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Examination of the Validity and Usage of the Basrah City Local Soils in the Construction of the Engineering Hydraulic Projects

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Abstract- The present study examines the possibility of using local soil from different Basrah city sites to construct earth dam embankment and sand filters. The sand filters have an important role to control seepage and internal erosion inside the dam embankment. Soils of three Basrah city sites were selected to use in the construction of the dam embankment and they are located in Karmat Ali, Shatt al-Arab, and Abu al-Khaseeb regions. Whereas soils of other two sites were selected to use in the construction of sand filters and they are located in Zubair and Sanam regions. The mechanical and hydraulic properties of the above regions' soils were investigated. A numerical mathematical model was implemented and developed in this study to calculate the hydraulic gradient in the dam embankment and find its effect on the piping and internal erosion. It is concluded from this study that the sandy soil of Zubair region can be used as sand filters in the dam body constructed from any above three sites, whereas the sandy soil of Sanam region can be used after a simple treatment. The safety factor against piping phenomenon and erosion was also calculated. It is found that the safety factor against piping and erosion increasing by decreasing the upstream water level, the length of the sand filter, and the degree of anisotropy.

Keywords- *Filters, Internal Erosion, Hydraulic Gradient, Embankment.*

I. INTRODUCTION

As embankment dam is constructed, the problem of internal erosion and piping will arise. Internal erosion and piping in embankments and their foundations is the main cause of failure and accident to embankment dams. In different countries, many existing dams, dykes and levees were not provided with filters and they are susceptible to internal erosion failure.

Huang, et al. (2014), used the coupled distinct element method (DEM) and computational fluid dynamics (CFD) model to compute the migration of the base soil through granular filters. Their results show that the time evolution of total soil mass, distribution of particles, porosity, pore water pressure, and the flow discharge are directly related to the gradation of the filter. Silveira (1965) used probabilistic methods to examine the migration of the base soil particles through filters and mathematical formulas were proposed for filters. Reddi et al. (2000) adopted a numerical model for simulating the filter and he found that the permeability coefficient is reduced due to the base soil particles clogging in the filter. Indraratna and Vafai (1997) established an erosion model for cohesionless soil based on the conservation of mass and momentum. Locke et al. (2001) used a complex 3D void network model to describe the variation of flow rate, particle size distribution, porosity, and permeability with the time of base soil filter system. Reboul (2008) proposed a methodology to compute the size distribution of granular filters. Frishfelds et al. (2011) established a numerical model which combines the minimization of dissipation energy rate with the discretization of the particle system. Zou et al. (2013) introduced a distinct element method and established a coupled model to study the base soil system with different filters.

In the present work, the suitability of the sandy and local soils selected from two and three sites of Basrah city respectively were investigated. The sandy soil material was used as seepage and protection control device to base local soil. The required mechanical and hydraulic properties of the filter materials and base soil were estimated and examined to decide their validity of use.

II. EXPERIMENTAL WORK AND DESIGN CRITERIA

The design of filter requires conducting mechanical and hydraulic experiments to estimate the properties of filter and soil materials. Therefore, the following tests should be performed:

1- The sieve analysis test is performed for the filter materials of Sanam and Al-Zubaier regions (Ranjan and Rao, 2000)

Coefficient of uniformity (heterogeneity), $C_u = \frac{d_{60}}{d_{10}}$

Coefficient of curvature, $C_z = \frac{d_{30}^2}{d_{60}\, d_{10}}$

Where, d_{60}, d_{30}, and d_{10} are diameters through which 60%, 30%, and 10% respectively of soil material will pass.

Based on grain-size distribution analysis, the soil is defined as well graded (broadly) if C_u>=4 and (1 <C_z≤3), whereas it is defined as poorly (uniformly) graded when C_u<4 and/or C_z<1 or C_z>3.

2- Pipette test is used to estimate the particle size distribution of all three base soils (Karmat Ali, Shatt el Arab, and Abu Al-Khaseeb).

3- The coefficient of permeability of the both two filter soils (Zubair and Sanam) is estimated experimentally using the constant head permeability test.

4- The coefficient of permeability of all three base soils is estimated experimentally using the consolidation test.

III. NUMERICAL MODEL AND HYDRAULIC GRADIENTS COMPUTATIONS

Consider the problem of two-dimensional ideal homogeneous embankment dam provided with horizontal filter drain as shown in Fig. 1. Initially, upstream water level (H) is maintained constant and equal to downstream water level. Then, the H-value is raised gradually until reaches the maximum upstream water level and the free surface is developed to a steady position. The soil particles and the fluid in the pores are considered as incompressible. The equation that describes the flow through a saturated porous media is: (Bear, 1979)

$$K_x \frac{\partial^2 h}{\partial X^2} + K_y \frac{\partial^2 h}{\partial Y^2} = S_s \frac{\partial h}{\partial t} \quad (1)$$

Where, K_x and K_y are the hydraulic conductivity in X and Y directions respectively, h is the hydraulic head, t is the time, and S_s is a specific storage and it is equal to zero for steady state condition.

The boundary conditions for this problem are as follows (Fig. 1).

$$h = H1 \quad \text{on face A-B} \quad (2)$$

$$h = H2 \quad \text{on face C-D} \quad (3)$$

(i.e. the hydraulic head is specified)

$$K_y * \frac{\partial h}{\partial Y} = 0 \quad \text{on face A-D} \quad (4)$$

(i.e. the velocity component normal to the boundary)

$$h = y \ and \ K_n * \frac{\partial h}{\partial N} = 0 \quad \text{on B-C} \quad (5)$$

(i.e. the hydraulic head is equal to the elevation and the velocity normal to the free surface is zero). Noting that two types of boundary conditions are specified on the free surface, whose position is, on the other hand, a priori unknown.

A numerical model has been developed using finite difference method by solving equation (1) subjected to the boundary conditions (equations 2 to 5). The resulting system of equations is solved using Iterative Alternating Direction Implicit Explicit (AIDIE) scheme (Remson, et al. 1971). The model computes the spatial and temporal hydraulic heads in the embankment dam (Fig. 1). From these hydraulic heads, the hydraulic gradient at each node is determined as follows:

$$\mathrm{i} = \frac{\mathrm{dh}}{\mathrm{dS}} \quad (6)$$

Where, i is hydraulic gradient, h is the hydraulic head, and S is the distance along the flow streamline. The safety factor against internal erosion calculated from the following equation:

$$F.S = \frac{I_c}{I_{av}} \quad (7)$$

Where, I_c is the critical hydraulic gradient, and I_{av} is the computed average hydraulic gradient. For usual range of voids ratio in sand soils is 0.6-0.7, the critical gradient will be just about one (I_c=1) (Ranjan and Rao, 2000).

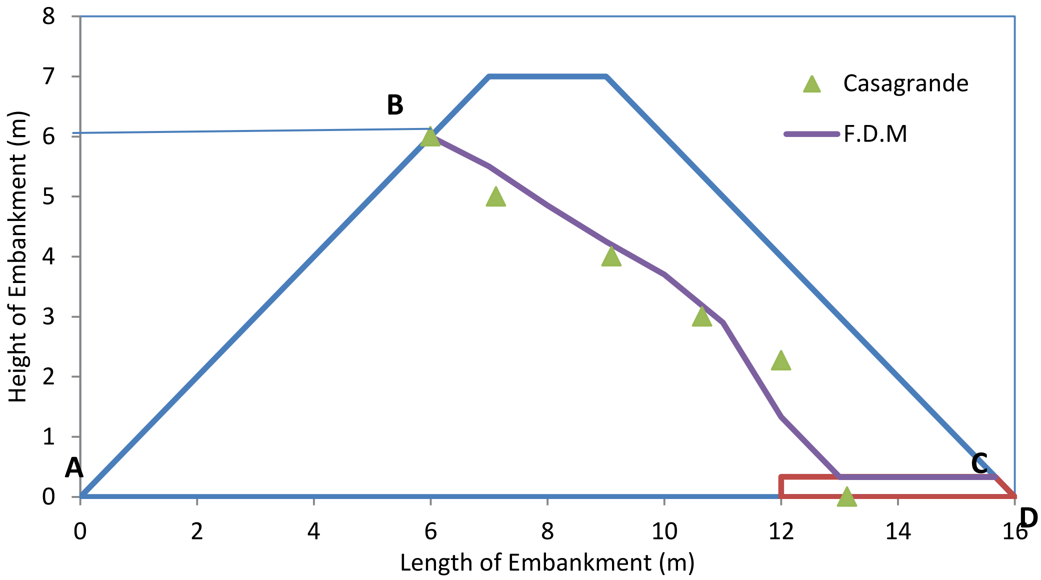

Figure 1. Embankment Dam section with Boundary Condition

IV. Design Criteria of Protection Filters

In the construction of earth dams, it is often necessary to provide layer/layers of filter material to prevent fine particles of being carried into the voids space of coarser materials. An effective filter material may be designed using a few simple rules and the grading characteristics of the soil to be protected as illustrated in Table 1:

TABLE I. The Characteristics of the Soil and Protection Filter

No.	Property	Permissible Range
1	d15 (Filter)	<4 to 5* d85 (Soil)
2	d15 (Filter)	>4 to 5* d15 (Soil)
3	d85 (Filter)	>2*Screen Mesh Size
4	Finer than 0.075mm	<5%

Where, d_{15}(Filter) is the diameter through which 15% of filter material will pass, d_{15}(Soil) and d_{85}(Soil) are the diameter through which 15% and 85%,of base soil respectively to be protected will pass.

In addition to the above criteria, the grading curve of the filter should have approximately the same shape as that of the base soil. Also, for the proper selection of the filter material, properties (1) and (2) (Table 1) should be kept in mind. The interpretation of property (1) is that the size of the voids in the filter material should be small enough to hold the larger particles of the protected material in place. The property (2) explains that the filter material should have a high permeability to prevent buildup of large seepage forces and hydrostatic pressures in the filters. The property (6) is computed by considering the maximum pipe perforation dimension that should be no larger than the finer side of the d50E where d50E is taken from the gradation of the envelope (drain) material that surrounds the drainpipe. The maximum pipe perforation dimension should be no larger than the finer side of the d50E where d50E is taken from the gradation of the envelope (drain) material that surrounds the drainpipe (FEMA, 2011).

V. Results and Analysis

The experimental tests were performed at the soil laboratory of the civil department/Technical institute of Basrah to estimate the coefficients of permeability of the filter materials and the soil to be protected. Also, a sieve analysis is carried out to evaluate the grain size distribution of the filter materials. The pipette test is performed at the Marine Science Center/ University of Basrah to determine the grain size distributions of the protected soil. The results of the above tests are illustrated in table 2 and Fig. 2.

TABLE II. The characteristics and Properties of the Filter materials and Protected Soil

Property	Filters		Protected Soil		
	Zubair	Sanam	Karmat Ali	Shatt El Arab	Abu Al Khaseeb
Coefficient of Permeability (cm/sec)	0.001975	0.004675	0.0001521	0.0004018	0.0001127
Coefficient of uniformity, C_u	3.571	2.432	21.11	14.61	19.00
Coefficient of curvature, C_z	0.893	0.942	0.442	0.415	0.645
d15 (mm)	0.21	0.34	0.0025	0.003	0.0033
d50 (mm)	0.4	0.8	0.034	0.034	0.034
d85 (mm)	0.72	2.75	0.053	0.054	0.054
Finer Than 0.075 (mm)	0.007	0.02	-	-	-
Porosity, n	0.32	0.4	-	-	-

Based on the computed values of C_u and C_z (Table 2), the base soil materials is defined as well (broadly) graded soil, while the filter materials defined as poorly (uniformly) graded. Fig. 2 shows the grain size distributions for the three sites of base soil (Karmat Ali, Shatt El Arab, and Abu Al Khaseeb) and the two sites of filter materials (Zubair and Sanam) in addition to the proper limits of these soils (Table 1).

To make the calculation more general, the values of d_{15} and d_{85} for the soils of Karmat Ali, Shatt El Arab, and Abu Al Khaseeb soils (Table 1) are averaged. So the averaged values of d_{15} and d_{85} are equal to 0.003mm and 0.054mm, respectively and they are used to determine the acceptable area of the filter zone. Also, the values of d_{50}E for the filters of Zubair and Sanam are averaged and equal to 0.6mm. So it is possible to determine $5d_{85}$=0.27mm (point D), $5d_{15}$=0.015 (point C), 2*d_{50}E=1.2mm (point E), d_5> 0.075mm (point F), and d_{100}<80mm (point G). The limits 1 and 2 are plotted in Fig. 2 and they refer to the link between points E and F and points G and D respectively. The zone between these two limits represents the acceptable zone for the filter grading curve. It is obvious from Fig. 2 that the small part of the grain-size distribution of the filter material for both Sanam and Zubair sites are out of acceptable zone. It is clear that the upper part of Zubair site is out of the acceptable zone and this results from not fulfilling property 2 in table 1 and then this type of filter will leads to build up of excess pore water pressure and seepage force. On the other hand, the lower part of Sanam is almost cross over the acceptable zone near the point (D), this results from the large value of d_{15} of this filter as shown in table 2. So the soil of the Sanam site needs simple regradiation to fulfill all the criterias of table 1. The properties 3 and 4 are fulfilled in both filters. An attempt is made to integrate the components of the Zubair filter and the Sanam filter in equal proportions. The resulting curve granular distribution from the merge is drawn. It is found that this curve is located within the acceptable area of the filters as shown in Fig. 2.

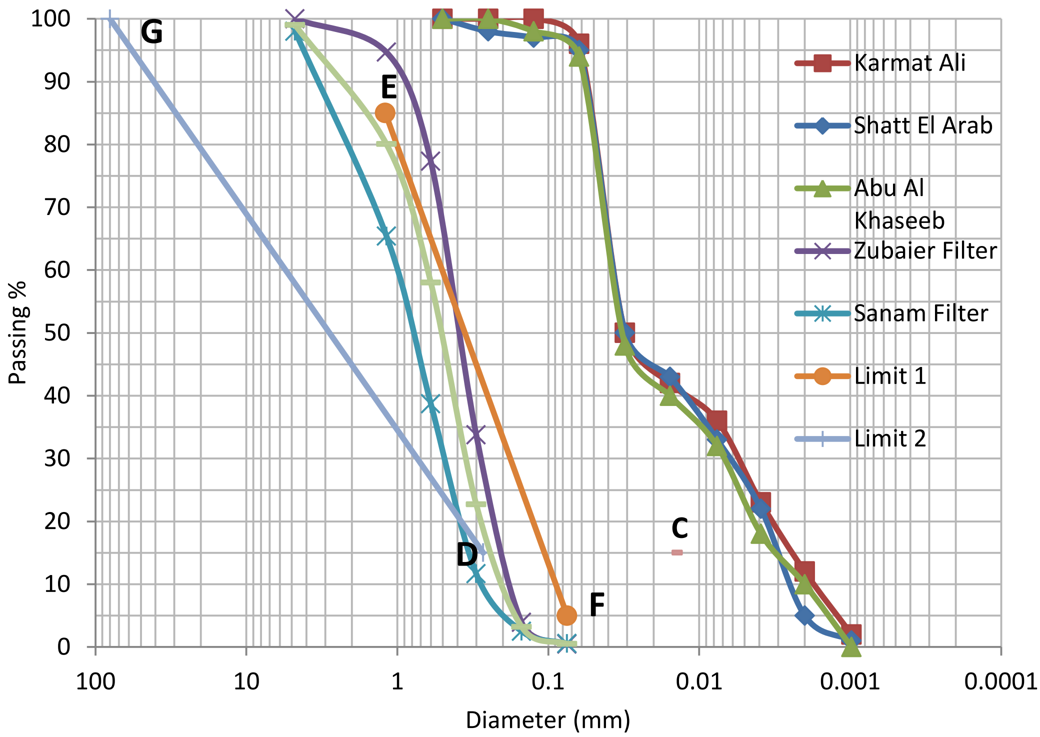

Figure 2. Grain size Distribution of Selected Filters and Protected Soils

VI. NUMERICAL MODEL VALIDATION

To validate the developed numerical model, the model results were compared with Casagrande's analytical solution (Sahasrabudhe, 2015) as shown in Fig. 1. Casagrande has considered and analyzed an embankment dam provided with a horizontal filter drain. In this study, the model considered an embankment of height 7m, top width 2m, with upstream and downstream slopes of 1:1, and a water level in the reservoir of 6m above the base. The domain was discretized into 10 rows and 21 columns with 120 nodes. The relevant soil parameters (Table 2) were used in this model. The water flow through the embankment has been simulated using the present model. Fig. 1 shows the simulated steady state free surface position comparing with that computed by Casagrande solution. It is clear from this Fig. that the model predictions are in close agreement with those computed by Casagrande solution.

VII. HYDRAULIC GRADIENT ANALYSIS:

The numerical model is applied to analyze the hydraulic gradient behavior in isotropic and anisotropic embankment dam provided with horizontal filter. To facilitate and make the calculation more general, the average values of hydraulic conductivity of soils of the three areas (K_s) and filters (K_f) were computed from Table 2 to determine the hydraulic conductivity at points linked between soil and filter. So the average values of K_s and K_f are equal to 0.000222 cm/sec and 0.00332 cm/sec, respectively. In this study, several cases were analyzed to investigate the effect of the length of horizontal filter (b) and the height of the upstream water level (H) with respect to the total length of the embankment (B) on hydraulic gradient. Fig. (3) shows the variation of hydraulic gradients with different H values represented by the dimensionless variable (H/B) for various horizontal sand filter lengths represented by the dimensionless variable (b/B) and for isotropic case. It is observed from this Fig. that the value of the hydraulic gradient increase with increasing in (H/B) and (b/B) values. Fig. (4) shows the variation of factor of safety with upstream water level (H/B) for different horizontal sand filter length (b/B) and for isotropic case. It is observed that the value of the factor of safety decreases with increasing in (H/B) and (b/B) values.

The effect of degree of anisotropy (ɳ) on the hydraulic gradient and factor of safety is studied. Here, the degree of anisotropy is defined as the ratio of saturated horizontal hydraulic conductivities. The variations of hydraulic gradient and factor of safety were plotted with various (H/B) values for different ɳ- values of protected soil as shown in Fig.s 5 and 6, respectively. It can be seen from these Fig.s that the hydraulic gradient decreases and the factor of safety increases with increasing in ɳ-values. As ɳ-value increases the water has a high tendency to move horizontally which results in the reduction of the horizontal hydraulic gradient. The reduction in horizontal hydraulic gradient is possible only when the free surface becomes flatter which results in the increase of free surface. It is also clear from Fig. 6 that the factor of safety has increased from 2.06 to 2.42 (increased in about 17%) when the ɳ-value increases from 5 to 10.

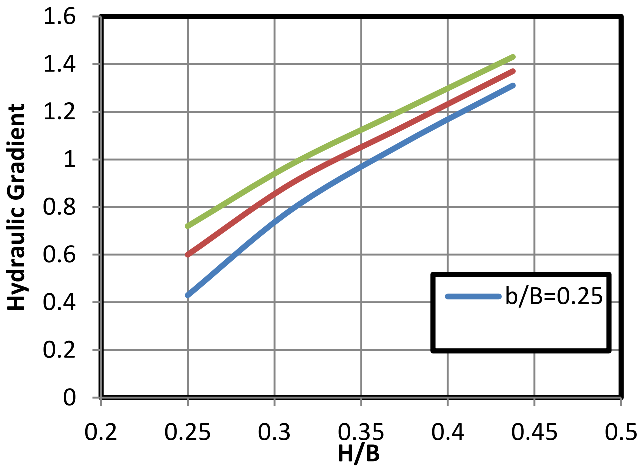

Figure 3. Variation of Hydraulic Gradient with Upstream Water Level for Different Sand Filter Length

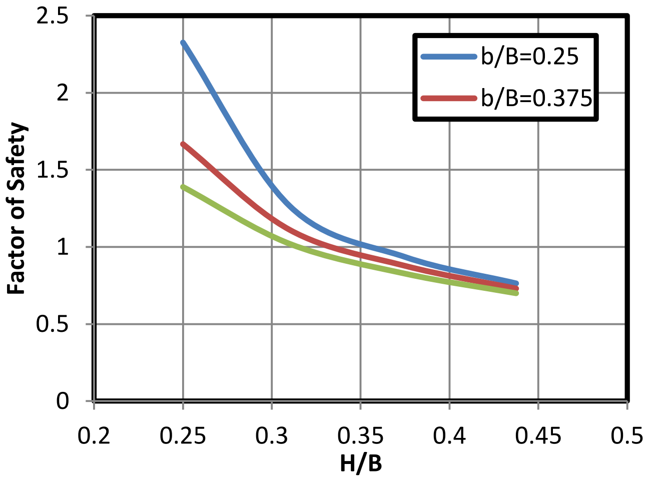

Figure 4. Variation of Factor of Safety with Upstream Water Level for Different Sand Filter Length

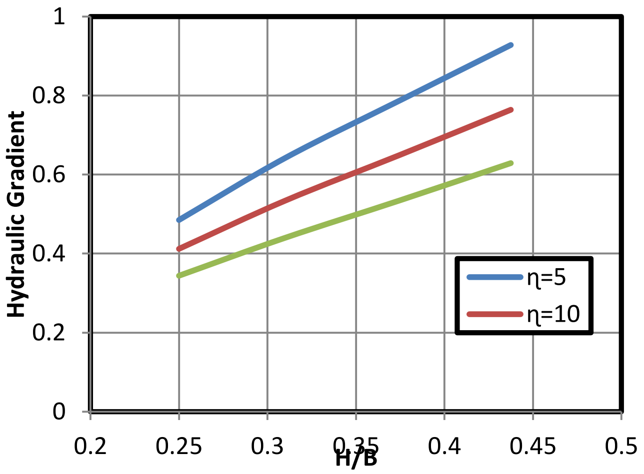

Figure 5. Variation of Hydraulic Gradient with Upstream Water Level for Different Degree of Anisotropy of Protected Soil

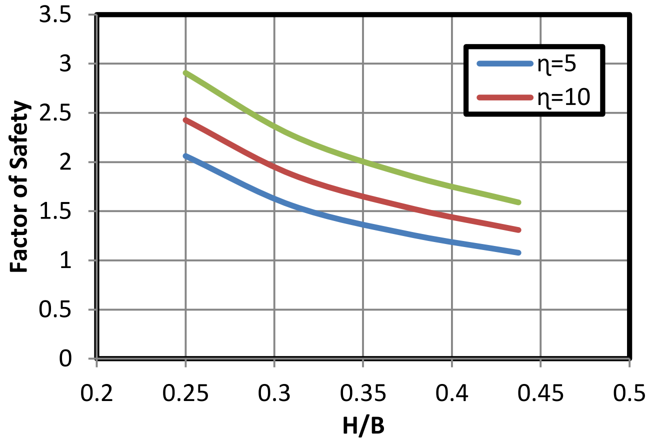

Figure 6. Variation of Factor of Safety with Upstream Water Level for Different Degree of Anisotropy of Protected Soil

VIII. CONCLUSIONS

This study aims to investigate the validity of the different Basrah City local Soils in the construction of earth dam embankment and sand filters. Several substantial points were inferred and can summarize as follows:

1- The minimum filter permeability of Zubaier is approximately 5 times the surrounding soil (Karmat Ali, Shatt-El-Arab, and Abu Al-Khaseeb), whereas the minimum filter permeability of Sanam is approximately 11 times the surrounding soil.

2- The (H/B) value of less than or equal 0.31 gives a safe design of the embankment against internal erosion and piping for isotropic case.

3- The perfect compaction of the embankment and filter materials leads to increase the anisotropy and then increase the factor of safety against and internal erosion.

4- The filter material of Sanam site is satisfy the permeability requirements whereas the soil protection against migration is not completely satisfy due to the high permeability of the filter materials.

5- The filter material of Zubair site is not satisfy the permeability requirements and this leads to high pour water pressure formation, whereas the soil protection against migration is completely satisfy due to the low porosity of the filter materials.

6- For the proper selection of the filter material, the filter material resulting from merge of Zubair site and Sanam site satisfy the permeability requirements as well as the soil protection migration.

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