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Type-curves to assess seepage under sheet-piles for dewatering geotechnical works in limited 2D geometries

Courbes types pour évaluer l'infiltration sous palplanche pour les travaux géotechniques de drainage dans des géométries 2D limitées

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ABSTRACT: Graphical methods based on flownets or numerical modelling are two procedures traditionally used to estimate groundwater flow under different geotechnical structures (dams, sheet-piles, diaphragm walls, among others). In this work, both methods are combined with dimensionless analysis to set out and verify the dimensionless groups that govern the groundwater discharge. The results are a set of type-curves charts easy-to-use to assess seepage per metre transversal length of sheet-pile. The chart is applied to flow under sheet-piles for maritime or fluvial shored scenarios, where permanent dewatering is required in the enclosure. Geometrical parameters like sheet-pile height, depth of sheet-pile embedment, impervious bedrock depth, excavation width, horizontal stretch in the back face and water levels and physical parameters as hydraulic conductivity are input data in the chart, all of them included in the monomials. The physical scenario assumes isotropic medium and cross-section symmetry.

RÉSUMÉ: Les méthodes graphiques basées sur les flownets ou la modélisation numérique sont deux procédures traditionnellement utilisées pour estimer le mouvement des eaux souterraines sous différentes structures géotechniques (barrages, palplanche, paroi moulée, entre autres). Dans ce travail, les deux méthodes sont combinées avec une analyse adimensionnelle pour définir et vérifier les groupes adimensionnels qui régissent le mouvement des eaux souterraines. Les résultats sont un ensemble de courbes types faciles à utiliser pour évaluer l'infiltration par mètre de longueur transversale de palplanche. Les courbes est appliqué au mouvement sous les palplanches pour des scénarios de berges maritimes ou fluviales, où un assèchement permanent est nécessaire dans la tranchée. Les paramètres géométriques tels que la hauteur des palplanches, la profondeur d'encastrement des palplanches, la profondeur du substratum rocheux imperméable, la largeur de l'excavation, l'étirement horizontal et les niveaux d'eau, ainsi que les paramètres physiques tels que la conductivité hydraulique, sont des données d'entrée dans le diagramme, toutes incluses dans les monômes. Le scénario physique suppose un milieu isotrope et une symétrie de la section transversale.

Keywords: Numerical modelling; dimensionless monomial; seepage; dewatering.

1 INTRODUCTION

Most civil engineering construction sites requires working under the ground surface. The stability of the excavation is, in many cases, supported by geotechnical structures like sheet pile walls, steel sheeting, diaphragm walls, cut-off walls, or cofferdams. The design of them relies on soil mechanics properties and on the presence of groundwater. The groundwater flowing under the retaining structure and into the excavation (seepage) is conditioned by the geometry, the specific boundary conditions and the hydraulic conductivity.

In this work, we focus on the calculus of seepage in a 2D isotropic scenario outlined in Figure 1. The 2D geometry of the aquifer is constrained by "*H*" and "*L*", both having finite values. The solution is given as a set of abacuses and the type curves depicted in them relates dimensionless monomials (groups of parameters involved in the solution).

Similar solutions are found in technical or scientific literature. For example, in Puertos del estado and Ministerio de Fomento (2005) and Graham (2006), the solution was given for a non-horizontal limited scenario (length "*L*" was not included). In Preene et al. (2014), the horizontal and vertical extend "*L*" and "*H*", respectively, were not defined. This last case was also studied in Navarro Carrasco et al. (2023), but considering anisotropic media. A problem we found in some of these works is the lack of explanation about the meaning of some parameters required to use the abacuses. Most of them are not even defined in the documents, what make them difficult to understand.

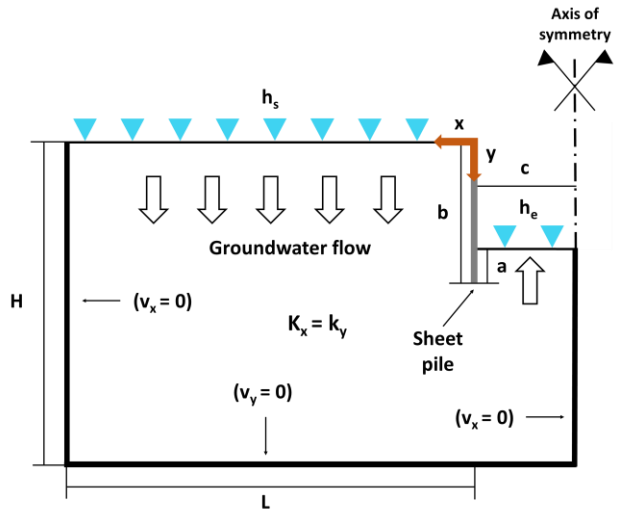

Figure 1. 2D schema of the problem with geometric data and boundary conditions.

This work is a first step before further studies with anisotropic media or heterogeneous layered substratum. A theoretical example of application is given at the end of section 3, to illustrate the use of the abacuses.

2 PHYSICAL MODEL AND GOVERNING GROUPS

The list of parameters that define the problem are shown in Figure 1: piezometric heads at the back of the wall (h_s) and inside (h_e) the excavation, the horizontal (L) and vertical (H) extend, the depth of the retaining structure in contact with groundwater b, the embedment a, half of the horizontal extend of the excavation c, and the isotropic hydraulic conductivity K. The transversal extend of the excavation is large enough to neglect effects at the edge and axis-symmetry is assumed. To ensure that the horizontal and vertical extension are short enough to influence on the solution, the concept of characteristic lenghts previously studied in Navarro Carrasco et al. (2023) and Martínez-Moreno (2022), is applied. This concept relates to specific vertical (T^*) and horizontal (L^*) lengths: if $H > T^*$ and $L > L^*$ the solution is similar to an infinite scenario (not the case here we are dealing with), and if $H < T^*$ and $L < L^*$ the solution is that of a finite scenario. In section 3 it will be clarified with and example.

As shown in Figure 1, water is flowing from the surface to the bottom of the excavation and under the geotechnical structure. The boundary conditions are Dirichlet condition (constant head) at the ground surface and bottom of the excavation and Neumann condition (impervious limits) at the geotechnical structure, vertical limits ($v_x = 0$) and at the bottom ($v_y = 0$). As it can be apreciated, the ground located over the prehatic level is not conditioning the seepage.

Each monomial (group of parameters involved in the solution) is obtained from classical dimensional analysis techniques (Palacios, 1964). The values of the 4 monomials obtained govern the solution. It means that, as long as the values of the monomial remain constant, the solution is the same irrespective of the values of the parameters included in the groups. The monomials are:

$$\pi_1 = a/b \quad (1)$$

$$\pi_2 = b/c \quad (2)$$

$$\pi_3 = b/H \quad (3)$$

$$\pi_4 = c/L \quad (4)$$

$$\pi_Q = \frac{Q}{(h_s - h_e)\cdot k} \quad (5)$$

According to Pi Theorem (Buckingham, 1914), the group π_Q with the unknown Q is a function of the rest of groups (1-4) and its value was previously set by Martinez-Moreno (2021). A total number of 72 simulations with MODFLOW (Harbaugh et al., 2000), each of them taking an average of less than 15 second to compute, were carried out to depict the abacuses and type curves, so the function π_Q was defined. The procedure required keeping three monomials constant and while changing the values of the fourth, so the variation π_Q can be drawn as a function of the fourth. The process is repeated by taking turns with all the monomials.

3 RESULTS: TYPE CURVES

4 abacuses containing 3 type curves each one, are shown in Figure 2.

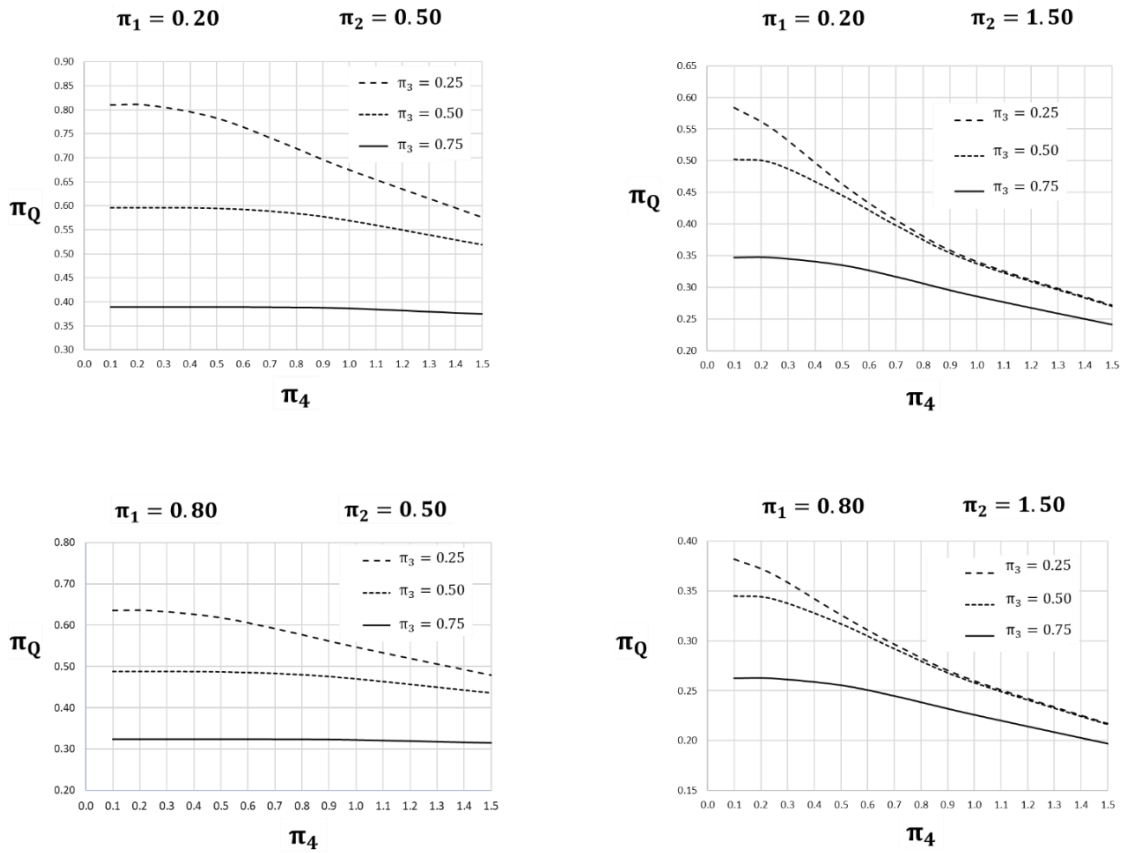

Figure 2. Type curves to calculate seepage under a retaining structure and into the excavation.

The curve parameter is π_3 and the values considered are 0.25, 0.50 and 0.75. The abacus parameters are π_1(0.2-0.8) and π_2 (0.5-1.5). On each graph, π_4 ranges from 0.1 to 1.5. These values were chosen to consider aspect related to stability or heave.

To illustrate the use of the abacuses, a theoretical application based on example 3.3 of Berry and Reid (1993) is solved. The parameter values and the monomials are shown in Table 1.

Table 1. values of the variables in the theoretical example.

Parameter/monomial	Value	Units
a	4.0	m
b	5.0	m
c	3.0	m
L	12.0	m
H	9.0	m
$\boldsymbol{h_s - h_e}$	4.0	m
k	$7 \cdot 10^{-5}$	m/s
$\boldsymbol{\pi_1 = a/b}$	0.80	dimensionless
$\boldsymbol{\pi_2 = b/c}$	1.67	dimensionless
$\boldsymbol{\pi_3 = b/H}$	0.56	dimensionless
$\boldsymbol{\pi_4 = c/L}$	0.25	dimensionless

The steps that must be followed are:

Step 1: Check if the values of L and H are lower than those of the characteristic legths L^* and T^*, so that the type-curves of Figure 3 can be used. Figures 3 and 4 are used in this step.

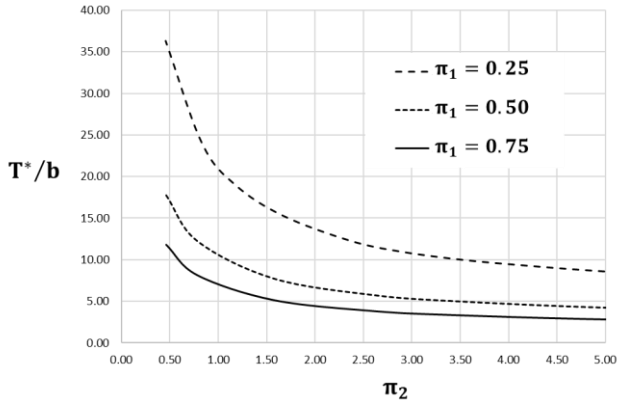

Figure 3. Type curves to calculate the vertical characteristic length T^*. Modified from Navarro Carrasco et al. (2023).

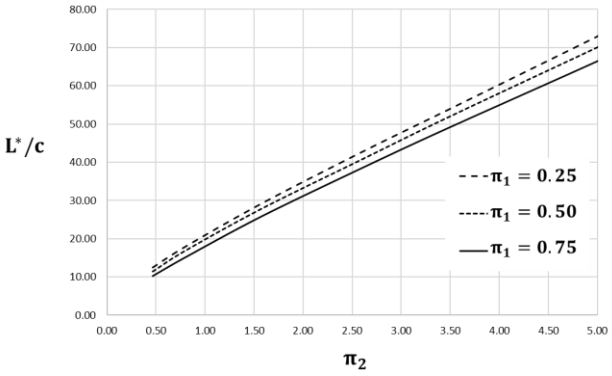

Figure 4. Type curves to calculate the horizontal characteristic length L^*. Modified from Navarro Carrasco et al. (2023).

According to values in Table 1, L^* = 84 m and T^* = 25 m, both greater than L = 12 m and H = 9 m, so the abacuses in Figure 3 can be used.

Step 2. We select the abacus according to the values of the monomials, in this case, the one with π_2 = 1.5 (the closest) and π_1 = 0.8. With the value of π_4 = 0.25 and π_3 = 0.56, the function containing the unknown is π_Q = 0.33.

Step 3. With the values of π_Q = 0.33, we obtain Q from equation 5: $Q = 9.24 \cdot 10^{-5}$ m^3/s/m.

In Berry and Reid (1993), the result for $L = \infty$ (in our variant we have considered L = 12 m) is $Q = 8.96 \cdot 10^{-5}$ m^3/s/m. Simulating the example of Berry and Reid with L = 12 m in MODFLOW, $Q = 9.14 \cdot 10^{-5}$ m^3/s/m.

4 CONCLUSIONS

In this work, we provide 12 type-curves distributed in 4 abacuses to calculate seepage under embedded retaining structures from geometrical and physical data. Each graph depicts the monomial containing the unknown π_Q, as a function of the 4 dimensionless groups. The conditions are isotropic hydraulic conductivity and limited horizontal and vertical extension of the scenario, so that the geometry is conditioning groundwater flow.

To illustrate the use of the type-curves, a modified example has been carried out. The first verification compares by using two charts, the vertical (H) and horizontal (L) length of the scenario with the characteristic lengths T^* and L^*, respectively. It allows to differentiate between limited and infinite scenarios, those where the geometry is not conditioning the seepage.

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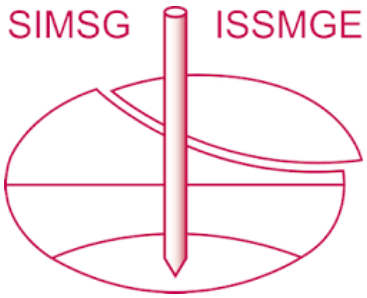

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