BEHAVIOR OF UNSATURATED CLAYEY SOILS

AT HIGH STRAIN RATES

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ABSTRACT

A sample of soil from the flood plain of the Rio Grande was collected and subjected to engineering and physicochemical characterization tests. The soil was cleaned of soluble components and organic matter. Then a soil suspension stock was prepared with a precisely known and controlled chemistry of the pore solution. This soil suspension was used as a stock to provide soil to prepare specimens for testing.

The first step in specimen preparation consisted of the centrifugation of the soil suspension to reduce water content and reduce the volume changes that the suspension would have to experience during consolidation. For this purpose, the soil cake recovered from the centrifuge bottle was placed on a glass plate and was thoroughly mixed. Then the mixed soil cake was placed in a rubber membrane and consolidated in a triaxial cell under 50 psi confining pressure, at constant temperature, and for a fixed length of time.

The test specimens were trimmed from the consolidated material to cylindrical specimens 1.4 in. in diameter. These in turn were placed in a triaxial cell over a high air entry porous stone to equilibrate the specimen to predetermined soil suction levels. Upon reaching the equilibration point some specimens were destined to perform creep/recovery tests, while the rest were used for dynamic tests at high strain rates.

The creep tests were performed on specimens equilibrated at three soil

suction levels and several deviatoric stress levels. The results of these tests were used to find viscoelastic models that could explain the observed behavior. The test matrix was selected to provide information on how the model parameters depended on deviatoric stress and soil suction levels.

The specimens destined for the dynamic tests were prepared following the same procedure and under conditions that duplicated the creep tests. The specimen was placed in a dynamic triaxial test system and was subjected to successive load pulses of increasing peak load intensity. During the test, the load-time and the strain-time histories were recorded for each load pulse.

The load-time history recorded was used in conjunction with non-linear viscoelastic models developed from the creep tests to predict the strain-time history of the specimens tested in the dynamic triaxial test. The best model was found to be a power law of time with the coefficient and the exponent being functions of the deviatoric stress and soil suction levels.

The predictions using this power law in conjunction with a modified superposition principle compare favorably with the recorded data at low deviatoric stress levels. However, at the peak loads, the predictions consistently are larger than the measured strain levels by factors from two to three. Although some of these discrepancies might be due to limitations of the viscoelastic model, the results of the present study suggest that a large part of the discrepancies might be due to inaccurate records of the load-time history applied on the specimen. The major concern being the friction between the push rod and the bushing of the triaxial cell.

In summary, the results of the present study suggests that the long term creep records do not provide the best models to predict the high strain rate behavior of unsaturated clayey soils. Nevertheless, it appears that the records of the transient creep phase can be advantageously used to model the soil behavior at high strain rates; although further research is necessary to further investigate this point.

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CHAPTER ONE

INTRODUCTION

1.1 PROBLEM STATEMENT

In order to properly analyze the survivability of military or security sensitive structures, the soil-structure interaction under extreme loading conditions, such as those caused by a conventional or nuclear attack, should be understood and accurately modeled. Under these conditions, the strain levels as well as strain rates experienced by the soil are extremely high. Furthermore, many of these structures rest on or is surrounded by soils that are in the unsaturated state. For a realistic prediction of the soil response, it is necessary to develop appropriate constitutive equations that account for the high strain rates imposed on the soil and should include the effects of the soil suction.

Strength and constitutive behavior of soils are known to be strain-rate dependent. This dependency is more pronounced for clayey soils than for granular soils. In the existing technical literature, the bulk of research has been directed towards the study of the strength and constitutive behavior of saturated clayey soils. However, most of those investigations have been performed at small strain-rates. Further more, a very limited amount of work has been performed to elucidate the effect of soil suction on the constitutive behavior of unsaturated clayey soils.

1.2 OBJECTIVES AND APPROACHES

The main focus of this thesis has been to evaluate the possibility of using low-strain rate test results and models to predict the behavior of unsaturated clayey soils at high-strain-rates. The study consisted of performing creep/recovery test on soil specimens equilibrated to these preselected soil suction levels. These results are then used to develop constituting models to explain the soil behavior at low strain rates. In a second phase, specimens of "identical" characteristics were subjected to high strain rates with a concurrent variation of the deviatoric stress in a MTS dynamic soil testing facility. Finally, the constitutive models developed from the creep-recovery tests were used to predict the behavior of the tests performed at high strain rates. The validity of the existing models were investigated by comparing the predictions to the actual measurements.

1.3 ORGANIZATION

This section provides a brief overview of the organization of this thesis that includes eight chapters. Chapter Two contains a review of the mechanics of unsaturated soils and the basis for the analysis of the creep and recovery tests. A detailed description of the test set-up, specimen preparation, creep and recovery test and data reduction are presented in Chapter Three. In Chapter Four, the static properties and index properties of the materials are described. The constitutive models at constant loading conditions are proposed in Chapter Five. Chapter Six describes the MTS dynamic testing facility, and the dynamic testing procedure. The

predictions of the behavior at high strain rates using the proposed models as well as the evaluation are contained in Chapter Seven. Chapter Eight is the closure, which contains a summary of the thesis, conclusions and recommendations for future studies. The results of individual tests are presented in the appendices.

CHAPTER TWO

BACKGROUND

2.1 INTRODUCTION

The purpose of the present study is to predict the dynamic behavior of unsaturated clayey soils. Accordingly, the basic considerations on the mechanics of unsaturated soils, and the time-dependent stress-strain behavior of soils and existing rheological models are described and discussed in this chapter.

2.2 BASIC UNSATURATED SOIL CONCEPTS

Unsaturated soils are composed of three phases, i.e. solid, liquid, and gaseous. When the pore pressure in the liquid phase is positive, any gaseous phase present in the soil can only exist as trapped gas at a higher pressure than the ambient air pressure on the soil. This gas will tend to diffuse out of the soil system and the soil will tend to reach a fully saturated condition with all the pore spaces completely filled with water. On the other hand, when the water table is drawn below the ground surface, decreasing pore water pressure and evapo-transpiration result in larger air bubbles in the pore space. Under these conditions, the pore pressure becomes negative, that is, below atmospheric pressure. A measure of the affinity of soil for water is the magnitude of the negative pressure or soil suction of the pore water.