Prediction of the pore water pressure under isotropic loading

Prédiction de la pression interstitielle d'eau sous chargement isotrope

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ABSTRACT: In this paper, we present the results of numerical modelling of the development of pore pressures depending on the applied isotropic stress. We will apply two approaches. The first one is the Hilf method (1948) which predicts the evolution of air pressure, under variations of the vertical stress in untrained conditions. The second approach Boutonnier (2007) is based on an unsaturated soil behaviour model integrating an aero-hydro-mechanical coupling. Boutonnier highlights the importance of the presence of occluded air in the soil and its influence on the hydromechanical behavior. We apply both models in order to compare the experimental results carried out on a compacted clay of an earth dam. The samples are compacted to the maximum normal Proctor dry density and different water contents around the optimum (SPO and SPO + 2%).

KEYWORDS: Numerical models, pore pressure, isotropic loading, compacted clay, unsaturated soil.

RÉSUMÉ : Dans cet article, on présente les résultats de simulations numériques montrant l'évolution des pressions interstitielles en fonction de la contrainte isotrope appliquée. On appliquera deux approches. La première est la méthode de Hilf (1948) qui prédit l'évolution de la pression d'air sous la variation de la contrainte verticale en condition non drainées. La seconde approche est celle de Boutonnier (2007) qui est basée sur un modèle de comportement d'un sol saturé intégrant un couplage aéro-hydro-mécanique. Boutonnier montre l'importance de l'air occlus dans le sol et son influence le comportement hydromécanique. On applique les deux modèles sur les résultats expérimentaux d'une argile de barrage en terre compactée. Les échantillons sont compactés à la densité maximale Proctor normale et à différentes teneurs en eau autour de l'optimum (OPN et OPN+2%).

MOTS-CLES : Modèles numériques, pression interstitielle, chargement isotrope, argile compactée, sol non saturé.

1 INTRODUCTION.

The compacted soils are widely used in different geotechnical fields, such as road embankment, earth dams… Consequently, there are many problems, related to compacted soils, which have to be solved by the geotechnical engineers. These soils have the particularity of being partially saturated and contains occluded air. Which makes the behavior of compacted soil very complex.

The study of the behaviour of the compacted unsaturated earth dams requires the knowledge of the pore water pressures' evolution under the effect of loading.

In this article, we present two models: Hilf's method (1948) and the second approach (Boutonnier, 2007 & 2010). Those models predict the evolution of pore pressure with the variation of isotropic stress in undrained conditions.

An experimental study was done on a compacted clay and the result were compared to the simulation.

2 PRESNTATION OF STUDIED MODELS

We present briefly the two models here, for more details see the following references (Hilf, 1948; Fredlund and Rahardjo, 1993; Boutonnier, 2007; Monnet and Boutonnier, 2012).

2 .1 *Hilf model (1948)*

Hilf has established a relationship to predict the development of air pressure in unsaturated compacted embankments due to variations in vertical stress under undrained conditions.

Hilf's approach is based on two main assumptions:

The pore air pressure u_a is equal to the pore water pressure u_w, which means that the suction is not taken into account and its value is zero.

2 .2 *Boutonnier model (2007)*

This model is based on the assumption that four domains of saturation for fine soils are defined. Boutonnier, 2010 distinguished them: unsaturated dry soils (D1 domain), quasi-saturated soils (D2 and D3 domains), and saturated soils (D4 domain) (see figure 1).

In each of these domains, this model uses a simple effective stress based on the Cambridge model with the coefficient of compressibility cf of the interstitial fluid (water + occluded air) which depends on the degree of saturation (Li, 2016).

The particularity of the model is to integrate the quasi-saturated domain. For this Boutonnier used a lot of correlations (Fleureau, 2002) to deduce parameters from the liquid limit which is a parameter easily measurable in the laboratory.

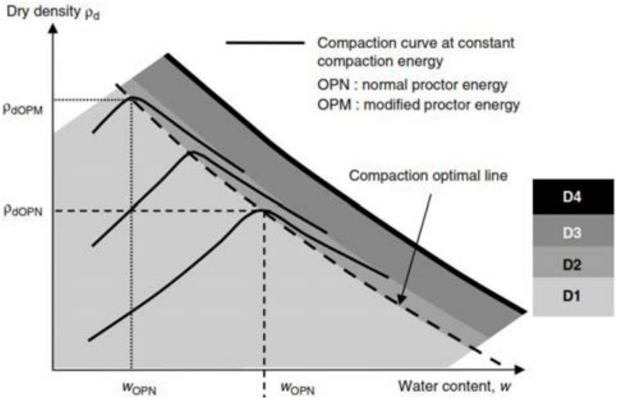

Figure 1. Qualitative position of the D1, D2, D3, and D4 domains in compacted soils according to literature experimental results (Boutonnier, 2010).

3 EXPERIMENTAL STUDY

In the aim of applying Hilf and Boutonnier models, an experimental study was carried on a compacted clay of Boughrara earth dam (North-West of Algeria). The characteristic of this material is reported on table 1.

Table 1. Physical and mechanical properties of Boughrara clay (Benchouk, 2014).

Grain size properties				Plasticity		Standard Proctor normal	
<80µm	<2µm	d_{60}	d_{10}	w_L	Ip	γ_d/γ_w	w_{SPO}
97%	72%	1µm	0.6µm	54%	28%	1.62	21 %

In the experimental program, we studied in a triaxial cell the evolution of water pore pressures in an unsaturated soil under the application of isotropic loading. This kind of test were rare (Taibi, 1993; Vaughan, 2009; Marhinho, 2003).

The triaxial cell used in the experimental tests is equipped at its base with a tensiometer to measure the initial suction of compacted samples.

The samples are compacted to the maximum dry density (1.62) and different water contents around the optimum (SPO and SPO + 2%), respectively 21% and 23%.

Different isotropic stresses are applied in successive steps: 100-200-400-600-800-1000-1200 and 1500 kPa. Before reaching the upper stage, the pore pressures must be stabilized, this phase of stabilization lasts from 24 to 48 hours for each stage. This means that each complete test lasts approximately 3 weeks.

The evolution of pore pressure under isotropic loading for samples compacted at the optimum Proctor SPO and SPO+2% is reported in figure 2.

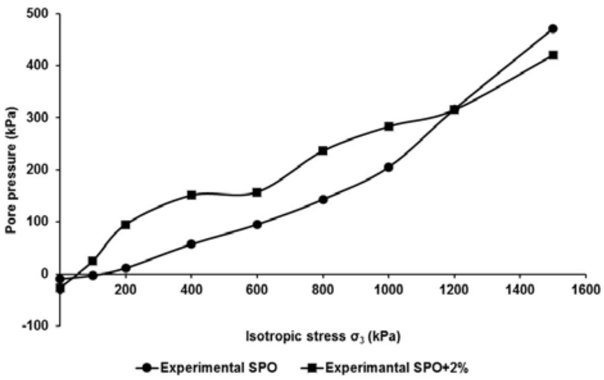

Figure 2: Result of the experimental study at the initial conditions of SPO and SPO+2%

The both curves started with negative pore pressure, those values are the initial suction measured by tensiometer.

4 APPLICATION OF THE NUMERICAL MODELS

Since the Boutonnier model introduced the mean bubble radius rbm as a data, two mercury porosimeter tests were performed on the compacted samples at OPN and OPN + 2% to see the dominant diameter of the macropores and thus consider it as the mean bubble radius (r_{bm}). The results are shown in Figure 3.

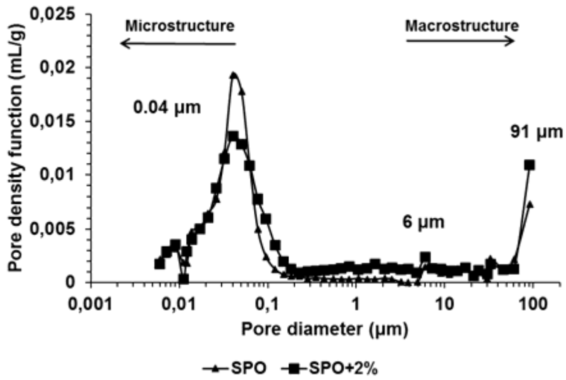

Figure 3: Results of the porosimetric test at SPO and SPO+ 2%.

These results show that the diameter of 91 µm is dominant for both samples. A slight peak can be considered, the diameter expressed by the latter is 6 µm. The largest peak is 0.04 µm but it represents micropores and not macropores.

For the simulations we adopt rbm équal to 6 µm.

The parameters of Hilf model introduce in the numerical program are listed in the table 2.

Table 2: Model parameters used in Hilf model for Boughrara soil

Initial condition	m_v (1/kPa)	S_0 (%)	n_0
SPO	9.04.10-5	90.3	0.38
SPO+2%	1.36.10-4	96.3	0.39

The parameters used in Boutonnier model are:
the liquid limit of the soil: w_L= 54 % and the mean bubble radius r_{bm}= 6 µm.

The results of the simulation at the SPO and the SPO + 2% for the two models are represented on the two figures 4 and 5 below:

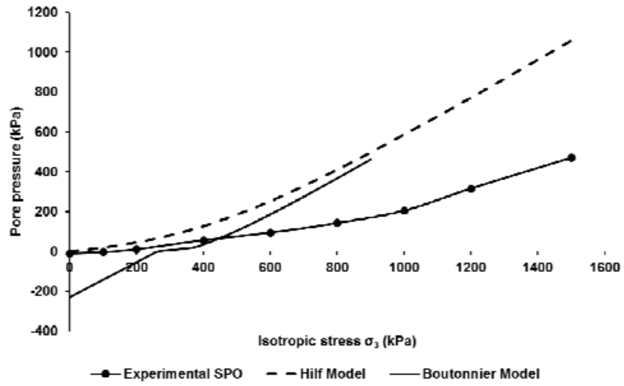

Figure 4. Result of the simulations with the Boutonnier, Hilf models and the experimental measure at the SPO initial condition.

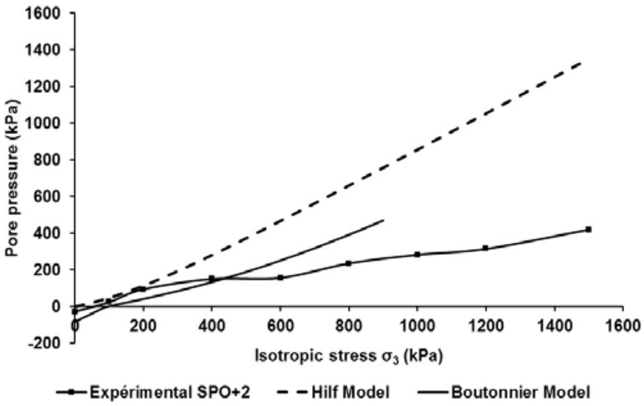

Figure 5.Result of the simulations with the Boutonnier, Hilf models and the experimental measure at the SPO+2% initial condition.

The results show a certain concordance between the Boutonnier model and the experimental results.
As for the model of Boutonnier and in comparison with Hilf, the same slope for the positive values of the interstitial pressure of water is found.
The advantage of the Boutonnier model is that it takes into consideration the initial suction of the compacted sample, unlike the Hilf model, which does not take into account this important parameter.

5 CONCLUSION

The Hilf model remains very easy to use, its main disadvantage is that it does not take into account the initial suction. This latter parameter is very important in the study of overpressures in embankments. This major inconvenience makes Hilf's approach obsolete, even if it can be tolerated for a pre-dimensioning.

Concerning the Boutonnier model, it has simplified many expressions by using only the correlations based on the liquidity limit. This is a great advantage as any laboratory can get this value with simple means. The main difficulty is to determinate the rbm which needs porosimettic tests.
The practicality of this model should be noticed as it is used to simulate the pressures at the SPO and the wet side of the Proctor curve, which is of most interest to the practicing engineer.
The comparison between experimental results and numerical modelling shows that the model of Boutonnier concords quite well with the experimental results. It’s main interest is that it takes the initial suction of the compacted sample into consideration, unlike the Hilf model which do not consider this important parameter.

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