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Strength and deformation characteristics and small strain properties of undisturbed gravelly soils

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Abstract

A series of medium-scale and large-scale triaxial and unconfined compression tests was conducted in order to evaluate the strength and deformation characteristics and small strain properties of undisturbed well-graded gravelly soils retrieved from three tunnel excavation sites in Toyama prefecture, Japan. Undisturbed gravelly soils were taken by means of a new sampling method using thick water-soluble polymer solutions. The strength and deformation characteristics were evaluated mainly by performing sustained loading and large amplitude unloading and reloading cycles during otherwise monotonic loading at a constant strain rate in drained triaxial compression tests. During isotropic consolidation and shearing, at several stress states, eleven very small vertical cycles were applied to evaluate the quasi-elastic deformation property at small strain levels around 0.001% by static measurement. Dynamic measurements using a pair of accelerometers attached to the side surface of the specimen and wave sources attached to the top cap were also conducted at the same stress levels as static measurements in a single test. Several effects including grading characteristics and pressure level on the difference between the moduli measured statically and dynamically were discussed. The relationship between the small strain and strength properties of undisturbed gravelly soils was evaluated. The small strain properties of air-dried dense Toyoura sand in large-scale triaxial compression tests were also investigated in this study to compare the results of undisturbed gravelly soils.

Keywords: Strength and deformation characteristics; Small strain stiffness; Static and dynamic measurements; Undisturbed gravelly soil; Triaxial compression; IGC: D6; D7

1. Introduction

The strength and deformation characteristics of gravelly soils (denoted as GSs) have been studied for about half a century in order to investigate their use in the large-scale structures such as rockfill dams and embankments (e.g., Holtz and Gibbs, 1956; Jiang et al., 1997; Okuyama et al., 2003). These experimental studies were mainly conducted under reconstituted conditions; however, the number of studies on undisturbed gravelly soils (UGSs) is limited due to technical problems in sampling methods for in-situ samples with cobbles and boulders. If the conventional sampling methods for

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Nomenclature

a	parameter on inherent anisotropy
c	cohesion
d	specimen diameter
D	partical diameter
D_{50}	mean particle diameter
D_{max}	maximum particle diameter
D_{r0}	initial relative density
E_{max}	maximum secant Young's modulus
E_{sec}	secant Young's modulus
E_{tan}	tangential Young's modulus
E_{v0}	reference vertical Young's modulus at a reference stress state
E_{vs}	quasi-elastic vertical Young's modulus by static measurement
FC	fines content
G_{vh0}	reference shear modulus at a reference stress state
G_{vhd}	shear modulus by dynamic measurement
G_{vhs}	shear modulus converted from E_{vs}
$(G_{vhd}/G_{vhs})_{50}$	G_{vhd}/G_{vhs} at isotropic stress state of $\sigma'_v = \sigma'_h = 50$ kPa
h	specimen height
L	distance between the sampling location and the borehole where in-situ PS logging test was conducted
m	parameter presenting stress-state dependency of E_{vs}
m'	parameter presenting stress-state dependency of shear modulus
m_d'	m' by dynamic measurement
m_s'	m' based on static measurement
p'	effective mean stress $=(\sigma'_v + 2\sigma'_h)/3$
q	deviator stress
q_{max}	maximum deviator stress
R	effective principal stress ratio$=\sigma'_v/\sigma'_h$
U_c	coefficient of uniformity
$V_{s(dynamic)}$	shear wave velocity by dynamic measurement
$V_{s(static)}$	equivalent shear wave velocity converted from G_{vhs}
Δt_{peak}	peak-to-peak travel time
Δt_{rise}	rise-to-rise travel time
$\Delta\varepsilon_v$	vertical strain increment
σ'_3	effective minor principal stress
σ'_h	effective horizontal principal stress
σ'_v	effective vertical principal stress
$\dot{\sigma}'_v$	effective vertical principal stress rate
ε_h	horizontal strain
ε_v	vertical strain
ε_{vol}	volumetric strain
$\dot{\varepsilon}_v$	vertical strain rate
ϕ	internal friction angle
λ	wave length in dynamic measurement
υ_0	Poisson's ratio at isotropic stress state
ρ_d	initial dry density of specimen
ρ_t	wet density of specimen

relatively finer geomaterials are used for GSs, positions of large particles may be moved largely during the coring process. Some studies using UGSs retrieved by the in-situ freezing method developed to provide temporary particle bonding were conducted (e.g., Nishio and Tamaoki,1988; Goto et al., 1992; Yasuda et al., 1994; Tanaka et al., 2000). However, this sampling method is in general costly, in particular with large diameter samples, and also may not be applicable if fine particles are included. In view of the above, by taking advantage of a newly developed sampling method using thick water-soluble polymer solutions (Tani et al., 2007), UGSs were retrieved from three tunnel excavation sites in Toyama prefecture, Japan.

Soil characteristics at a small strain level are important in order to predict the overall deformation behaviour and have been studied by many researchers (e.g., Jardine and Potts, 1988; Tatsuoka and Shibuya, 1992; Kohata et al., 1997; Fioravante, 2000; AnhDan et al., 2002). The methods to evaluate small strain properties experimentally are divided into static and dynamic ones. The soil behaviour observed by applying many small unload/reload cycles of axial stress statically in the laboratory tests is essentially linear and nearly recoverable within a very small strain range lesser than 0.001% (Tatsuoka and Shibuya, 1992). For this static measurement, the experimental devices have to be very precise and accurate. On the other hand, the main method to evaluate small strain stiffness dynamically in the laboratory is the use of bender element (e.g., Brignoli et al., 1996; Fioravante, 2000; Leong et al., 2005). However, in this method, the disturbance induced by inserting the plates into soil specimens as well as the effects of bedding error have a negative influence on the accurate evaluation of small strain properties (Wicaksono et al., 2008). In addition, this method may not be applicable to GSs with large particles due to its limited capacity of excitation and insufficient contact between the plates and coarse soil particles. In view of the above, the precise equipment for measurements of axial loading and deformation (e.g., Tatsuoka and Shibuya, 1992; AnhDan et al., 2002) and a new technique originally developed by AnhDan et al. (2002) were used for static and dynamic measurements, respectively.

In order to evaluate the strength and deformation characteristics and small strain properties of UGSs mentioned above, a series of medium-scale and large-scale triaxial and unconfined compression (TC and UC, respectively) tests with static and dynamic measurements was conducted. Small strain properties of air-dried dense Toyoura sand in large-scale TC tests were also investigated to compare with those of UGSs.

2. Tested materials and their sampling

The tested UGSs were retrieved from construction sites of Makurano, First Uozu and Second Uozu Tunnels (MT, FUT and SUT, respectively) for Hokuriku bullet train, in Toyama prefecture, Japan.