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Modeling Seepage Effects In Heterogeneous Soil Under Heading-Up Structures Using An Experimental And Numerical Methodology

Thesis
Submitted in Partial Fulfillment of the Ph.D. Degree in Civil Engineering

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Statement

This thesis is submitted to the Irrigation and Hydraulics Department, Faculty of Engineering, Ain Shams University in partial fulfillment of the Ph.D. degree in Civil Engineering.

The work in this thesis was carried out in the Irrigation and Hydraulics Department, Faculty of Engineering, Ain Shams University.

No part of this thesis has been submitted for a degree or a qualification at any other university or institution.

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Abstract

Seepage of water under the aprons of heading-up structures is one of the most important factors that should be carefully studied while designing any heading-up structure. Seepage can cause different problems related to uplift pressure and undermining and piping. These problems threaten the stability of the structures and can lead to their failure. In nature, soil is normally heterogeneous rather than uniform. One of the special cases of soil heterogeneity is stratified soil where soil layers are usually horizontal as most soils deposit in this manner.

This study introduces a new electric analogue experimental modeling methodology to simulate the effect of soil stratification under the apron of heading-up structures on the safety against uplift and piping. This is achieved through making different scenarios for the hydraulic conductivity values of the layers and their configurations under the apron. Both SEEP2D and electric analogue models are applied to study seepage under heading-up structures occurring on both a single layer and stratified soils. The two models are compared to check the accuracy of the electric analogue in simulating seepage in a trial to add more verification cases of the electric approach.

The results showed that the pressure distribution under the floor of heading up structures is actually non-linear, and accordingly, the linear assumption can be a weak assumption to study seepage under large heading up structures and dams. Stratification is found to affect the head distribution under the apron, and the total flow rate.

The results of the electric analogue are very promising and of good accuracy compared to numerical modeling. This gives rise to the applicability of the electric analogue to study seepage under heading up

structure. This can become very useful if future studies could reveal relations between the electric analogue model and seepage failures.

This research also includes a comparison between 2D and 3D numerical models, in an attempt to evaluate the effect of neglecting the third dimension in studying seepage under an apron for both laterally homogeneous and heterogeneous conditions. Charts relating the exit gradient resulting from 2D model to that from the 3D model at centerline and sides of the apron's width for different values of H/B and different structure configurations including the presence and lack of an upstream sheet pile have been developed. In addition, the effects of downstream wing walls (guide walls) existence on seepage are also assessed.

The results prove that studying seepage in 3D can significantly become critical over the traditional 2D approach. This makes 3D simulation essential when studying seepage under large heading up structures (e.g. large dams) especially in complicated 3D configurations and lateral heterogeneity and/or anisotropy cases.

In this research piping problem under hydraulic structures is also reconsidered and a modification to Ojha (2003) critical velocity based piping model is suggested in an attempt to improve the accuracy of the critical hydraulic gradient estimation.

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NOTATIONS

B = Width of apron [L]

d = Particle size [L].

d_1 = Depth of upstream cutoff from its point of intersection with the apron to its toe level [L].

d_2 = Depth of downstream cutoff from its point of intersection with the apron to its toe level [L].

d_e = Depth of point (e) under the downstream bed [L].

d_e/T = Relative depth of point (e) [Dimensionless].

e = Any point located on the critical (exit) section along the whole thickness of pervious stratum (T) under the apron.

f = Coefficient of friction.

g = Gravitational acceleration [LT^{-2}].

h = Head difference between upstream and downstream sides of the apron [L].

h_e = Piezometric head at point (e) [L].

h_e/h = Average relative piezometric head at point (e) [Dimensionless].

H = Head acting on the structure [L].

H_{crit} = Critical head [L].

h_f = Head loss due to friction [L].