LIQUEFACTION AND UNDRAINED RESPONSE EVALUATION OF SANDS FROM DRAINED FORMULATION

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ABSTRACT: A general approach has been established to assess the undrained stress-strain curve and effective stress path under monotonic loading from drained triaxial tests. An appropriate formulation of a drained and drained rebounded (i.e., overconsolidated) triaxial test response is developed that, in turn, allows the assessment of developing liquefaction and the undrained behavior of saturated sands. The formulation presented is based upon reported experimental drained test results that were obtained from different investigators using different testing techniques. This formulation is a function of the confining pressure and basic properties of the sand, such as relative density, uniformity coefficient, and particle shape (roundness), which can be obtained from visual inspection. The approach is verified by comparing predicted and reported (observed) undrained behavior. The developed formulas allow one to predict the potential of sand to liquefy, the type of liquefaction, the peak and residual strength values, as well as the whole undrained stress-strain curve and effective stress path. The simplicity of this approach makes it an attractive general method to characterize the undrained behavior of sands in a preliminary analysis with no need to run sophisticated experimental tests.

INTRODUCTION

Several studies have been conducted to provide a better understanding of the undrained behavior of saturated sand under different types of loading. Some of the pioneering work in this field has been performed by Seed and Lee (1967), Castro (1969), Ishihara et al. (1975), Casagrande (1976), Castro and Poulos (1977), Poulos (1981), and Castro et al. (1982). In addition, several recent studies (Mohamad and Dobry 1986; Guzman et al. 1988; Vaid et al. 1989; Ishihara 1993) have made significant contributions to the understanding of the undrained behavior of saturated sands. The main interest in these studies is to relate the undrained strength of sand to its initial state in order to allow the designer to predict the potential for a saturated sand to liquefy. In other words, most of the investigations focused on the influence of the consolidation pressure and the associated void ratio of the sand on the undrained behavior of the saturated sand under monotonic and cyclic loading.

The undrained behavior of isotropically consolidated saturated sand under monotonic loading is accompanied by a change in the excess pore-water pressure, which, in turn, leads to different forms of undrained behavior. Unfortunately, no prior study provides a clear picture of mobilized undrained behavior and the associated effective stress path under undrained monotonic loading. The available studies indicate the potential for sand to liquefy, and characterize it as liquefiable or nonliquefiable material. The only way to assess the mobilized undrained behavior of a saturated sand (its stress-strain and stress path) under monotonic loading is via laboratory testing. By consolidating the saturated sand to different values of confining pressure or void ratio, a series of isotopically consolidated undrained (ICU) tests allow one to assess the variation in the peak undrained resistance, the residual stress of the saturated sand, and the associated levels of strain.

Recently, it has been shown that the undrained response of sand can be assessed from its drained laboratory response (Norris et al. 1997). The present paper deals specifically with the formulation of drained behavior as a function of state conditions and sand properties, thus reducing the need for laboratory testing. Therefore, the current study provides a general approach to assess the mobilized undrained behavior of saturated sand under monotonic loading, whether the sand is loose, medium dense, or dense. Moreover, the present study allows one to characterize the undrained response of the saturated sand, whether the sand is contractive and/or dilative, to define the potential for the sand to liquefy, and to characterize the type of the expected liquefaction (complete or limited liquefaction), as seen in Fig. 1.

The approach presented here assesses the undrained behavior of saturated sand under monotonic loading and is based on the most basic properties of the sand, such as its void ratio, e_c, or the relative density, Dr_c, at the end of consolidation to pressure, σ_{3c}, the roundness of sand grains, ρ, the uniformity coefficient, C_u, the effective angle of the internal friction, φ, and the drained axial strain at 50% stress level, ε_{50}. This work was developed to deal with most types of sand under different levels of confining pressure. The validity of the work presented and the equations formulated are verified by several comparisons with observed results employing Nevada, Ione, Ottawa, Banding, and Fraser River sands.

METHOD OF ANALYSIS

The technique developed by Norris et al. (1997) employs a series of drained tests, with volume change measurements, on samples isotropically consolidated to the same confining pressure, σ_{3c}, and void ratio, e_c, to which the undrained test is to be subjected. However, the drained tests are rebounded to dif-

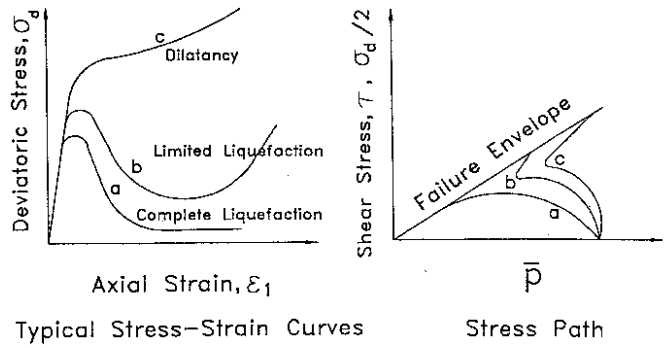

FIG. 1. Undrained Behavior of Saturated Sand under Monotonic Loading

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