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Dilative Behavior of Granular Materials

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ABSTRACT

The dilative behavior of soils is found to be very important when analyzing the critical or ultimate states of granular soils. However, scant previous research work has been done to identify the dilative behavior of granular soils, and very few dilation angles of actual soils have been reported, especially in the low confining pressure range. In an effort to study the dilative behavior of granular soils, the authors performed a number of triaxial tests on various granular soils. Test results indicate that dilation angles are much higher than the theoretical values suggested in the literature. The authors verified the test results through laboratory work as well as through a finite difference method computer program. Results of the numerical analysis showed that predictions of stress-strain relationships of granular soils are obviously improved when actual dilation angles are applied.

INTRODUCTION

There is an increasing need for research leading to the identification of volumetric soil behavior, usually dilative, at critical states. In the past, scant research work was done, and very few dilation angles of actual soils were reported, especially in the low confining pressure range. Previous studies on soil dilatancy mostly concentrated on the theoretical or analytical solution of the dilation angle, as well as on its influence on soil strength. Very few real test data of dilation angles were reported. In addition, past research did not carefully investigate the influence of condition factors such as grain angularity, grain size distribution and confining pressure on soil dilation angles.

In an effort to improve the performance analysis of many offshore and retaining structures, the authors have conducted an extensive study on the dilative behavior of granular soils in the confining pressure range of 30~100 kPa, performing a series of triaxial tests on various granular soils. Test results indicate that, besides the relative density, the dilation angles of granular soils were also very sensitive to grain angularity and confining pressure. Especially at low confining pressure, the dilation angles of granular soils were found to be much higher than the empirical or theoretical values suggested by the previous literature and guidelines of numerical analysis computer codes. In addition, numerical techniques were also supported to create models of granular soils under low confining pressure. By using these numerical models, the performance of granular soils was analyzed. A finite difference computer program was used to develop the numerical models of granular soils' behavior for the purpose of building a numerical model of granular soils using case histories, inputting a suggested value of the dilation angle, testing its result value and comparing results. Results of the numerical analysis showed that predictions of stress-strain relationships of granular soils were obviously improved when actual dilation angles were applied.

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KEY WORDS: Granular materials, dilation angle, numerical analysis, triaxial test.

PREVIOUS STUDIES

Granular materials, especially densely packed, tend to dilate during shear loading. This dilative behavior is found to have great influence on the apparent strength behavior of granular soils. To characterize such dilative behavior, the dilatancy of granular soils is defined as the need for volume change during shear loading. In most cases, granular soils would reach their maximum volume change at their peak strength stages, and start to exhibit plastic flow. To quantitatively describe the dilatancy of granular soils, the dilation angle defined by Eq. 1 introduced the direct dilatancy measurement of granular soils. The peak dilation angle is simply defined as the dilation angle when granular soil has its peak strength:

$$\tan\psi = -(\delta\varepsilon_v)/(\delta\gamma) \tag{1}$$

where ψ = dilation angle, ε_v = volumetric strain, and γ = shear strain.

The strength and dilatancy of soils received a great deal of attention in the 1960s. By following the early work of D. W. Taylor, Bolton (1986) indicated that both effective stress and soil density affect the dilative behavior of soils and their strength parameters. Ignorance of such dilative behavior can lead to significant error in predicting ultimate bearing stresses, deformation or stability of geotechnical structures. Vermeer and de Borst (1984) first reported the typical values of dilation angles of various geological materials based on the empirical data (Table 1). As shown in this table, only the relative density condition is considered an influence factor of the dilation angle for granular soils. The dilation angle values suggested by Vermeer and de Borst are presently used in most geotechnical numerical analysis software. Bolton (1986) proposed a theoretical solution of the maximum dilation angle in the plane strain condition (Eq. 2), suggesting the typical dilation angle of granular soil is in the range of 10 to 20 degrees,