Soils and Foundations 2016;56(4):691–703

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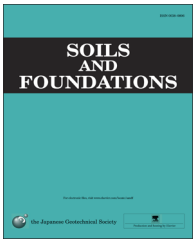

Technical Paper

Effect of in-situ sample quality on undrained cyclic strength and liquefaction assessment

T. Kiyota[a,*], T. Ikeda[b], Y. Yokoyama[a], H. Kyokawa[c]

[a]*Institute of Industrial Science, University of Tokyo, 4-6-1 Komaba, Meguro-ku, Tokyo 153-8505, Japan*
[b]*Department of Civil and Environmental Engineering, Nagaoka University of Technology, Japan*
[c]*Advanced Analysis Department, Civil Engineering Design Division, Kajima Corporation, Japan*

Received 28 September 2015; received in revised form 5 April 2016; accepted 11 April 2016
Available online 25 August 2016

Abstract

This study investigates the effects of quality of in-situ sandy samples, which were taken by a conventional tube sampling (TS) method, on liquefaction assessment. The sandy samples were retrieved from a loose fill layer and medium-dense Holocene deposit in young reclaimed land in Urayasu City where significant liquefaction occurred during the 2011 off the Pacific Coast of Tohoku Earthquake. First, a series of small strain measurements and undrained cyclic triaxial tests was conducted on the TS and reconstituted samples. Second, in order to investigate an applicability of the tested samples for the liquefaction assessment, an effective stress analysis was performed by use of soil parameters obtained from the examined samples. Input earthquake motions of the analysis are the 2011 off the Pacific Coast of Tohoku Earthquake and the 1987 Chiba Toho-oki Earthquake, the first and the second largest earthquakes the investigation site has experienced. The result of a sample quality assessment with the small strain shear moduli indicates that the TS sample retrieved from the Holocene deposit remains of high quality. In addition, for the reconstituted sample of the fill layer, since the small strain shear moduli of the sample are found to be nearly equal to those obtained at the field, it can be considered that the in-situ soil structure condition is reproduced in the reconstituted sample. According to an official report, the liquefaction resistance of the TS sample of the loose fill layer is $R_{L20}=0.38$, which is much larger than that of medium-dense Holocene deposit ($R_{L20}=0.29$) measured in this study. This is because the fill layer is so loose that the TS sample could have been strengthened due to disturbance during the sampling. On the other hand, the test result for the reconstituted sample of fill layer shows an appropriate level of liquefaction resistance ($R_{L20}=0.14$). The results of the effective stress analysis using the soil parameters obtained from the TS sample of Holocene deposit and the reconstituted sample of fill layer show the most probable behaviors of the ground at the investigation site for both the 2011 off the Pacific Coast of Tohoku Earthquake and the 1987 Chiba Toho-oki Earthquake, which are consistent with the evidence reported after the earthquakes. The results indicate that the sample quality assessment by using a small strain shear moduli is applicable for the rational liquefaction assessment, and it would be possible to employ the reconstituted sample, which the small strain shear moduli are the same with the in-situ value, in substitution for a high quality sample.

Keywords: Liquefaction; Undisturbed sample; Small strain shear moduli; Effective stress analysis; The 2011 off the Pacific Coast of Tohoku Earthquake

1. Introduction

The 2011 off the Pacific Coast of Tohoku Earthquake (denoted as the 2011 Tohoku Earthquake hereafter), with a *Mw* of 9.0, caused significant soil liquefaction over a wide

*Corresponding author. Fax: +81 3 5452 6752.
E-mail address: kiyota@iis.u-tokyo.ac.jp (T. Kiyota).
Peer review under responsibility of The Japanese Geotechnical Society.

http://dx.doi.org/10.1016/j.sandf.2016.07.009

range in the Kanto and Tohoku Regions (Towhata et al., 2014; Yamaguchi et al., 2012; Tsukamoto et al., 2012). The occurrence of liquefaction has been observed in a total of 190 local cities, towns and villages, and a large number of liquefaction-induced damage to residential houses and buried lifelines was reported, especially in the young reclaimed lands in Tokyo Bay area and in downstream basin of the Tonegawa River (JGS, 2014) A number of investigations have been carried out on bore hole data and in-situ sandy samples in the laboratory to determine the cause of liquefaction due to seismic activity and the best remediation methods to prevent liquefaction in future earthquakes.

However, the soil structure of the sandy samples, retrieved by means of conventional tube sampling (denoted as TS hereafter) methods, is prone to disturbance during the sampling at field and/or by poor handling during sample preparation in the laboratory (Yoshimi et al., 1994).

In this study, therefore, in order to investigate the effect of sample quality on the liquefaction characteristics, a series of small strain measurements and undrained cyclic triaxial tests was performed on both TS samples and reconstituted samples. The samples were retrieved from fill and Holocene sandy deposits at an investigation site in Urayasu City, Chiba Prefecture, where significant liquefaction was observed during the 2011 Tohoku Earthquake. On the other hand, the occurrence of liquefaction at the investigation site has been unreported for the 1987 Chiba Toho-oki Earthquake, with a Mw 6.7 (denoted as the 1987 Chiba Earthquake), which was the largest earthquake at the investigation site before the 2011 Tohoku Earthquake. In light of the situation, a simple effective stress analysis was performed using two input motions, the 2011 Tohoku Earthquake and the 1987 Chiba Earthquake, and the soil parameters obtained from the above examined samples. Finally, the applicability of the TS and reconstituted samples for the liquefaction assessment was discussed.

2. A brief review of previous studies

One of the pioneering experimental approaches to investigate a quality of a TS sample was applied by Mori et al. (1978) and Seed et al. (1982). They showed that the TS sample from a deposit previously subjected to cyclic loading history had a loss of the prior loading effect as well as the resistance to undrained cyclic loading. Hatanaka et al. (1995) investigated the effects of disturbance in the TS samples on liquefaction characteristics by comparing with a sample taken by the in-situ freezing sampling (denoted as FS) technique. They reported that the liquefaction resistance of the TS samples was higher than that of the FS samples for loose fill sands, while that of the TS samples was much lower than that of the FS samples for medium dense natural sands, and the difference between them increases with increases in the SPT-N value. In another study, Tokimatsu and Hosaka (1986) conducted a series of small strain measurements and liquefaction tests on TS and FS samples, and reported that the effect of sample disturbance on the liquefaction resistance could be evaluated by comparing the small strain characteristics measured in the laboratory and in the field.

Based on previous studies on sample disturbance, a sample quality assessment has been carried out by means of shear wave velocity and/or small strain shear moduli (Shibuya et al., 1995; Chiara et al., 2006; Ferreira et al., 2011, among others). In fact, more than half of bender element users use the shear wave velocity measurement for the purpose of checking the quality of undisturbed samples and quality management of improved soil (JGS, 2010). This trend can be understood easily because the small strain characteristics reflect the soil fabric, as was suggested by Santamarina et al. (2001). Tokimatsu et al. (1986) reported that a promising method for assessing liquefaction characteristics was to measure shear moduli in the field, to obtain samples by economical TS method, and to pre-stress them to recreate the in-situ shear modulus and density under simulated in-situ stress condition. In addition, Kiyota et al. (2009a, 2009b) conducted a series of liquefaction tests on FS sandy samples and their reconstituted samples, and found that the method suggested by Tokimatsu et al. (1986) is appropriate for the less-cemented soils like recent fill layers and/or Holocene deposits.

Although we have known for decades the significance of sample disturbance by the TS method and its serious effects on liquefaction characteristics in the laboratory tests, cost-effective sampling technology for liquefiable loose sandy deposits has not advanced yet. Matsuo and Tsutsumi (1998) investigated the performance of existing TS methods and concluded that the current TS methods are not applicable for sandy soils. Recently, a new technique for obtaining high quality undisturbed samples using a "Gel-push" sampler was developed by Tani and Kaneko (2006) and was employed in New Zealand (Taylor et al., 2012), Taiwan and Japan (Chen et al., 2014). Yet, a comprehensive discussion on the quality assessment of Gel-push samples for liquefiable soils has not been made.

Since the 2011 Tohoku Earthquake in Japan, a concerted effort has been made to determine the cause of significant liquefaction in the young reclaimed lands in Tokyo Bay area based on the laboratory tests with conventional TS samples (e.g., Yasuda et al., 2012). As expected from the previous studies, however, the values of liquefaction resistance of fill layer obtained from the TS samples are larger than the expected values that are derived from SPT-N value at the sampling depth and from the fact that significant liquefaction occurred at the sampling site (Urayasu City, 2012). As a result, although a number of liquefaction tests has been carried out with the TS samples since the 2011 Tohoku Earthquake, a limited number of case studies has been focused on liquefaction using soil parameters obtained from the TS samples.

3. Investigation site and soil profile

The investigation site of this study is located in Urayasu City, Chiba Prefecture. Fig. 1 shows spatial distribution of observed boiled sand after the 2011 Tohoku Earthquake in Urayasu City. A large amount of boiled sand was seen on the