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Estimating *in situ* dynamic strength and deformation properties of Niigata East Port sand deposits

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Abstract

The dynamic strength and deformation properties of Niigata East Port sand deposits were examined based on cyclic triaxial tests on samples obtained from two-chamber hydraulic piston samplers with inner diameters of 50 mm and on samples obtained using the frozen sampling method. An economically feasible method of estimating the *in situ* void ratio, the relative density D_r, the cyclic stress ratio R_{L20} under 20 uniform stress cycles, and the initial modulus of rigidity G_{CTX} as obtained from cyclic triaxial testing was also developed, and its applicability to samples of sand deposits obtained from Niigata's East Port, the 3rd Meiji fortress in Tokyo Bay, a port in the Kansai area of Western Japan, Niigata Meike, and Niigata Airport was also assessed. The measured R_{L20} values ranged from 0.1 to 0.33 and were independent of both D_r and the normalized standard penetration test *N*-values. The ratios of G_{CTX} to the initial *in situ* modulus of rigidity calculated using P/S logging during tube sampling ranged from 0.43 to 0.71 and were similar to those obtained by the frozen sampling method. The change in the dynamic strength and deformation properties caused by tube sampling can be adjusted appropriately to reflect the *in situ* conditions by using the economically feasible method. When combined with the economically feasible method, the tube sampling method can provide a simpler and more economical method of sand sampling than can be achieved using the frozen sampling method.

Keywords: Dynamic strength; Earthquake; Frozen sampling; Liquefaction; Modulus of initial rigidity; Sand; Sample disturbance; Standard penetration test; Tube sampling; Relative density (**IGC:** C6/D7)

1. Introduction

Sample quality determines the reliability of not only laboratory test results but also designs based on those tests. Studies on the dynamic strength and deformation properties of geotechnical materials have been conducted since the Alaska and Niigata Earthquakes of 1964. Site investigations, laboratory tests, and design code specifications have been established based on the results of such studies. However, the liquefaction of soils, excluding clean sand, in the Hanshin Awaji-Earthquake of 1995 and the 2011 off the Pacific coast of Tohoku earthquake has revealed the need to revise these design codes. The tube sampling method for sand deposits has seen improvement through the introduction of thin-walled tube samplers (Japanese Geotechnical Society (JGS), 2015a) and double-(JGS, 2015b) and triple- (JGS, 2015c) tube samplers. Research in these areas is gaining importance with the increasing likelihood of the occurrence of strong earthquakes across Japan, particularly in the Kanto, Tokai, Nankai, and Tonankai regions.

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Nomenclature

D_{10} 10th percentile grain size
D_{30} 30th percentile grain size
D_{50} 50th percentile (median) grain size
D_{60} 60th percentile grain size
D_r relative density
$D_{r(m)}$ measured relative density
$D_{r(TS\text{-}i)}$ *in situ* relative density estimated using the economically feasible method
$D_{r(TS\text{-}m)}$ measured relative density obtained by tube sampling
$D_{r(FS\text{-}m)}$ measured relative density obtained by frozen sampling
e void ratio
$\bar{e}_c$ mean void ratio after consolidation
$e_{c(m)}$ measured mean void ratio after consolidation
$e_{(FS\text{-}m)}$ measured void ratio obtained by frozen sampling
$e_{(TS\text{-}i)}$ *in situ* void ratio estimated using the economically feasible method
F_c percentage of grains smaller than 0.075 mm
G_{CTX} initial modulus of rigidity obtained from cyclic triaxial tests
$G_{CTX(TS\text{-}m)}$ measured modulus of rigidity obtained by tube sampling
$G_{CTX(FS\text{-}m)}$ measured modulus of rigidity obtained by frozen sampling
G_F *in situ* modulus of rigidity obtained from P/S logging
L_{max} *in situ* maximum shear stress ratio
Re correlation coefficient for estimating *in situ* void ratio
RD_r correlation coefficient for estimating *in situ* relative density
RR_{L20} correlation coefficient for estimating *in situ* cyclic stress ratio at 20 uniform stress cycles
RG_{CTX} correlation coefficient for estimating *in situ* modulus of rigidity
R_{L15} cyclic stress ratio at 15 uniform stress cycles
R_{L20} cyclic stress ratio at 20 uniform stress cycles
$R_{L20(TS\text{-}i)}$ *in situ* cyclic stress ratio estimated using the economically feasible method
$R_{L20(TS\text{-}m)}$ measured cyclic stress ratio obtained by tube sampling
$R_{L20(FS\text{-}m)}$ measured cyclic stress ratio obtained by frozen sampling
N number of standard penetration test blows
N_1 N value considered to be the effective overburden pressure
N_c number of uniform stress cycles
U_c uniformity coefficient
U'_c coefficient of curvature
V_s secondary wave velocity
ρ_s soil particle density
σ'_{vo} effective overburden pressure
ϕ' angle of repose

The frozen sampling method for undisturbed clean sand is useful in dynamic strength and deformation tests because it causes little sample disturbance (Yoshimi et al., 1978, 1984). However, the cost of frozen sampling has been reported to be 5.2 times that of tube sampling at the Canadian Liquefaction Experiment (CANLEX) test sites (Wride et al., 2000). Therefore, its use is limited to research sampling and geotechnical investigations of relevant soils and building structures. In addition, the effects of freeze and thaw cycles on the dynamic strength properties of sands containing fines are generally very complex (Goto, 1993), and there are simpler and more economical sampling methods, such as the tube sampling method (JGS, 2015a, 2015b, 2015c; ISO 22475-1, 2006). To establish a tube sampling method for natural sand deposits and a technique for evaluating the quality of the obtained samples, systematic sampling was conducted by the Soil Sampling Committee of the JGS in 1987 and 1988 and the Japan Geotechnical Consultant Association in 1998. The CANLEX project (Wride et al., 2000) and previous studies conducted by Broms (1980), Seed et al. (1982), and Yoshimi et al. (1989) have shown that high-quality fixed piston tube sampling tends to increase the density of loose sand and loosen dense sand. The fixed piston samples obtained at CANLEX sites became somewhat denser on average, with changes in the void ratios e ranging from 0.03 to 0.05 for saturated samples and 0.1–0.15 for unsaturated samples (Robertson et al., 2000). Although conventional tube sampling can be less expensive per site, the sample quality is inferior and generally unacceptable, especially in loose sand deposits where liquefaction assessments are most frequently conducted (Hofmann et al., 2000). Therefore, the void ratios and dynamic strength and deformation properties of samples obtained by tube sampling must be adjusted to estimate realistic *in situ* values. For this purpose, an economically feasible method of estimating the *in situ* void ratio e, the relative density D_r, the cyclic stress ratio R_{L20} for 20 uniform stress cycles, and the initial modulus of rigidity G_{CTX} has been proposed based on cyclic triaxial tests on sand samples obtained by tube sampling (Shogaki and Sato, 2011; Shogaki and Kaneda, 2013). This method is highly applicable to different sediment sites and sands, as shown by Shogaki (2016).

In this study, the dynamic strength and deformation properties of Niigata East Port sand deposits were examined through cyclic triaxial tests on samples from two-chamber hydraulic piston samplers (Shogaki, 1997) with an inner diameter of 50 mm and on samples collected using