Soils and Foundations 2016;56(3):506–519

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Soils and Foundations

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Technical Paper

The relation between liquefaction resistance and shear wave velocity for new and old deposits

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Received 28 July 2015; received in revised form 11 October 2015; accepted 27 January 2016
Available online 4 June 2016

Abstract

Multiple series of cyclic triaxial tests were performed on undisturbed and reconstituted samples of sandy soils obtained from areas of known liquefaction at the time of the 2011 East Japan Earthquake. In this test scheme, the shear wave velocity was firstly measured and then cyclic loads were applied to determine the cyclic shear strength. The undisturbed samples were classified into two groups, namely, one from old alluvial (Pleistocene) deep deposits and the other from near-surface shallow depths which had apparently been disturbed by the liquefaction in the 2011 event. The data thus obtained were plotted in terms of the cyclic strength versus the shear wave velocity, and two curved lines were drawn through average points in the plot for the two groups of soils, that is, one for the undisturbed soils and the other for the liquefaction-disturbed soils. It was found that for a given cyclic strength, the shear wave velocity does have the propensity to become larger for the undisturbed samples from the old deposits in comparison to the undisturbed samples from the seemingly liquefaction-disturbed samples. Similar sets of laboratory tests were also performed on several sand samples reconstituted to a completely disturbed state. The plots of the test results for these reconstituted samples also showed a tendency in the relation between the cyclic strength and the shear wave velocity which is similar to that for the liquefaction-disturbed samples recovered from the in-situ deposits. In order to understand the outcome of the above observations, the ratio between the cyclic strength and the shear modulus from the shear wave velocity was taken as a parameter to distinguish the two different relations as mentioned above. This ratio, which might be called the “reference strain” of the “yield strain”, is used to provide an interpretation of the difference in correlation between the cyclic strength and the shear wave velocity.

1. Introduction

The evaluation of the liquefaction potential during earthquakes has been an important subject for geotechnical engineers in seismically active regions of the world. In fulfilling this task, it is of critical importance to assess the cyclic resistance of sandy soil deposits in the field.

One of the methods to this end would be to secure undisturbed samples of soils from in-situ deposits in question and to test them in the laboratory under cyclic loading conditions. This methodology is deemed to give sufficiently accurate information regarding the cyclic strength of in-situ soils reflecting their inherent characteristics formed during depositional processes under their own environments. However, a shortcoming of this method would be the difficulty in evaluating the levels of sample disturbance and the high costs incurred in the sampling and testing operations.

Another method would be to assess the cyclic resistance of in-situ soils via the use of some empirical formulae or charts

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Peer review under responsibility of The Japanese Geotechnical Society.

http://dx.doi.org/10.1016/j.sandf.2016.04.016
0038-0806/

correlating the cyclic strength with the resistance of penetration tests, such as the Standard Penetration Test (SPT) and cone penetration resistance (CPT). The shortcoming of these methodologies is the level of accuracy and the credibility of the empirical formulae correlating the cyclic strength with the penetration resistance which may change depending upon several factors.

Still other method would be to use the shear wave velocity which can be measured in-situ at a low cost by means of several procedures without necessarily drilling boreholes. However, there is suspicion regarding its use, because liquefaction is related to medium to large shear strain in contrast to the infinitesimal shear strain involved in the propagation of the shear wave. In spite of such potential shortcomings, there have been a lot of works promoting the use of the shear wave velocity and attempting to establish some charts correlating the cyclic strength with the shear wave velocity. Typical papers dealing with this subject include Dobry et al. (1980), Stokoe et al. (1988), Tokimatsu and Uchida (1990), Andrus and Stokoe (2000), Wang et al. (2006), Liu and Mitchell (2006), Baxter et al. (2008), Kayen et al. (2013), Ahmadi and Akbari Paydar (2014), and Dobry et al. (2014). Thus, if some physical interpretation can be provided for the correlation, the shear wave velocity will be regarded as a meaningful tool for assessing the liquefaction resistance of the in-situ deposits of sandy soils.

It is an objective of this paper to obtain the results of multiple series of test data in the laboratory and in the field, and to try to seek for separate correlations for new and old deposits.

2. Recovery of undisturbed samples

With an aim to determine cyclic strength R_L and shear wave velocity V_s, multiple series of tests were conducted in the field and in the laboratory using the cyclic triaxial test apparatus for undisturbed and disturbed samples of sandy soils. The undisturbed samples were secured from man-made fills and alluvial deposits at two sites which were affected by liquefaction at the time of the 2011 East Japan Earthquake. One area is located in Asahi City, Chiba Prefecture, along the coastal line of the Pacific Ocean. Its location is shown in Fig. 1. The other area is the site of a tailing dam, south of Kesen-numa, which suffered the breach and release of liquefied tailings at the time of the 2011 event. Its location is also indicated in Fig. 1.

2.1. Asahi site

Man-made fills and alluvial (Holocene) deposits near the surface suffered ground settlement and the tilt of private houses due to liquefaction at the time of the 2011 earthquake. The individual locations of the undisturbed samplings are indicated in Fig. 2. The area of ground destruction is a broad flat plain surrounded by hills in the north and west. Soil borings were conducted at six places, as indicated in Fig. 2. Measurements of the shear wave velocity were taken using the downhole method to depths 15–20 m and by means of a suspension device for deeper deposits. More detailed soil profiles for the three selected locations are shown in Fig. 3(a), (b), and (c), where SPT N-values, shear wave velocity V_s, and the depths of the samplings are also indicated. The recovery of the

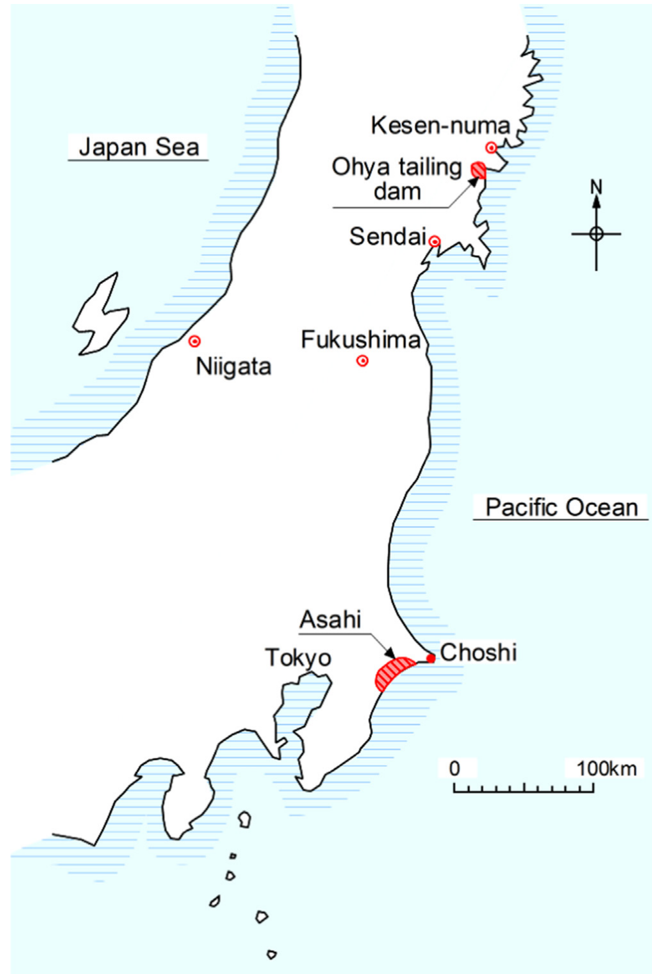

Fig. 1. Locations of two sites for undisturbed sampling.

undisturbed samples was conducted by means of a thin-wall tube sampler at medium shallow depths denoted by S-1, S-2, etc., by a triple tube sampler for the medium soft soil deposits (T-1, T-2, etc.), and by a Denison sampler for the stiff old deposits (D-1, D-2, etc.). Note, however, that samples T-1, T-2, D-1, and D-2 were not tested. The type of sampler used in each case is indicated on the right-hand side column in each of the figures in Fig. 3. In the practice of site investigations in Japan, it is common to make use of these sampling techniques. The degree of disturbance during sampling is difficult to quantify accurately. It is believed, however, that despite some degree of disturbance, the recovered intact samples still retain their inherent structures, such as a thinly stratified complex matrix which was formed under respective depositional environments. These structures in intact soils are conceived to have more significant influence on the soil response in cyclic loading than changes in density during sampling and sample handling.

2.2. Tailing dam site

The location of the site of the tailings dam, which failed during the 2011 earthquake, is indicated on the map in Fig. 1. The site, about 60 km north of Sendai, was shaken strongly with a peak