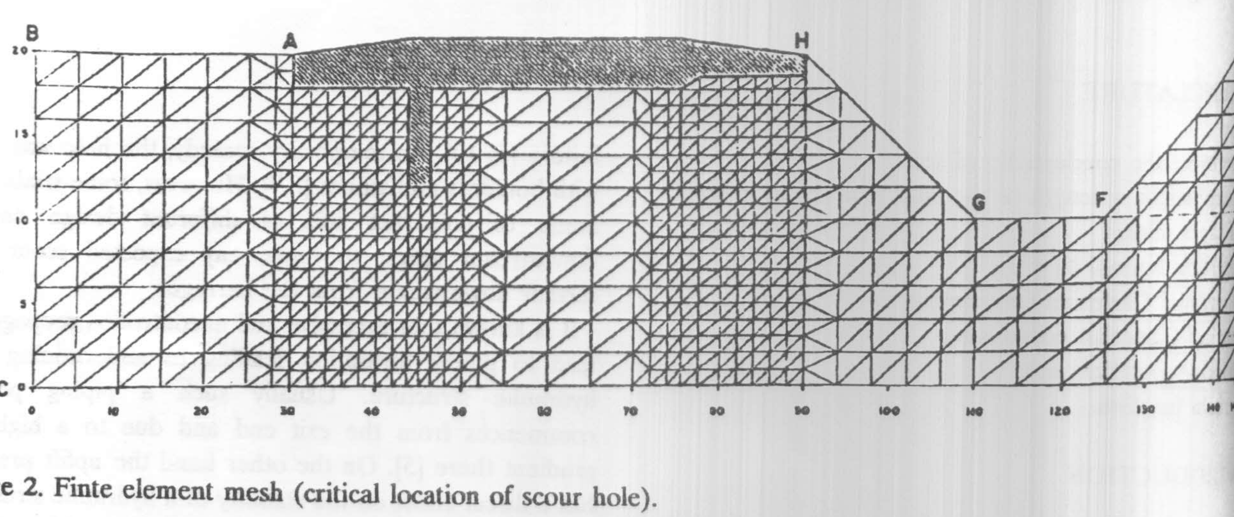

Figure 2. Finte element mesh (critical location of scour hole).

For steady flow in an isotropic and homogeneous soil the general governing partial differential equation is expressed in two dimensions as

$$\frac{\partial}{\partial x}\left(K\frac{\partial\phi}{\partial x}\right)+\frac{\partial}{\partial y}\left(K\frac{\partial\phi}{\partial y}\right)=0 \qquad (1)$$

in which ϕ is the velocity potential and K is the hydraulic conductivity of soil. The finite element method is used to provide solutions for the problem considered in this paper. The details of the finite element method may be found in text books on the subject [6,7].

The finite element mesh for the most critical location of the scour hole is shown in Figure (2). For the other locations of the scour hole, the mesh beneath the upstream bed and the barrage remains unaltered and vertical rows of elements are added between the hole edge of the downstream apron.

The computer program FEM2D, with expan dimension statements [6] is used throughout the pa The program runs are designed to find the velo potential ϕ, the stream function ψ and the maximum gradient for each of the different locations of the sc hole.

3. BOUNDARY CONDITIONS

Referring to Figure (2), the boundary conditi associated with the problem investigated herein are follows:

The base of the barrage, including sheet piles form streamline $\psi = 0$ at which $\partial\phi/\partial n = 0$, n being direction normal to the direction of ϕ. Lines BC, CD, DE are streamlines along which $\partial\phi/\partial n = 0$. On the other hand line BA is an equipotential with $\phi = 4.5$ m, whereas the boundary HGFE has $\phi = 0.0$.

4. ANALYSIS OF THE RESULTS

It was necessary to choose a reference condition to demonstrate the relative effect of the scour hole with respect to the downstream apron on the seepage characteristics beneath the barrage.

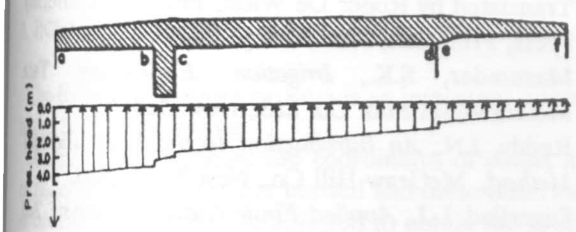

Figure 3. Uplift pressure distribution (without scour hole).

For convenience the case in which no scour hole exists vis the case of scour hole at a large distance from the barrage is considered. Figure (3) shows the uplift pressure distribution on the base of the barrage in the case of seepage without a scour hole. The maximum and initial pressure head is 4.5 m at the upstream end of the base. As mentioned before, this value represents the design differential head acting on the barrage. On the other hand the maximum exit gradient corresponding to the case of no scour hole, according to calculations is 0.0901.

Analysis of the computer runs for different locations of the scour hole indicates that as the hole proceeds towards the upstream direction both the uplift pressure and the maximum exit gradient decrease. Figure (4) shows the percentag decrease in theuplift pressure at points a,b,c, ..., and the maximum exit gradient, versus the location of the scour hole. The ratio X/L is the non-dimensional representation of the location of the scour hole, X is the distance between the hole and the end of the downstream apron, Fig. 4, and L is the creep length (length of base plus total length of sheet piles). It is evident from Fig. 4 that the effect of a scour hole on both the uplift pressure distribution and the maximum exit gradient practically disappears for $X/L \geq 0.33$.

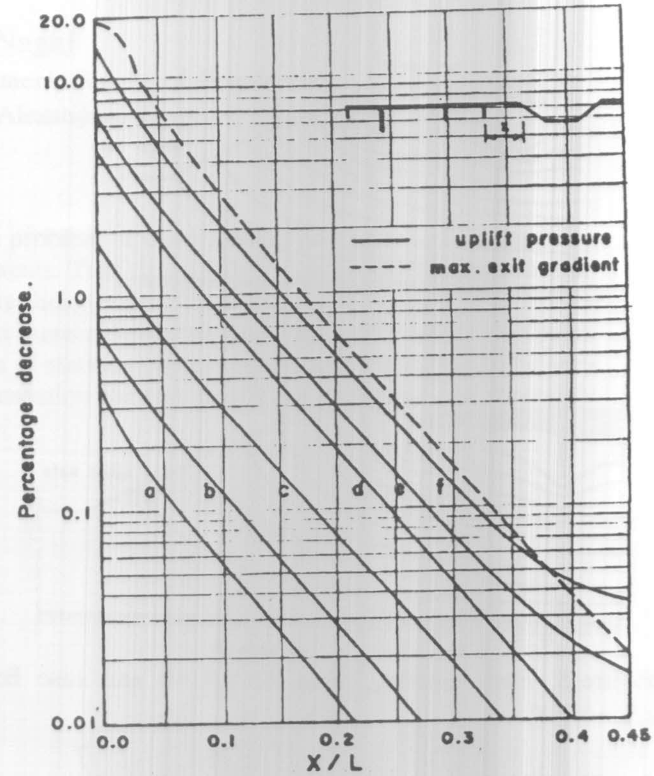

Figure 4. Percentage decrease in uplift pressure and maximum exit gradient versus location of scour hole.

Beneath the base of the barrage, points near the upstream end are slightly affected compared to points near the downstream end. At point (a) the maximum reduction in upstream pressure is 0.85%, at an internal point (d) the reduction is 5.3% and at point (f) the reduction exceeds 18.4%. It is clear that the downstream part of the base (ef) is mostly affected, however, this part is subject to low uplift pressures in general and hence the stability of the barrage would not be materially affected by the aforementioned reduction percentages.

On the other hand the percentage reduction in the maximum exit gradient reaches about 18.7% at X/L = 0.0. Computer results provide exit angles -90° for all runs except at X/L = 0.0 the angle is -116.57°. This is attributed to the condition that streamlines at exit are generally perpendicular to the river bed but at X/L = 0.0 they are perpendicular to the upstream side of the scour hole. This explains the unusual feature of the dashed curve in the neighbourhood of X/L = 0.0, Figure (4).

Inspection of streamlines at exit, Figures (5-a,b), shows that they diverge near the end of the downstream apron as the scour hole moves upstream.

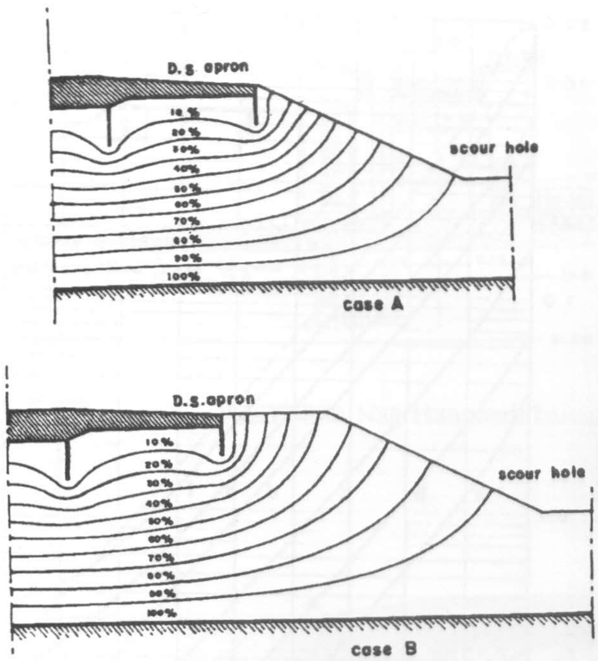

Figure 5. Flow pattern, (case A: x/L=0 and case B: x/L=0,108).

5. CONCLUSION

The existence of a scour hole at $X/L < 0.33$ reduces both the uplift pressure beneath the barrage and the maximum exit gradient. The maximum reduction occurs at $X/L = 0.0$, i.e. when the scour hole is adjacent to the end of the downstream apron. The reduction at points beneath the upstream apron, where pressures are generally high, are mostly as low as 1%, whereas reduction may exceed 18% at points beneath the downstream apron. The reduction in the maximum exit gradient reaches about 19%. A study on the flow pattern shows that stream lines diverge as the scour hole approaches the downstream apron which explains the reduction in the maximum exit gradient.

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