A Constitutive Model for Normally Consolidated Clays

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Abstract

A new constitutive model is proposed for normally consolidated clays. A main skeleton of the proposed model is based on the concepts of the incremental stress-strain theory by Roscoe and Porooshahb. The equation of the undrained stress path is formulated by introducing the new pore pressure parameter (C), which is the slope of the linear line in the plot of the normalized pore pressure against the stress ratio. Once the stress increment along the constant stress ratio path (followed by undrained stress path) is known, the volumetric strains are calculated from the linear characteristics between void ratio and logarithm of the mean normal stress for any stress ratio. Then the incremental shear strains are successfully predicted by applying the flow rule derived in the modified theory by Roscoe and Burland.

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1. Introduction

Several stress-strain theories such as the Cam-clay theory and the modified theory have been developed at the Cambridge University to describe the stress-strain behaviour of normally consolidated clays. In these theories, a fully saturated normally consolidated clay is assumed to behave as an elasto-plastic material. Based on this assumption, concepts such as yield surface and normality rule were used to obtain an expression for the strain increment ratio in terms of the stresses.

On the other hand, the incremental stress-strain theory was proposed by Roscoe & Poorooshesh based on the assumption of a unique state boundary surface (SBS) for normally consolidated clays. Existence of a unique state boundary surface was studied by Henkel and Roscoe et al.

Efforts to examine a unique SBS were also made by Balasubramaniam, and he found that the SBS is unique and is independent of the applied stress paths, provided that the loading steps are infinitely small.

The incremental stress-strain theory of Roscoe & Poorooshesh is mathematically similar to the Cam-Clay theory or the modified theory which is based on some of the concepts of plasticity theory and an energy equation. It therefore appears that close examination of Roscoe & Poorooshesh's theory is more fundamental to understand the basic behaviour of normally consolidated soils under the stresses.

However, though the incremental stress-strain theory is a conceptually good model, it needs quite a large number of experiments which are rather complicate.

This paper is therefore concerned with a direct application of the incremental stress-strain theory in a numerical form by using some of basic soil parameters which can be obtained in a simple manner from the results of basic soil tests.

2. Definition of Stress and Strain Parameters

The stress parameters p and q are defined by:

\[ p = \frac{(\sigma_1' + 2\sigma_3')}{3} \]
\[ q = (\sigma_1' - \sigma_3') \]

where \( \sigma_1' \) and \( \sigma_3' \) are the principal effective compressive stresses, and \( \sigma_2' = \sigma_3' \) under the triaxial stress system. Similarly the incremental strain parameters \( d\varepsilon \) and \( d\varepsilon \) are given by:

\[ d\varepsilon = d\varepsilon_1 + 2d\varepsilon_3 \]
\[ d\varepsilon = 2(d\varepsilon_1 - d\varepsilon_3) / 3 \]

where \( d\varepsilon_1 \) and \( d\varepsilon_3 \) are the principal incremental compressive strains and \( d\varepsilon_2 \) is equal to \( d\varepsilon_3 \) under the triaxial stress system. The stress ratio, \( q/p \), is denoted by \( \eta \).

3. Basic Features of Model by Roscoe & Poorooshesh

An incremental stress-strain theory for normally consolidated clay was proposed by