The relationship of the unsaturated soil shear strength to the soil-water characteristic curve

D.G. Fredlund, Anqing Xing, M.D. Fredlund, and S.L. Barbour

Abstract: The measurement of soil parameters, such as the permeability and shear strength functions, used to describe unsaturated soil behaviour can be expensive, difficult, and often impractical to obtain. This paper proposes a model for predicting the shear strength (versus matric suction) function of unsaturated soils. The prediction model uses the soil-water characteristic curve and the shear strength parameters of the saturated soil (i.e., effective cohesion and effective angle of internal friction). Once a reasonable estimate of the soil-water characteristic curve is obtained, satisfactory predictions of the shear strength function can be made for the unsaturated soil. Closed-form solutions for the shear strength function of unsaturated soils are obtained for cases where a simple soil-water characteristic equation is used in the prediction model.

Key words: soil suction, soil-water characteristic curve, shear strength function, unsaturated soil.

Résumé : La mesure des paramètres de sol tels que la perméabilité et les fonctions de résistance au cisaillement, utilisés pour décrire le comportement du sol non saturé, peut coûter cher, être difficile et souvent impraticable à réaliser. Cet article propose un modèle pour prédire la fonction de résistance au cisaillement (vs succion matricielle) des sols non saturés. Le modèle de prédiction utilise la courbe caractéristique sol-eau et les paramètres de résistance au cisaillement du sol non saturé (i.e., la cohésion effective et l'angle de frottement interne). Lorsqu'une estimation raisonnable de la courbe caractéristique sol-eau est obtenue, des prédictions satisfaisantes de la fonction de résistance au cisaillement pour les sols non saturés peuvent être faites. Des solutions exactes pour la fonction de la résistance au cisaillement des sols non saturés sont obtenues pour des cas où une simple équation caractéristique sol-eau est utilisée dans le modèle de prédiction.

Mots clés : succion dans le sol, courbe caractéristique sol-eau, fonction de résistance au cisaillement, sol non saturé.

[Traduit par la rédaction]

Introduction

A theoretical framework for unsaturated soil mechanics has been firmly established over the past couple of decades. The constitutive equations for volume change, shear strength, and flow for unsaturated soil have become generally accepted in geotechnical engineering (Fredlund and Rahardjo 1993*a*). The measurement of soil parameters for the unsaturated soil constitutive models, however, remains a demanding laboratory process. For most practical problems, it has been found that approximate soil properties are adequate for most analyses (Fredlund 1995). Hence, empirical procedures to estimate unsaturated soil functions are adequate.

Laboratory studies have shown that there is a relationship between the soil-water characteristic curve and the unsaturated soil properties (Fredlund and Rahardjo 1993*b*). Several models have been proposed to empirically predict the permeability function for an unsaturated soil from the soil-water characteristic curve by using the saturated coefficient of permeability as the starting value (Fredlund et al. 1994).

Received September 15, 1994. Accepted February 5, 1996.

D.G. Fredlund, A. Xing, M.D. Fredlund, and S.L. Barbour. Department of Civil Engineering, University of Saskatchewan, Saskatoon, SK S7N 5A9, Canada.

This paper provides engineers with a means of estimating the shear strength function for an unsaturated soil from the soil-water characteristic curve by using the saturated shear strength parameters as the starting values.

Literature review

The shear strength of a soil is required for numerous analysis, such as the prediction of the stability of slopes, the design of foundations, and earth retaining structures. The effective stress variable proposed by Terzaghi (1936) has been used in the Mohr-Coulomb theory for predicting the shear strength of *saturated* soils. The shear strength equation for saturated soils is expressed as a linear function of effective stress and is given as follows:

$$[1] \quad \tau = c' + (\sigma_n - u_w) \tan \phi'$$

where

τ is the shear strength;
c' is the effective cohesion;
ϕ' is the effective angle of internal friction;
σ_n is the total normal stress on the plane of failure;
$(\sigma_n - u_w)$ is the effective normal stress on the plane of failure; and
u_w is the pore-water pressure.