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An extended elasto-plastic model for unsaturated clays

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Abstract
This paper presents an extension of a clay model from saturated to unsaturated response. The original model employs a non-associated flow role. Besides, yield and plastic potential functions may be subjected to rotation/distortion with fabric anisotropy. The extended model is formulated based on Bishop's effective stress. By comparing the model prediction with experimental data, it is shown that the modified model can reproduce reasonably the mechanical behavior of both saturated and unsaturated clays.
Keywords: constitutive models, clay, effective stress, suction, SANICLAY.

1. INTRODUCTION

In geotechnical engineering, structures are usually designed based on the parameters obtained in saturated state. In this regard, numerical analyses are commonly based on constitutive models specially formulated for modeling of saturated soils. However, soils are primarily in unsaturated state in nature. Only in the recent years, the importance of partial saturation has been recognized by the community. Therefore, constitutive models for soils should represent the soil behavior over the entire ranges of saturation. Constitutive modeling for unsaturated soils was pioneered by Alonso et al. [1]. Since then, a number of successful constitutive models have been proposed [1-9]. The state variables employed in most of the existing elastoplastic models of unsaturated soils are net stresses (the difference between total stresses and pore air pressure), suction, s (the difference between pore air and pore water pressures), and specific volume, v (e.g., [1-3]).The influence of the unsaturated condition is therefore expressed solely through the suction, with any direct influence of degree of saturation, Sr, being ignored. This is important, because the occurrence of hydraulic hysteresis in the water retention curve during drying and wetting means that two samples of the same soil subjected to the same value of suction can be at significantly different values of S_r in drying and wetting paths [8]. Thus, models using only suction in their formulation are incomplete [10]. Recently, a thermodynamiccaly consistent theory has been suggested in which constitutive equations for unsaturated geomaterials should be expressed in terms the effective average stress and suction as stress variables and the strain of solid skeleton and degree of saturation as strain like variables [10-12].

2. GENERAL FORMULATION OF SANICLAY FOR SATURATED CLAYS [13]

SANICLAY can be considered as an extension of the Modified Cam-Clay model (MCC) with a non-associated flow rule. In SANICLAY, yield and plastic potential functions are subjected to rotational/distortional hardening as a result of anisotropy. In sequel, formulation of SANICLAY in triaxial space is presented.

The volumetric and deviator elastic strain rates are calculated by:

$$\dot{\varepsilon}_v^e = \frac{\dot{p}}{K}; \quad \dot{\varepsilon}_q^e = \frac{\dot{q}}{3G} \tag{1}$$

where, p and q are the average mean effective stress and deviator stress. K and G are, respectively, the bulk and shear moduli: