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Numerical Bearing Capacity Prediction of Unsaturated Soils by the Method of Stress Characteristics

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Abstract

Bearing capacity is often calculated for saturated state of the soil, due to its simple and conservative results. However, this assumption results in very uneconomic design for a wide range of climates. In this paper, the bearing capacity of unsaturated soils is studied numerically and then compared with experimental results obtained from different authors. A generalized method of stress characteristics based on Bishop (1959) effective stress concept and Mohr-Coulomb yield criterion is presented and solved numerically. It is revealed that the method of stress characteristics can be generalized for unsaturated soils.

Keywords: Bearing Capacity, Foundation, Effective Stress, Unsaturated Soil, Stress Characteristics.

1. INTRODUCTION

Unsaturated soil mechanics has been developed extensively in the recent decades as a very useful tool to prevent conservative designs in arid and semi arid areas of the world. Terzaghi (1936) described the first definition of stress state variables for saturated soils [1]. Later, it was believed that two independent variables can be assigned to unsaturated soils as stress state parameters [2]. Unsaturated soils have commonly been viewed as a three phase system, i.e. solids, water and air [3]. However, contractile skin, which is the air-water interface, has also been introduced as the fourth phase [4].

The shear strength of soils is related to the effective stress and for a three phase system, Bishop (1959) suggested an effective stress expression for unsaturated soils that has been widely employed in unsaturated soil mechanics. This effective stress is described as the summation of two independent stress state tensors by standard notations of continuum mechanics [5]:

$$\sigma'_{ij} = (\sigma_{ij} - u_a \delta_{ij}) + \chi (u_a - u_w) \delta_{ij} \tag{1}$$

In this equation, σ' is the effective stress, u_a and u_w are the pore air and pore water pressures respectively, and χ is the effective stress parameter that is usually related to soil suction or matric suction. It is equal to unity for saturated soils and decreases as the degree of saturation decreases. The first term, $(\sigma_{ij}-u_a\delta_{ij})$ is also known as net stress and δ_{ij} is Cronecker's delta. Some similar relationships have been introduced as modifications to this equation incorporating solute suction term [2,6,7].

Parameter χ may be envisaged as the ratio of all pore areas filled with water, A_{uw}, to the total pore area, A_{sw} as shown in Figure 1 [8]. There are many methods to obtain effective stress parameter from SWCC results as well as soil pore size distributions [9,10,11]. Khalili et al. (2004) presented a review on the effective stress parameter of Bishop (1959) and presented the following equation for the χ parameter [10]: