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GENERALIZED PLASTICITY CONSTITUTIVE MODEL BASED ON STATE PARAMETER APPROACH FOR SATURATED AND UNSATURATED SOILS

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ABSTRACT. The study developed in this work is focused on constitutive modelling of saturated and unsaturated granular soils from the state parameters point of view. The Generalized Plasticity constitutive equation has been extended in order to reproduce stress-strain behaviour of granular soils with a single set of intrinsic model constants for different densities, confining pressures and saturation conditions.

1. Introduction

The growing interest in understanding the behaviour of partially saturated soils and their modelling has caused an increase of the number of experimental data. This has lead to the formulation of various constitutive models. From the pioneering work of Alonso et al. (1990) a series of constitutive models has been developed depending of net stress and suction (Cui & Delage, 1996). After the work of Housby (1997) who analyzed the work input to unsaturated granular materials, a new generation of models for unsaturated soils based on both the Bishop - effective stress and suction was produced. At first they were focused on isotropic compression tests (Gallipolli et al, 2003, Wheeler et al, 2003), and then the shearing behaviour was modelled (Tamagnini & Pastor, 2004; Fernández Merodo et al., 2005 among others)

The state parameter concept has been incorporated in order to take into account the dependant of granular soil behaviour on density and confining pressure. This concept, introduced for the first time in the work of Uriel (1975), has allowed to relate the variation of density (or void ratio) with a reference state, as for example the Critical State. The state parameter concepts have generally been used in saturated sand modelling (Li & Dafalias, 2000). The dependence of the initial conditions (density, confining pressure, degree of saturation, suction) and the stress paths in the soil behaviour imply that the same material is modelled with different constants.

The aim of this work is to suggest a unified formulation of constitutive model of Generalized Plasticity for saturated and partially saturated soils.

2. Generalized Plasticity Framework

Generalized Plasticity Theory was first presented by Zienkiewicz & Mróz (1984) and later extended by Pastor et al. (1990) with a generalized constitutive model for different types of soils in saturated conditions. Based on the previous work of Tamagnini & Pastor (2004) for unsaturated soils, the proposed constitutive model is combining versatile and hierarchical formulation of Generalized Plasticity Theory with the critical state framework where the total strain rate is defined as a sum of the elastic component (ε_{ij}^e), the plastic component coupled with the stress tensor (ε_{ij}^p) and the plastic component coupled with suction (ε_{ij}^s). The constitutive equation is written:

$$d\varepsilon = (\mathbf{D}^e)^{-1} : d\sigma'' + \frac{1}{H_{L/U}} \mathbf{n}_{gL/U} \otimes \mathbf{n} : d\sigma'' + \frac{1}{H_b} \mathbf{n}_{gL/U} ds \quad (1)$$

In order to reproduce the elastoplastic behaviour of a material according to the Generalized Plasticity Theory, the following items must be known: \mathbf{D}^e elastic behaviour tensor, \mathbf{n} tensor discriminating loading and unloading situations, \mathbf{n}_g tensor of plastic flow direction in loading and unloading; $H_{L/U}$ plastic modulus in loading and unloading; and H_b plastic modulus in wetting and drying path. σ'' is the "Bishop stress" (Bishop & Blight, 1963) and s is the difference between the pore-air pressure and pore-water pressure.

3. Unified Generalized Plasticity model

State parameter approach has been used in various constitutive models in order to generalize the modelling constants for different stress paths and different initial conditions in saturated soils. The state parameter is defined as the vertical distance between the current state and critical state line in the $e - p$ plane. Manzanal et al. 2006 suggest a modification of the formulation of dilatancy, plastic module and unit vectors of loading, unloading and plastic flow as a function of state parameter for saturated soils. The extension of the constitutive equation for partially saturated soils includes a generalization of the critical state for different suctions as a function of a bounding parameter. The constitutive model has a hydro-mechanical formulation through the relation of saturation degree and normalized suction. The model has also considered the void ratio and hydraulic hysteresis effect on the hydraulic behaviour. To take into account the hardening and softening effect caused by the change on suction, the plastic modulus H_b is the function of a bonding parameter.

The model has been calibrated by using the experimental results reported in literature. The simulated tests are covering a wide range of densities, confining pressures and suctions on saturated and partially saturated soils and they are collected in Manzanal (2008). The Figure 1 shows the predictions of the model during the triaxial tests at constant suction (200kPa) under the confining pressures of 50kPa and 100kPa.

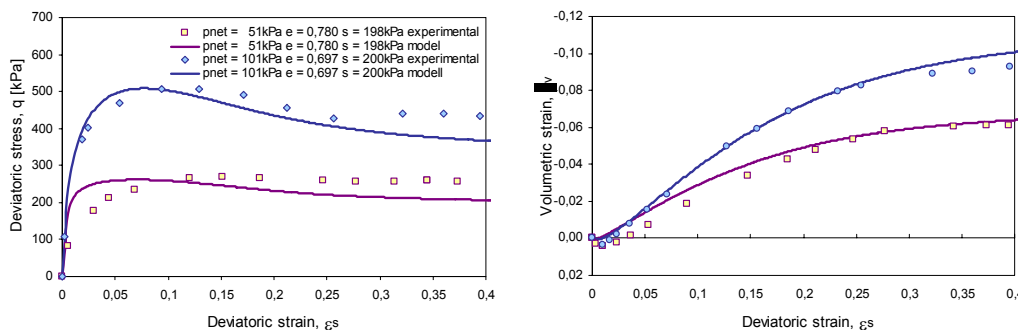


Figure 1. Comparisons between the experimental data of triaxial tests at constant suction ($s = 200\text{kPa}$) for different confining pressures and void ratios from Russell (2004) and model simulations.

4. Conclusions

A unified constitutive model based on the Generalized Plasticity Theory and the concepts of state parameter have been presented. The model is capable of reproducing stress-strain behaviour of unsaturated soils for different densities, confining pressures and suction, using the same materials constants. The Generalized Plasticity Theory gives a suitable framework to reproduce not only the monotonic stress path but also the cyclic behaviour.

5. Acknowledgements

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