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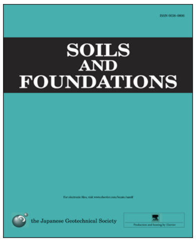

Rate-dependent behaviour of undisturbed gravelly soil

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Abstract

A series of drained triaxial compression tests was performed to evaluate the rate-dependent stress–strain behaviour of large- and medium-size undisturbed gravelly soil samples (UGSSs). A newly developed sampling method, using thick water-soluble polymer solutions, was employed for retrieving the samples from three tunnel excavation sites in Toyama Prefecture, Japan. To evaluate the rate-dependent stress–strain behaviour, the loading rate was changed stepwise many times and drained sustained loading was performed at prescribed stress states during otherwise monotonic loading at a constant vertical strain rate in the tests. The UGSSs from natural deposits at two of the sites exhibited Isotach-type viscous properties. For the UGSS retrieved from the site improved by chemical injection prior to the start of the excavation, the type of viscous property changed from Isotach to P&N with strain. A comparison between the values of the viscous parameters of reconstituted granular materials evaluated in previous studies and those of these UGSSs was discussed. Test results from drained unconfined compression tests were also presented to investigate the cementation of UGSSs.

Keywords: Loading rate effect; Viscous properties; Isotach viscosity; Undisturbed gravelly soil; Triaxial compression; Unconfined compression

1. Introduction

The viscous properties of geomaterials, such as the loading rate effects on the stress–strain behaviour, including creep deformation, play an important role in the prediction of short- and long-term residual ground deformation and structural displacement. As demonstrated by many cases of the significant long-term residual settlement of structures constructed on clayey soil (e.g., Leroueil and Hight, 2003), this issue has mainly been investigated for clayey soil (e.g., Murayama and Shibata, 1958; Bishop, 1966; Leroueil et al., 1985). The main cause of long-term residual settlement is attributed to the primary and the secondary consolidations of the geomaterials. Creep behaviour, caused by the viscous properties of geomaterials, corresponds to the secondary consolidation in which deformation occurs under the constant effective stress state.

On the other hand, the viscous properties of gravelly soils have not been systematically studied, as they have usually been considered as practically non-viscous materials. However, unbound gravel may exhibit significant rate-dependent stress–strain behaviour, such as significant creep deformation, in full-scale cases (e.g., Oldecop and Alonso, 2007). In such cases, the viscous properties of gravelly soil become one of the most important geotechnical engineering issues. In the conventional geotechnical

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Abbreviations: FUT, First Uozu Tunnel; LDTs, local deformation transducers; MT, Makurano Tunnel; P&N, positive and negative; SUT, Second Uozu Tunnel; TESRA, temporary or transient effects of strain rate and strain acceleration; UGSSs, undisturbed gravelly soil samples

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Notations

c^*	cohesion term for evaluating R_{eq}
d	specimen diameter
D	particle diameter
D_{50}	mean particle diameter
D_{max}	maximum particle diameter
FC	fines content
R	effective principal stress ratio$=\sigma_1'/\sigma_3'$ $(=\sigma_v'/\sigma_h'$ in triaxial compression)
R_{eq}	equivalent effective principal stress ratio $=(\sigma_1'+c^*)/(\sigma_3'+c^*)$
U_c	coefficient of uniformity
β	rate-sensitivity coefficient
γ^{ir}	irreversible shear strain
$\dot{\gamma}^{ir}$	irreversible shear strain rate
σ_0'	isotropic effective confining pressure
σ_1'	effective major principal stress
σ_3'	effective minor principal stress
σ_h'	effective horizontal principal stress
σ_v'	effective vertical principal stress
ε_h	horizontal strain
ε_v	vertical strain
ε_{vol}	volumetric strain
$\dot{\varepsilon}_0$	reference vertical strain rate
$\dot{\varepsilon}_v$	vertical strain rate
ρ_d	initial dry density of specimen
ρ_t	total density of specimen evaluated after compression test

design of a given structure-ground (or backfill) system, its global safety factor for ultimate failure is usually evaluated, while it is assumed that ground deformation and structural displacement will not exceed specified allowable limits if the global safety factor is larger than a certain specified value. Recently, performance-based designs are often employed, for which it must be ensured that the evaluated long-term residual deformation of the ground/backfill and/or the structural displacement does not exceed a specified allowable limit. Also in that case, the viscous properties of gravelly soils become one of the most essential design factors.

A series of recent studies on the viscous properties of a number of different geomaterials has revealed that there are four basic viscous property types, illustrated in Fig. 1, namely, Isotach, Combined, TESRA and P&N (e.g., Matsushita et al., 1999; Hayano et al., 2001; Di Benedetto et al., 2002; Tatsuoka et al., 2002, 2006, 2008; Komoto et al., 2003; Aqil et al., 2005; Kongsukprasert and Tatsuoka, 2005; Anh Dan et al., 2006; Kiyota and Tatsuoka, 2006; Sorensen et al., 2007, 2010; Duttine et al., 2008, 2009; Kongkitkul et al., 2008; Enomoto et al., 2009). Among them, Enomoto et al. (2009) reported that, in the pre-peak regime in drained triaxial compression tests, air-dried well-graded Shinanogawa riverbed gravel, consisting of round gravel and relatively angular sand particles, exhibited the TESRA type, while air-dried poorly graded Hime gravel, consisting of relatively round particles, exhibited the P&N type. On the other hand, it was often observed in a single shear test that the viscous property type changed with strain. For example, in drained triaxial compression tests on compacted moist cement-mixed gravelly soil (Kongsukprasert and Tatsuoka, 2005), the viscous property type changed from Isotach in the pre-peak regime to TESRA in the post-peak regime. In drained triaxial compression tests on compacted moist well-graded gravelly soil, consisting of angular particles (called Chiba gravel), the viscous property type changed from Isotach in the pre-peak regime to Combined in the post-peak regime (Anh Dan et al., 2006). Compared with these studies on reconstituted gravelly soils, investigations of the viscous properties of undisturbed ones have been very limited due mainly to the technical difficulties of obtaining undisturbed samples of gravelly soil, particularly those containing cobbles.

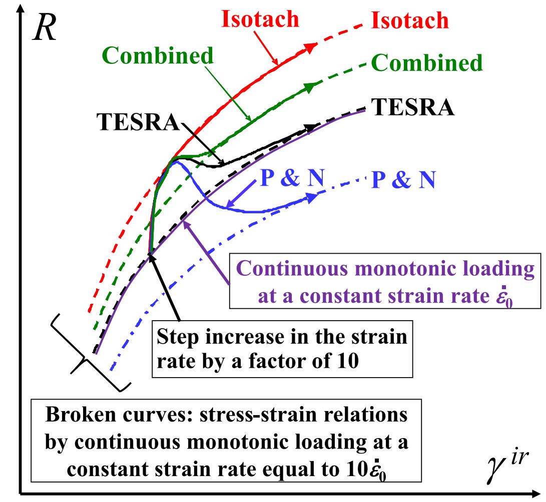

Fig. 1. Four basic viscous property types of geomaterials in shearing (Tatsuoka et al., 2008). For all these types, the same positive stress jump for a step increase in strain rate by a factor of 10 is assumed.

In view of the above, in this study, large- and medium-size undisturbed gravelly soil samples (UGSSs) were retrieved from three tunnel excavation sites in Toyama Prefecture, Japan, by means of a newly developed sampling method using thick water-soluble polymer solutions (Tani et al., 2007). To evaluate the loading rate effects on the stress–strain behaviour, a series of drained triaxial compression tests was conducted on these UGSSs. Drained unconfined compression tests were also conducted to investigate the cementation of UGSSs.

2. Various viscous property types

As mentioned in the Introduction, four basic viscous property types, illustrated in Fig. 1, namely, Isotach, Combined, TESRA and P&N, are confirmed. In the case of the Isotach type, an

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