Time effects on the deformation of sand in plane strain compression

The University of Tokyo,	Student,	○ Hasbullah Nawir
Ministry of Construction,	Member,	Masanori Ishihara
The University of Tokyo,	Member,	Reiko Kuwano
The University of Tokyo,	Member,	Fumio Tatsuoka

1. INTRODUCTION

The time-dependent behavior of sand has been evaluated by Plane Strain Compression (PSC) tests (Matsushita et al. 1999; Ishihara and Tatsuoka, 2000). It was shown that stress-strain relationship of sand was not affected by different constant shear-strain rates, but when the constant shear strain rate was changed stepwise or gradually, the shear stress increased or decreased temporarily and the stress-strain state rejoined the unique stress-strain relationship that was independent of constant $\dot{\varepsilon}$ as the strain increased. Recently, one-dimensional model to predict the phenomena of temporary effects of strain rate and acceleration has been developed. When limiting to the shear deformation along a fixed stress path (only a single stress path at a constant confining pressure), the time-dependent behavior can be simulated successfully (Ishihara and Tatsuoka, 2000).

In this study, the time effects on the stress and strain behavior of sand were investigated by performing monotonic and cyclic loading PSC tests.

2. GENERAL VISCOUS DEFORMATION

A general framework was proposed by Di Benedetto (1997), to describe the viscous aspect of the stress-strain relationship. Figure 1 shows one specific version proposed by Tatsuoka et al. (1999).

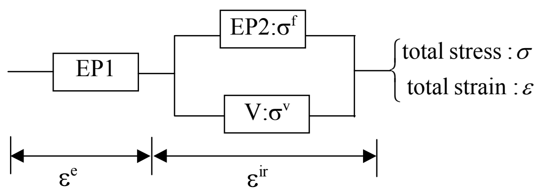

Figure 1. One specific three-component of model (Tatsuoka et al., 1999)

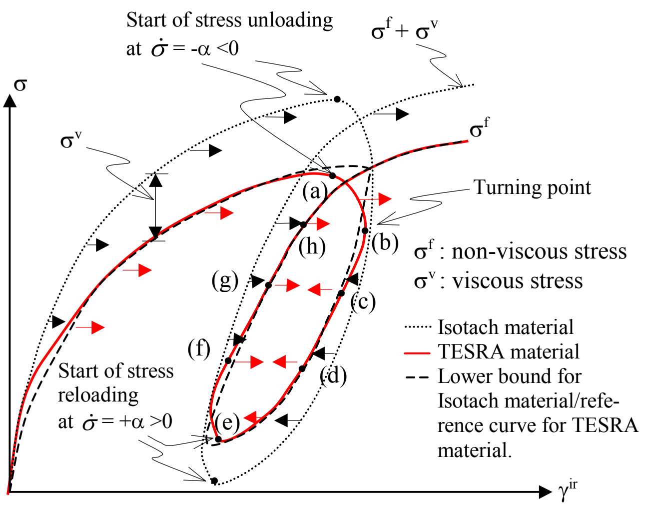

Figure 2. Possible direction of irreversible shear strain increment for TESRA and Isotach materials.

The behavior of the model is illustrated in Figure 2, which shows the direction of irreversible shear-strain increment in the course of loading, unloading and reloading when geomaterials exhibit the isotach property and the temporary effect of overshooting or undershooting due to strain rate and acceleration (TESRA model) (Tatsuoka and Ishihara, 2000).

The relationships between the shear stress and the shear strain for any given arbitrary time histories of strain (and strain rate) for poorly graded sand, as illustrated in Fig.3, can be predicted very well with the TESRA model (Tatsuoka and Ishihara, 2000).

The following PSC test was performed in order to examine the overall behavior of irreversible shear strain increment of sand as indicated in Figure 2 and 3.

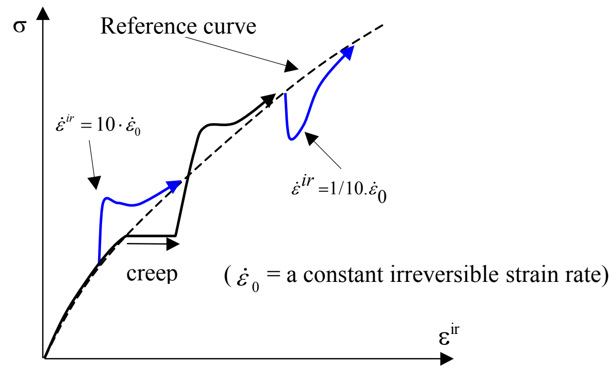

Figure 3. Schematic diagram illustrating the viscous effects on sand deformation.

3. TEST METHOD

3.1 *Sand type and specimen preparation;*

Saturated Toyoura sand, a sub-angular poorly-graded fine sand with Gs = 2.65, e_{max}= 0.98 and e_{min}=0.62, was used. A rectangular specimen (20 cm in height, 16 cm in length and 8 cm in width) was prepared in a medium dense state by air-pluviation.

3.2 *Apparatus;*

An automated plane strain test system, described in Park and Tatsuoka (1994), consisting of smooth and rigid σ_1 and σ_2 boundaries and flexible σ_3 boundaries of latex membrane, was used. Loading and unloading in the vertical direction were achieved by driving the loading shaft with a displacement rate control motor, without time delay and backlash.

Axial strains were measured locally with a pair of LDTs (Goto et al., 1991) and lateral strains were measured locally with eight proximity transducers, four on each side of the σ_3 surface.

3.3 *Test procedure*

The test was performed under drained conditions. A saturated pecimen was first isotropically consolidated to σ'_1=σ'_3=400 kPa and then subject to shearing at a constant axial strain rate dε/dt of 0.045% per minute, up to σ'_1=2000 kPa, then unloaded until σ'_1=400 by a constant stress rate of –1.6 kPa per minute. Finally second loading was applied up to σ'_1=2500 kPa by a constant axial strain rate $d\varepsilon/dt$ of 0.045% per minute. At several stages during both loading and unloading, in constant stress state (creep) were applied for 3 hours each.

4. TEST RESULTS AND DISCUSSION

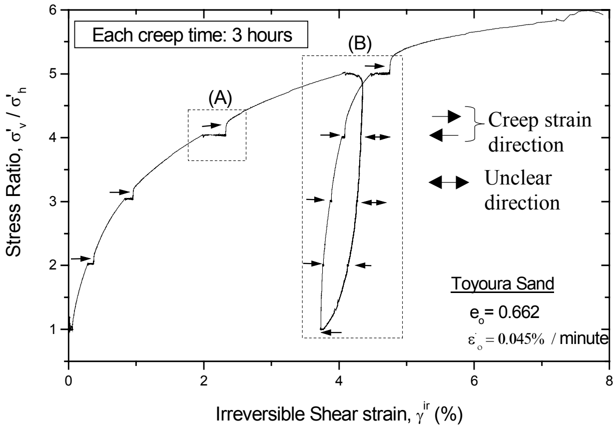

Figure 4. Drained PSC test at a constant vertical strain rate on saturated Toyoura sand.

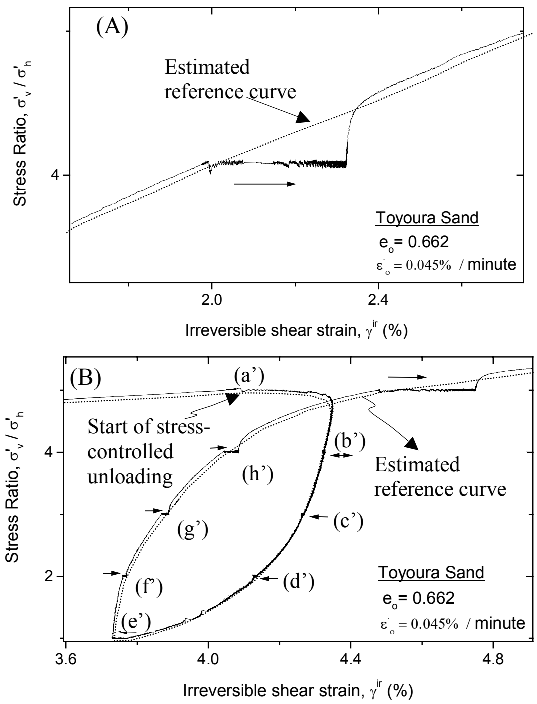

Figure 5 (A) Detail of creep strain in the loading stage
(B) Detail of large cyclic loading

Total strains were decomposed into elastic and irreversible components. The relationship between the stress ratio R and the irreversible shear strain is shown in Figure 4. The following time dependent phenomena were observed which correspond to the behaviors indicated in Figure 2 and 3.

(1) When loading was resumed after the creep stage, the behavior became much stiffer and recoverable than before the creep, and the stress-strain relationship tended to rejoin the original relation, as indicated in Figure 5(A). The reference curve was estimated and shown in Figure 5.

(2) In the zoomed up figure (Figure 5B), it can be seen that the positive irreversible shear strain increment developed after stress unloading was started for some stress range from point (a'), at R ≈ 5. This point is correspond to point (a) in Figure 2.

(3) The overall behavior of the relationship between R and the irreversible shear strain is almost similar to the behavior illustrated in Figure 2 and 3;

- Creep stage at R≈4 during unloading (point (b')), nearly no positive nor negative creep is clearly observed.
- Creep stage at R≈3, 2 and 1 (point (c'), (d') and (e')), the negative creep strains (creep recovery) were developed, which are correspond to points (c), (d) and (e) in Figure 2 respectively.
- Creep stage at R≈2,3 and 4 during reloading (point (f'),(g') and (h')), the positive creep strains were developed as well as predicted in points (f), (g) and (h) of Figure 2.

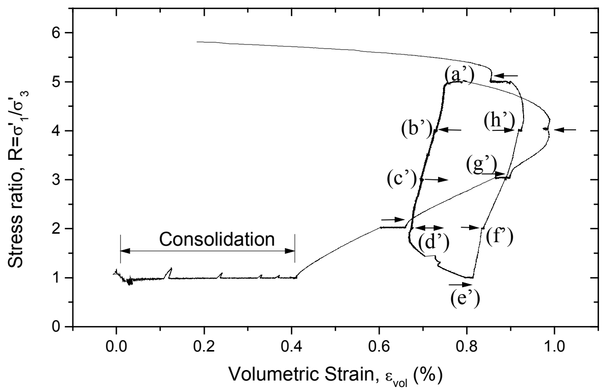

Figure 6. Relationship between R and volumetric strain ε_{vol}.

As the behavior of soil is influenced by the stress history, it should be examined whether the models can be applied to general stress paths (with various instantaneous ratios dp'/dq), including cyclic loading. It may be seen from Fig.6 that the time-dependency of volumetric strain is much more complicated than the shear strain property. A proper model will be necessary to develop for predicting the volumetric strain.

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