12 Mar 1991, 10:30 am - 12:00 pm

Cyclic Non-linear Constitutive Equations for Sands

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Proceedings: Second International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, March 11-15, 1991, St. Louis, Missouri, Paper No. 1.52

Cyclic Non-linear Constitutive Equations for Sands

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SYNOPSIS: A series of triaxial cyclic tests are performed on Hostun sand; each test undergoes several two-way, strain-controlled cyclic loadings under drained conditions. The purpose of these tests is to investigate the behaviour of this sand under complex loadings.

This paper extends the previous works during the last years, and aimes at showing that the non-linear incremental constitutive equations can describe the behaviour of saturated sand subjected to various stress loadings in drained conditions.

INTRODUCTION

In the last Workshop on constitutive equations for granular non-cohesive soils (Cleveland 1987), we have shown the capability or our incremental non-linear model to describe several complex loadings, including circular stress paths in the deviatoric plane, and cyclic tests with rotation of principal stress directions. The results of our model are globally correct for the first few cycles.

In this paper, by incorporating some rules derived from observed behaviour of saturated sands under triaxial cyclic loadings, our constitutive equations can simulate the multistage, strain-controlled, two-way cyclic tests, over a great number of cycles.

EXPERIMENTAL FINDINGS

After the experimental results of drained cyclic triaxial tests on loose sand, performed by Mohkam (1983), the following features of sands behaviour may be modelled by the constitutive equations:

1- The experimental results show that the volumetric strain occured in extension is not always of a contractive manner. When a loose sample is subjected to a strain-controlled drained test, contractancy is applicable to the first cycles in extension; but dilatancy also appears on following cycles, where the sample densifies.

2- The volumetric contraction occurs during a complete sequence extension-compression. The magnitude of this volume contraction decreases as the number of cycles inscreases. A stabilisation of the volumetric strain is always obtained, even under multistage cyclic loadings.

3- After and on the second cycles, the behaviour of the triaxial compression changes, and does not follow the hyperbolic equation of the first triaxial compression.

Similar experimental observations can be also found on cyclic tests carried out by Franco Vilela (1979) or Thanopoulos (1981).

The experimental results of the first part of the cyclic drained test SLCY47 between ±3% of axial deformations are represented in figure 2a (the stress-strain behaviour), and in figure 2b (the volumetric deformation). The cell pressure σ_c of this test is 400 kPa, and the void ratio e = 0.754.

Figures 4a,b show the three-stage strain controlled cyclic test SLCY45, (σ_c = 100 kPa and e = 0.769), between ±1%, -1% and 2%, ±3% of axial deformations; the final compression test is not showing. Only five cycles are performed in each stage.

CONSTITUTIVE EQUATIONS

The constitutive equations, restricted to the generalized triaxial paths, can be written in the following form in the orthotropic axes of the material, Darve (1978):

$$d\varepsilon = M(h,d)\ d\sigma$$

where d is the direction of the stress increment tensor $d\sigma$, defined as $d = \frac{d\sigma}{\|d\sigma\|}$, $d\varepsilon$ the strain rate tensor, and M a tensor of second order depending on the whole stress - strain history h and on the direction d. The model has been used in specialized workshops (Grenoble 1982, Cleveland 1987).

For any direction d of $d\sigma$, and for a given history, M is interpolated from M^+ and M^-, whose columns correspond to the values obtained in its orthotropical directions. M^+ and M^- are generally expressed by using the Pseudo-Young's moduli E_i and the Pseudo-Poisson's ratio ν_{ij}.

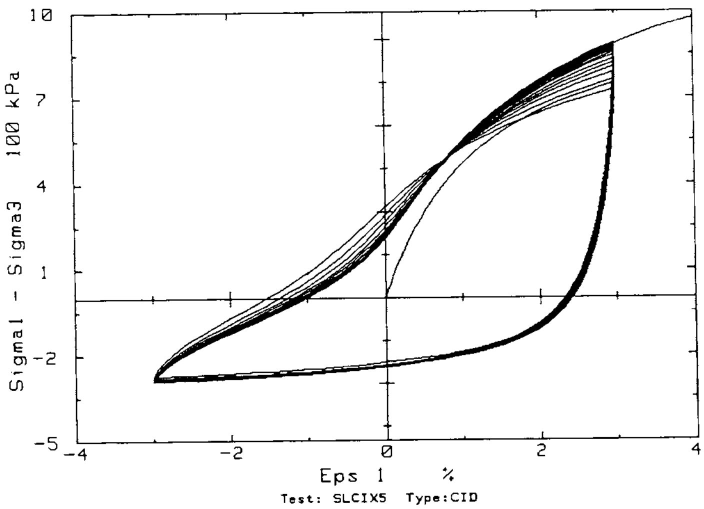

Figure 1: Simulation of cyclic drained test

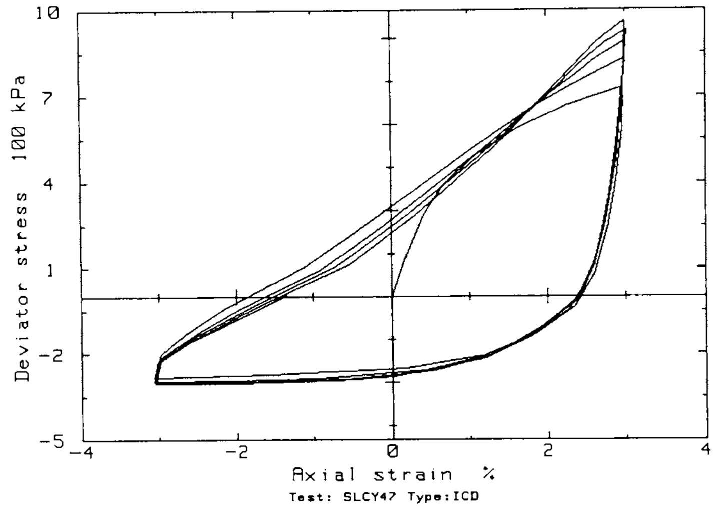

Figure 2: Experiment of cyclic drained test

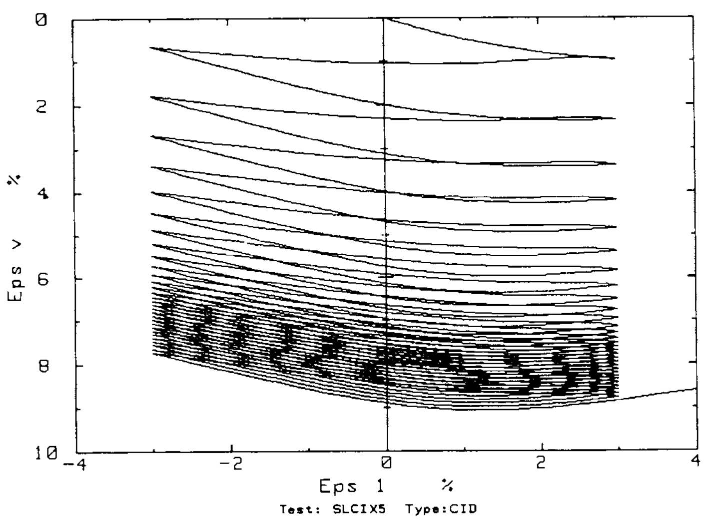

Figure 1: Simulation of cyclic drained test

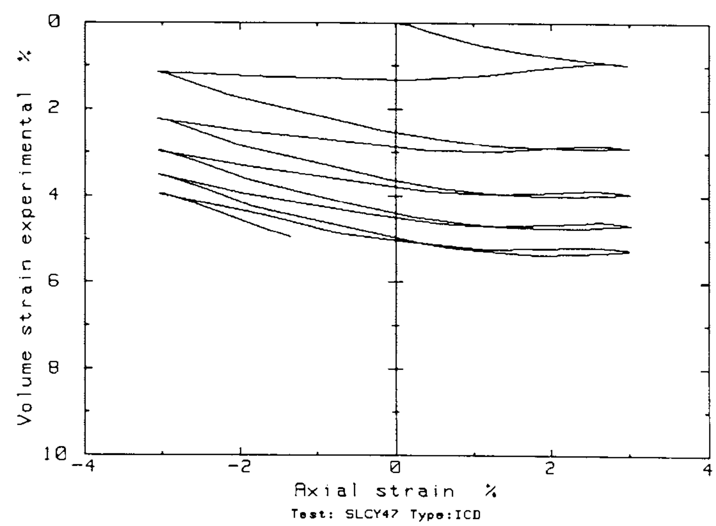

Figure 2: Experiment of cyclic drained test

A new interpolation function is developed (Royis 1990),to take into account the directional dependency of M and the interpolation process of the elementary stress paths.

GENERALIZATIONS

The generalization of the model to cyclic loadings has been formulated in terms of the cyclic stress and strain amplitudes at each reversal of M^+ and M^-. Within this generalization, the progressive irreversible compaction of granular materials can be described.

It is assumed that the material parameters may not possess the constant values, but depend on the stress and strain at each reversal, and the accumulated volumetric strain in the past cyclic loadings.

Under multistage strain-controlled cyclic loadings, it is also assumed that the materials erase the memory of the previous loadings, when the actual strain exceeds, in amplitude, those of previous loadings.

The parameters of the model are identified usually with a set of classical triaxial compression and extension tests; and additional data from a multistage cyclic loadings are required, for example test SLCY45.

The experimental response curves of the first stage of test SLCY47 are well simulated (figures 1 a,b), particularly the cyclic hardening effect and the stabilization of the stress-strain behaviour; the volumetric deformation decreases significantly, and stabilizes after 20 cycles.

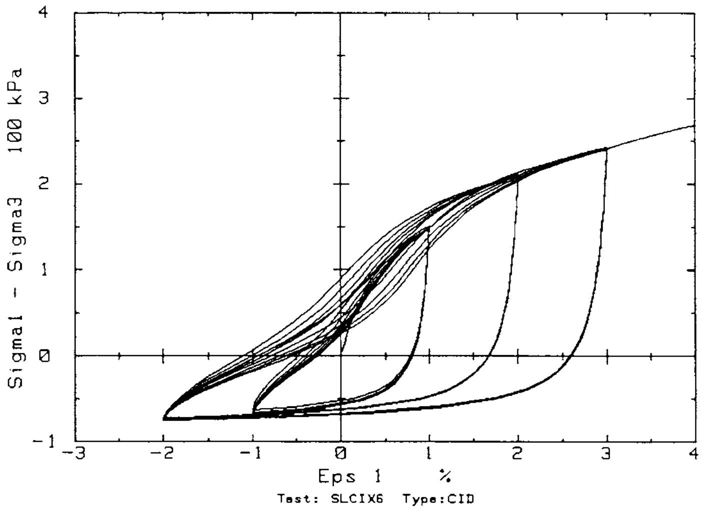

Figure 3: Simulation of cyclic drained test

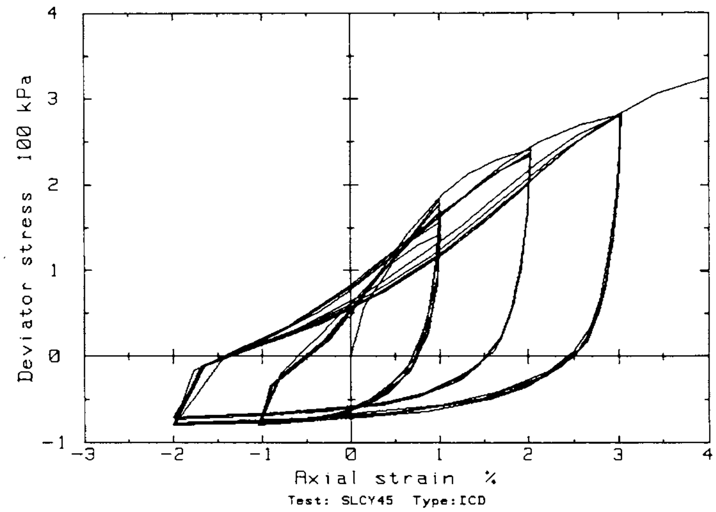

Figure 4: Experiment of cyclic drained test

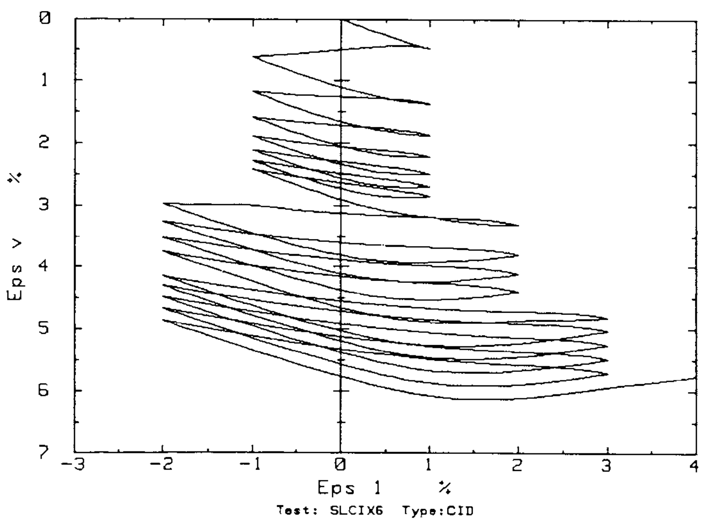

Figure 3: Simulation of cyclic drained test

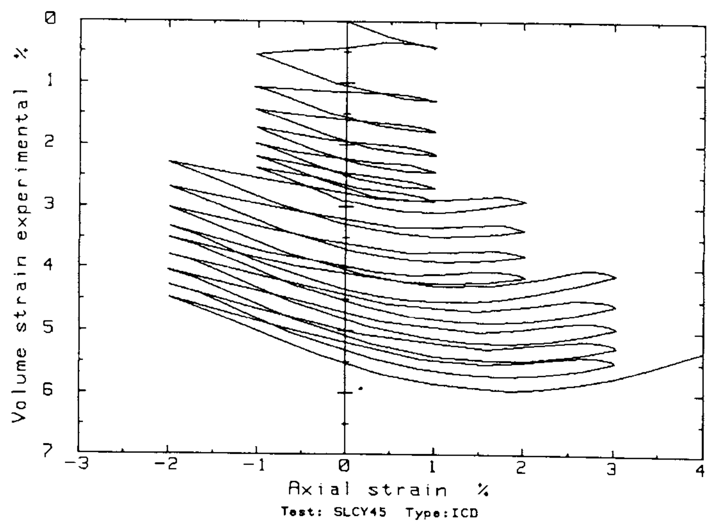

Figure 4: Experiment of cyclic drained test

In the absence of experimental data, we don't know if this stabilization represents the real deformation characteristics of the materials.

The prediction curves match partially the observed aspects of the multistage cyclic test SLCY45 (figures 3 a,b). The different behaviour between the first and the second cycles is simulated by the model; but the hardening effect of the multistage cyclic loadings is less pronounced. However, the model simulation follows the trend of the behaviour of sands.

The last example is the four-stage, one-way, and two-way strain-controlled cyclic test SLCY46, (σ_c = 200 kPa and e = 0.764). Figures 5 a,b shows the theoretical simulation and figures 6 a,b the experimental results.

CONCLUSIONS

Experimental data of three multistage cyclic strain-controlled tests under drained triaxial compression condition on Hostun's dense sand designed to explore the behaviour of granular material are presented, together with an improved version of our constitutive equations.

These multistage cyclic loadings are selected to check the prediction capability of a non linear incremental constitution model of interpolation type. Several aspects of observed responses are simulated by the model, with a reasonable degree of accuracy.

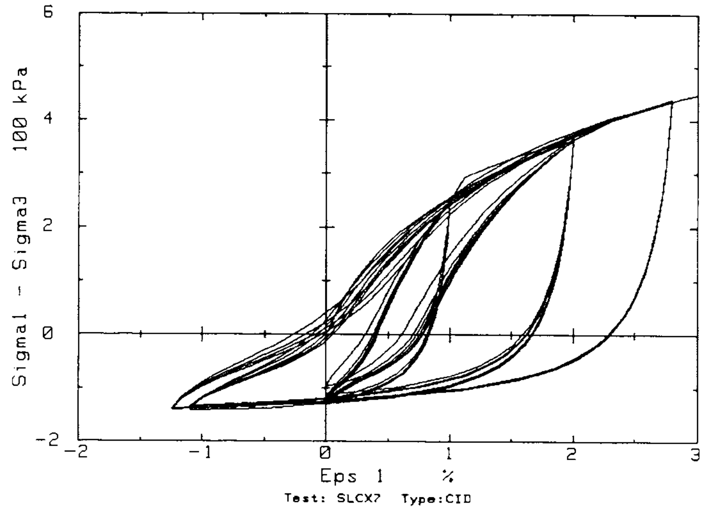

Figure 5: Simulation of cyclic drained test

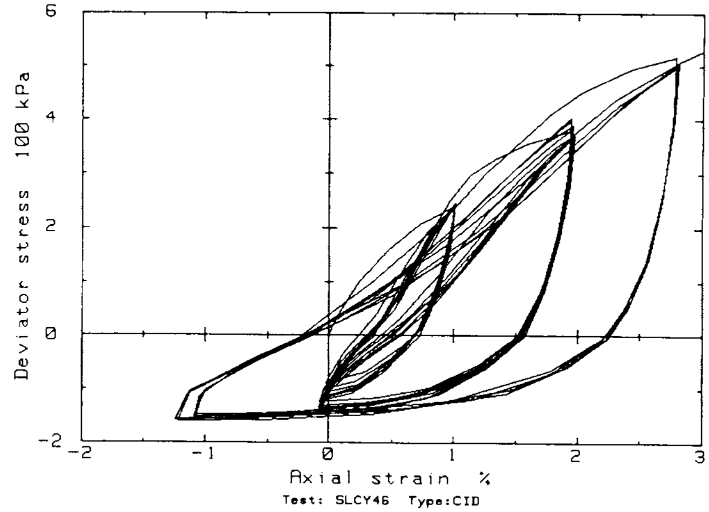

Figure 6: Experiment of cyclic drained test

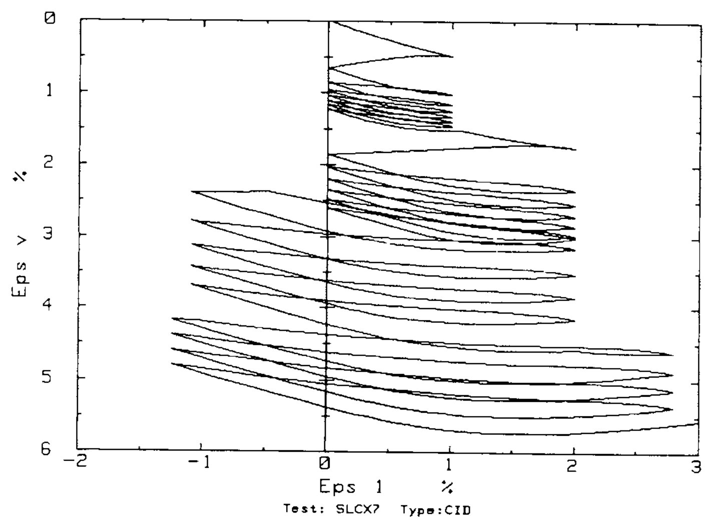

Figure 5: Simulation of cyclic drained test

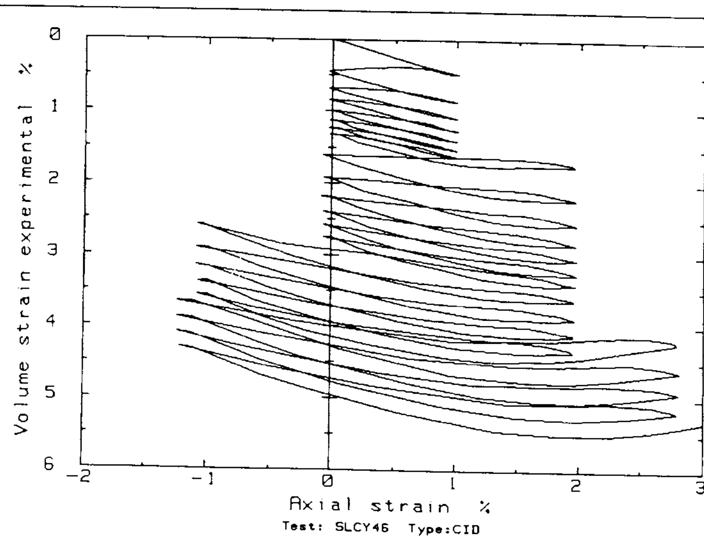

Figure 6: Experiment of cyclic drained test

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