THE EFFECT OF CHANGING SOIL PERMEABILITY RESULTING FROM SEDIMENT MATERIALS ON THE HEAD DISTRIBUTION UNDER NEW HINDIYA MAIN BARRAGE+

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Abstract

The purpose of this work is to study the effect of changing of soil permeability, K due to the existing of sediment materials in reservoir behind the hydraulic structures ,which enter with flowing water into foundation during deposition and which may reduce the value of K. This reduction would be affecting the head distribution under structures. A mathematical model is developed for analyzing two-dimensional steady seepage through a stratified soil .A numerical solution using finite element Galerkin method is applied to predict the head distribution under the base of structure for the different values of K. The results indicate that the void ratio of soil would decrease when the particles are deposited through the soil foundation, so the value of K, decreases in order that the value of head is increased.

المستخلص

الغرض من هذا البحث دراسة تأثير المواد المترسبة في خزان المنشأ الهيدروليكي في نفاذية تربة أساس المنشأ أثناء جريانها مع الماء داخل الأساس . أن انعزال هذه الحبيبات من المحتمل أن يسبب نقصان في نفاذية التربة أي في قيمة K. لقد تم تطوير انموذج رياضي لتحليل التسرب المستقر ثنائي الأبعاد خلال الترب المتطبقة . وتم استخدام الحل العددي بطريقة العناصر المحددة (Finite Element Method) لتخمين توزيع الشحنة الهيدروليكية تحت قاعدة المنشأ. لقد بينت النتائج أن الحبيبات المنتقلة مع الماء سوف تنعزل خلال تربة الأساس مسببة نقصان في نسبة الفجوات للتربة ونتيجة لذلك فان قيمة Kسوف تقل وعندها فان الشحنة الهيدروليكية سوف تزداد .

Introduction

Sedimentation in reservoirs behind the hydraulic structure is an important problem .In this area of reservoir where streams carry heavy sediment loads the rate of sedimentation must be estimated accurately in order to determine the useful life of any proposed reservoir.

When water enters into the foundation of structure it may carry off some fine particles from sediment material with it. Consequently the permeability ,K , of soil foundation may vary with time because of this external load represented by the flowing water which follows Darcy's law that gives the velocity of fluid with respect to the (possibly moving) solid [1].

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When these sediment materials are deposited, the volume occupied by the solid material remains practically unchanged but the volume of void decreases. As consequence the permeability of soil also decreases.

In this work a finite element model is used to predict the piezometric head distribution below the structure for all cases of change in value of , K.

Theory of Flow in Anisotropic Media

Seepage flow of water through porous media depends on the properties of the medium in which flow occurs ,the properties of liquid and the hydraulic gradient [2].

For steady state condition, the governing partial differential equation that describes the two dimensional flow through anisotropic, homogenous porous media can be represented by Laplace equation as follows: -

$$k_x \frac{\partial^2 H}{\partial x^2} + k_y \frac{\partial^2 H}{\partial y^2} = 0 \quad ....(1)$$

where :-

K_x , K_y = The hydraulic conductivity in the x and y directions , L / T

H = Piezometric head, L

The boundary conditions for steady ground water flow are defined as follows:

1-Reservoir boundary

$H=H_0$ on S_1 ………(2)

where,

H_0 is the piezometric head on the permeable reservoir boundary S_1 .

2-Impermeable boundary

In these boundaries the water can not seep through the surface, so that components of vertical seepage flux, q_n , on the surface must be equal to zero .

$$k_x (\frac{\partial H}{\partial x}) lx + k_y (\frac{\partial H}{\partial y}) ly = 0 \qquad on\ S_2 \quad ....(3)$$

where :

respectively lx , ly the direction cosine of normal vector on the surface with directions x and y respectivel .

Principle of the Finite Element

The finite element method is a very powerful computation tool for obtaining solution to many of the problems encountered in engineering analysis [3].The basic idea behind it is to divide the region being analyzed into finite element sub-domains joined by nodes at the boundaries of each element. The variation of field variable on each element is represented approximately by continuous function depending on the nodal value of the field variable as follows:

$$H_e = \sum_{i=1}^{n} N_i H_i \quad ....(4)$$

where: -

H_e :Approximate solution for piezometric head distribution in the element .

H_i : Nodal values of head , H , of the element .
N_i : Shape function of the element
n : Number of nodes per element .
Then, the approximate solution for head distribution of the whole domain is given by :

$$H = \sum_{i=1}^{ne} [N_i]\{H_i\} \quad ....(5)$$

where :
n_e is the total number of elements in the problem domain .

There are mainly two different approaches to formulate the approximate solution of the problems. In this work, Galerkin method has been used. Galerkin finite element method is applied because weighting function can be set equal to the interpolation function [4] ,where

$$\sum_{1}^{ne} \int_A w_j R \quad dA = 0 \quad .... (6)$$

Mathematical Model

Deriving the finite element equations using weighted residual method by substituting the approximate solution (H_e) into governing equation results in :

$$k_x \frac{\partial^2 H_e}{\partial x^2} + k_y \frac{\partial^2 H_e}{\partial y^2} = R_e \neq 0 \quad ....(7)$$

where :

R_e is an element residual.

A pplying, Galerkin weighted residual method, and substituting equation (6) into equation (5) result in:

$$\sum_{i=1}^{n_0} \left[\int_A N_i (k_x \frac{\partial}{\partial x} (\frac{\partial}{\partial x} \sum_1^n N_i H_i) + k_y \frac{\partial}{\partial y} (\frac{\partial}{\partial y} \sum_1^n N_i H_i) dA \right] = 0 \quad ...(8)$$

where , dA = dx dy and I,j=1 to n

To reduce the continuity requirements for the shape function, N, from C^1- continuity to C^0 - continuity, integration by parts with Green's theorem is applied to eq. (7) , as follows

$$\sum_{i=1}^{n_0} \left[(\int_A \frac{\partial Ni}{\partial x} k_x \frac{\partial}{\partial x} \sum_1^n N_i H_i + \frac{\partial N_i}{\partial y} k_y \frac{\partial}{\partial y} \sum_1^n N_i H_i) dx \quad dy \right.$$

$$\left. = \int_{S_e} N_j kn \frac{\partial}{\partial n} \sum_1^n N_i H_i \quad ds \right] \quad ....(\quad 9)$$

where :

$S_e = s_{e1} + s_{e2}$ represent the surface boundaries of the element

A pplying the same finite element method to the boundary condition (S2) and adding to equation (8) result:

$$\sum_{i=1}^{n_0}\left[\left(\int_A \frac{\partial Nj}{\partial x} k_x \frac{\partial}{\partial x}\sum_1^n N_i H_i + \frac{\partial Nj_i}{\partial y} k_y \frac{\partial}{\partial y}\sum_1^n N_i H_i \right) dx\, dy \right.$$

$$\left. - \int_{S_1} \left(N_j k_x \frac{\partial}{\partial x}\sum_1^n N_i H_i\, Ix + Njk_y \frac{\partial}{\partial y}\sum_1^n NiHiIy \right) ds \right] = 0 \quad ....(10)$$

where :
dx=Ixds and dy=Iyds

Therefore; the matrix form of the above equation can be written as :

$$\sum_1^{n_e} [K_e]\{H_e\} = 0 \quad ...... \quad (11)$$

where , $[K_e]$ is the element matrix in which

$$[Ke] = \int_A [Be]^T [De][B]\, dx\ dy = 0 \quad .....(12)$$

where :

$$[B] = \begin{bmatrix} \frac{\partial Ni}{\partial x} & ----- & \frac{\partial Nn}{\partial x} \\ \frac{\partial Ni}{\partial y} & --- & \frac{\partial Nn}{\partial y} \end{bmatrix}, \qquad D = \begin{bmatrix} k_x & 0 \\ 0 & k_y \end{bmatrix}$$

and for assemblage

[K]{B}=0 ……..(13)

In this work, two-dimensional quadratic isoparametric element are used in order to obtain the small degree of accuracy in the final result .Then the assembled equation (13) is solved by frontal solution because of its efficiency to minimize core storage requirement and the number of arithmetic operations [5].

Results and Discussions

In this work a New Hindiya Main Barrage was taken as a case study and the cross section of it is shown in Figure (1). The region under the structure is subdivided into a quadratic isoparametric element with eight nodes to obtain some accuracy at final results .The mesh is shown in Figure (2).

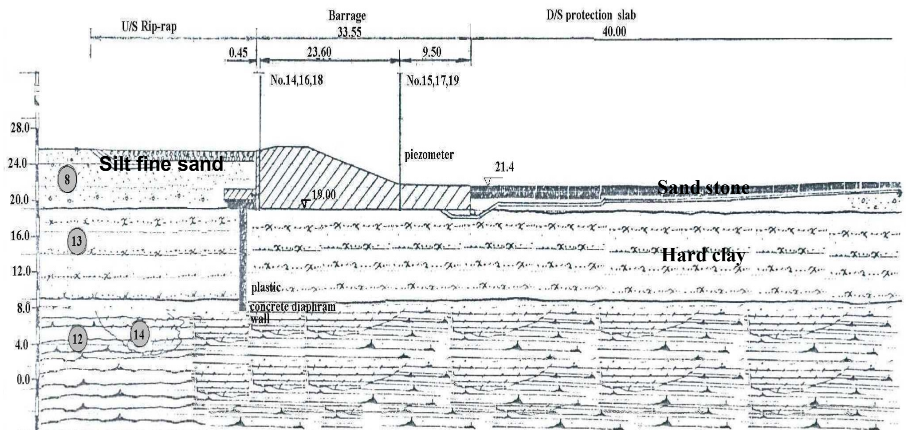

Fig. (1): Typical cross section in hydraulic structure ,shown boundary conditions ,dimension of the section and % of the head at U/S and D/S

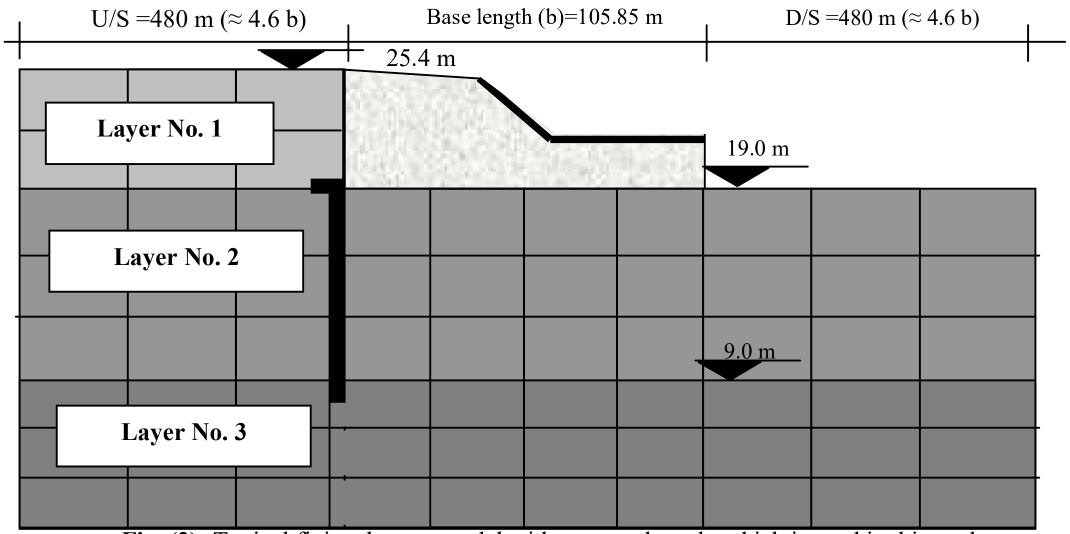

Fig. (2): Typical finite element model with a general mesh, which is used in this study

The computer program used in this work is taken from [6] and modified to analyze 2D seepage under the hydraulic structure and compute the piezometric head at any point on the mesh. This study is done to find the effect of reduction, K, resulting from sediment materials that are deposited through soil foundation on head distribution under the structure. For this purpose, it is assumed theoretically that the value of, K, is accumulative reduced by about 1% from its value for each year since the first year of operation of the Barrage. This assumption is since there is no field investigation on the soil permeability through the adopted period of operation of the Barrage.

The study is applied for 10 years by taking three years from the period of existing field data and selecting the same months for each three years .The results are given in Figures (3) to (5) and table (1) to illustrate the distribution of head under the base of structure before and after the reduction in value of, K.

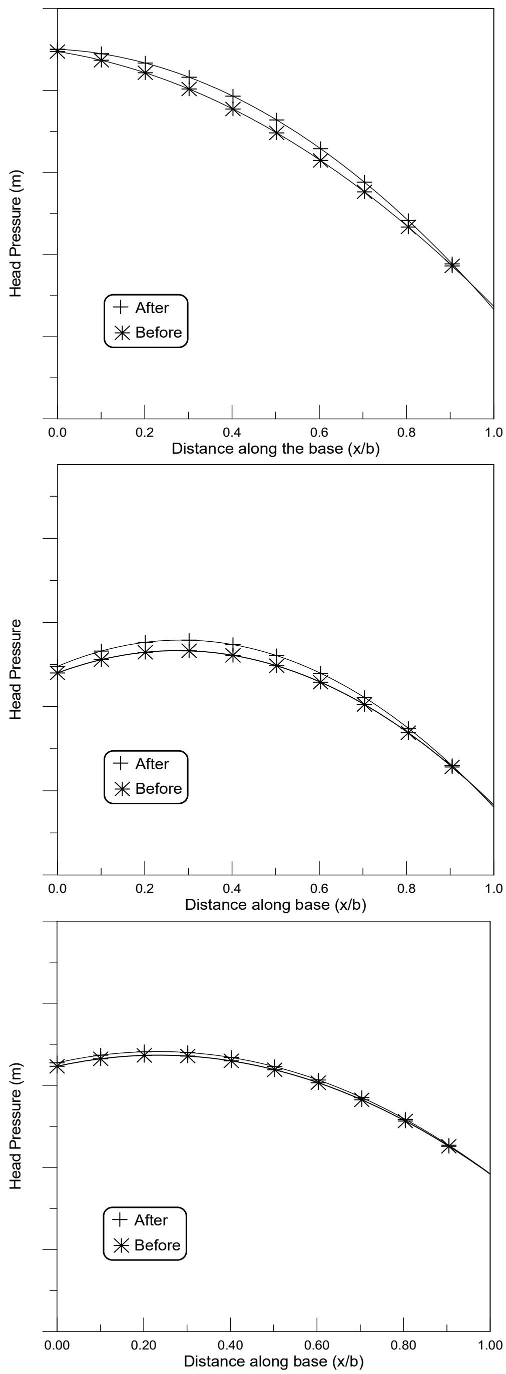

Fig. (3:ffect of sedimentation material on the head distribution (88-89)

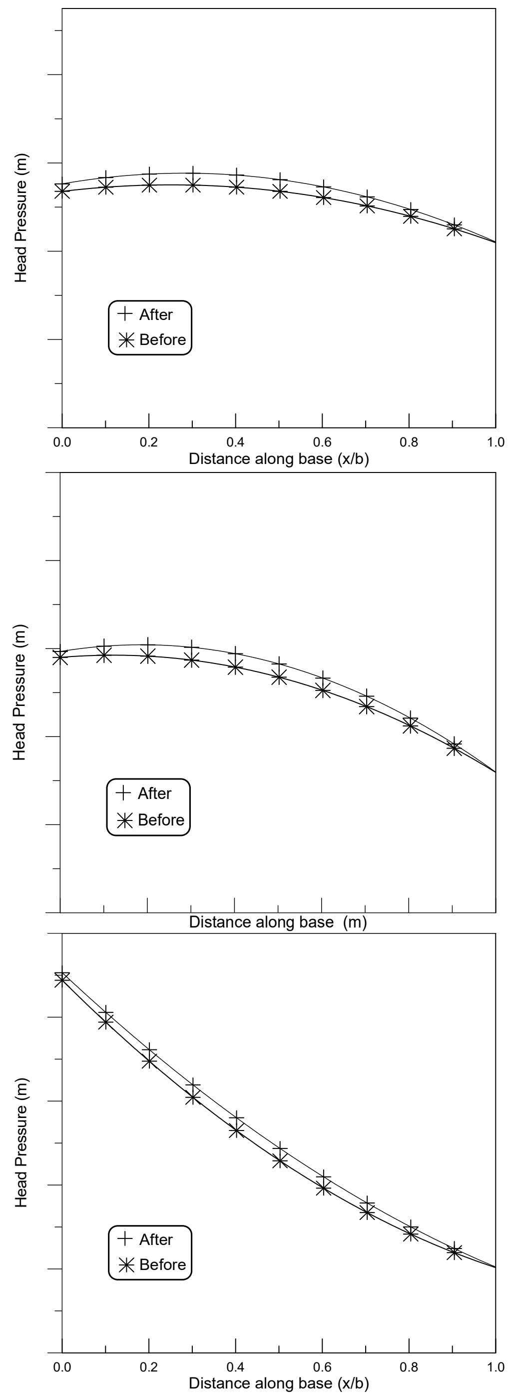

Fig. (4): Effect of sedimentation material on the head distribution (93-94)

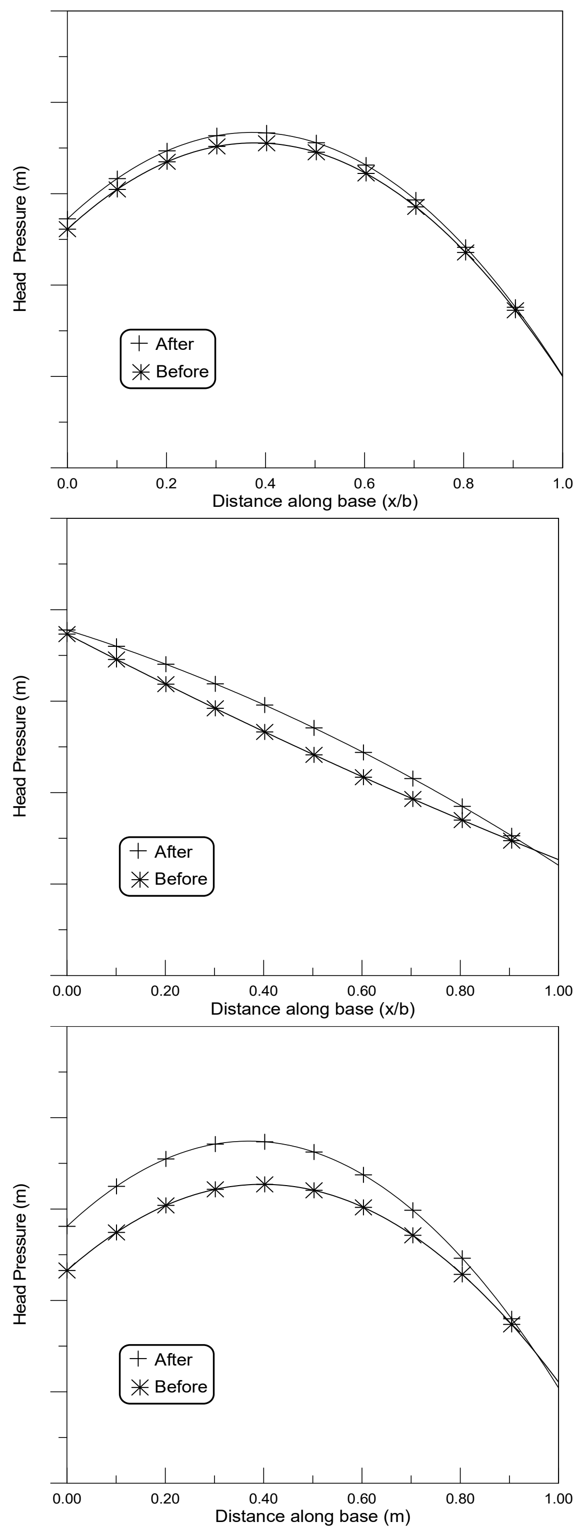

Fig. (5): Effect of sedimentation material on the head distribution (97-98)

Table (1): Effect of sedimentation materials on head distribution

1988-1989						
Distance	**JUN.**		**Mar.**		**Oct.**	
X/b	After	Before	After	Before	After	Before
*0	29.08967	29.08956	28.4719	28.47176	29.95606	29.95599
0.116	29.07968	29.07954	28.45971	28.45954	29.94916	29.94906
0.25	29.04562	29.04547	28.41815	28.41797	29.9256	29.92549
0.375	28.98989	28.98976	28.35016	28.35001	29.88705	29.88697
0.5	28.91058	28.91049	28.25342	28.25331	29.8322	29.83215
0.625	28.81484	28.81477	28.13664	28.13653	29.76599	29.76593
0.75	28.6877	28.68764	27.98154	27.98145	29.67806	29.678
0.875	28.48702	28.48697	27.73673	27.73667	29.53926	29.53922
*1	28.17	28.17	27.35	27.35	29.32	29.32
1993-1994						
Distance	**JUN.**		**Mar.**		**Oct.**	
X/b	After	Before	After	Before	After	Before
*0	29.08239	29.22518	27.77902	27.63547	28.47968	27.43958
0.116	29.07233	29.21564	27.76432	27.62027	28.46747	27.42368
0.25	29.03816	29.18322	27.71434	27.56857	28.42598	27.32368
0.375	28.98226	29.1302	27.6326	27.48402	28.35814	27.22368
0.5	28.90273	29.05475	27.51627	27.36372	28.26159	27.15534
0.625	28.80672	28.96364	27.37586	27.21845	28.14505	27.0034
0.75	28.67922	28.84265	27.18937	27.02553	27.99027	26.80162
0.875	28.47796	28.65167	26.89502	26.72102	27.74596	26.48312
*1	28.16	28.35	26.43	26.24	27.36	25.98
1997-1998						
Distance	**JUN.**		**Mar.**		**Oct.**	
X/b	After	Before	After	Before	After	Before
*0	28.9391	29.63956	28.9391	28.93888	28.48705	28.48684
0.116	28.92857	29.6315	28.92857	28.92833	28.47492	28.47467
0.25	28.89267	29.6041	28.89267	28.89243	28.43354	28.43329
0.375	28.83395	29.5593	28.83395	28.83373	28.36585	28.36562
0.5	28.75038	29.49555	28.75038	28.75021	28.26952	28.26934
0.625	28.64951	29.41855	28.64951	28.64935	28.15325	28.15308
0.75	28.51554	29.3163	28.51554	28.5154	27.99883	27.99868
0.875	28.30407	29.15492	28.30407	28.30397	27.75507	27.75497
*1	27.97	28.9	27.97	27.97	27.37	27.37
* at the end of cut-of						
** at the end of dam						

From these figures, it can be seen that the values of head increases with decrease in the value of ,K, at the same month and year .This behavior can be concluded from Darcy's law (v=Ki) which indicates that the value of hydraulic gradient (i.e head) increases with decreasem the value of ,K, in order to keep the same quantity of water to flow through soil.

Conclusion

In this work a finite element method is employed to analyze two-dimensional steady seepage through a stratified soil with anisotropic porous media below hydraulic structure to predict the piezometric head distribution for different periods with change in soil permeability.

The results are represented by a set of curves to indicate the effect of decreasing the value of, K, on the head distribution under the base of structure .It is shown that the value of head increases with decrease in the value of, k, due to the deposition of sediment materials. These materials are transported with flowing water into soil foundation of structure and lead to decrease in the value of, k.

The maximum reduction of K occur in the final year because of accumulative reduction of K with time. Consequently the largest increase in value of head is noticed in the (97-98) year from period operation of Barrage.

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