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Laboratory tests on cyclic undrained behavior of loose sand with cohesionless silt and its application to assessment of seismic performance of subsoil

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ABSTRACT

Geotechnical earthquake engineering in the recent times has been paying special attention to themes such as liquefaction of sand with cohesionless fines, performance-based design, and seismic mitigation measures for housing areas. Because recent earthquakes in Japan and New Zealand caused many liquefaction problems in residential zones, the above-mentioned issues have become even more important than before. The present study conducted laboratory tests on sand with cohesionless fines in order to show how the seismic performance of loose subsoil is assessed, thus developing a practical methodology of performance-based mitigations. Most experimental data obtained is presented together with interpretations, and the mathematical framework for the performance assessment is described together with an example of specified mitigation methods. It is worth mentioning that the target of this assessment is the residential land of people who cannot afford high costs of testing and analysis, therefore, the methodology is simplified as much as possible.

1. Introduction

The major point of discussion in geotechnical earthquake engineering in the recent times lies in the development of performance-based design in which the seismic factor of safety does not necessarily have to be greater than unity, if the induced damage is within an acceptable limit [11,15,18–20,25,37,39,40,42,43]. One of the reasons for this trend is the increasing intensity of seismic load for design due to the people's desire for safety. Obviously it is difficult to maintain, on a reasonable budget, the seismic factor of safety greater than unity under a significant intensity of seismic actions. Hence, the idea of seismic performance has emerged in which the seismic performance is synonymous with the residual displacement/deformation being less than the allowable limit at the end of a seismic event. Therefore, it is essential to be able to assess the residual displacement and deformation in a practical manner considering both technical and financial senses.

Another point of argument is the liquefaction behavior of loose sand with cohesionless (non-plastic) silt [1,12,14,2,28,31,44,45]. In contrast with the cohesive fines content in sand that has been regarded in many design codes to increase the liquefaction resistance of subsoil, liquefaction disasters developed in sand with cohesionless silt during recent earthquakes as the 1999 Chi Chi Earthquake of Taiwan [24], the 2001 Tottoriken-Seibu Earthquake [38], the 2010–2011 sequence of earthquakes in Christchurch [10] and the 2011 Great Earthquake in East Japan. In spite of such liquefaction vulnerability, the experimental studies as cited above present contradictory remarks as liquefaction resistance of sand being increased or reduced by adding a certain amount of cohesionless silt. Hence, this controversial issue needs to be examined in a more rational manner.

The third issue is the mitigation of liquefaction effects in residential areas. Because the financial ability of people is low, the available mitigation measures are limited. Moreover, the Japanese people in liquefaction-hit areas in 2011 chose to improve the liquefied subsoil but keeping their affected houses untouched. This means that vibratory compaction or other technologies that might damage the fragile houses are impossible. This situation is in clear contrast with that in Christchurch, New Zealand where the liquefaction-prone areas were declared to be dangerous and residents are advised to move out of the area, leading to demolition of affected houses.

With these circumstances in mind, the authors made an attempt to propose some solutions to the current controversial issues by running field investigations, carrying out laboratory tests and developing analytical/numerical methods of seismic performance assessment.

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2. Field investigation

The first stage of the present study addressed the situation of real liquefaction of sand with cohesionless silt. The selected sites were in Christchurch, New Zealand, where significant liquefaction affected the residential areas. In December 2012, portable dynamic cone penetration tests (DCPT) were conducted to comprehend the stiffness of the ground around the Avon River where substantial damage was observed [9]. The DCPT is similar to the standard penetration test (SPT) except that resistance is measured

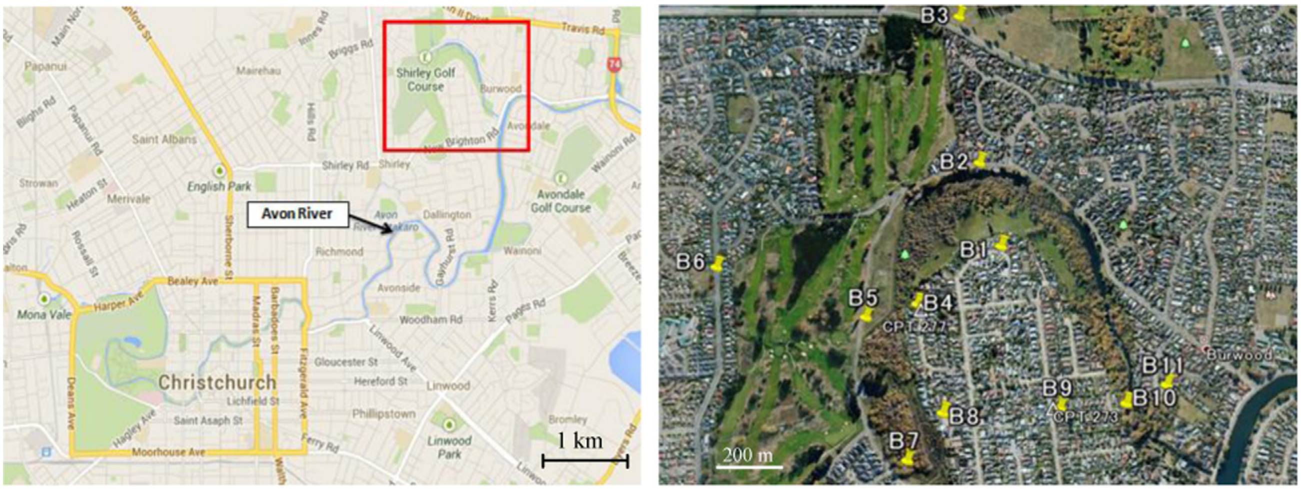

Fig. 1. The studied area in Christchurch, New Zealand (from Google Maps).

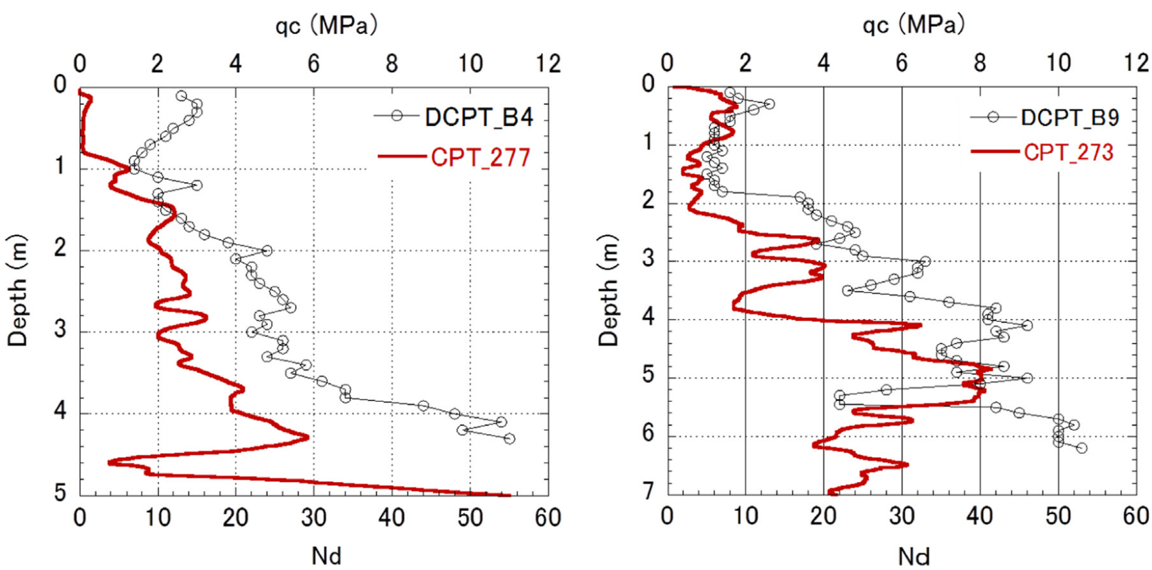

Fig. 2. The soil profiles obtained by dynamic cone penetration and conventional CPT.

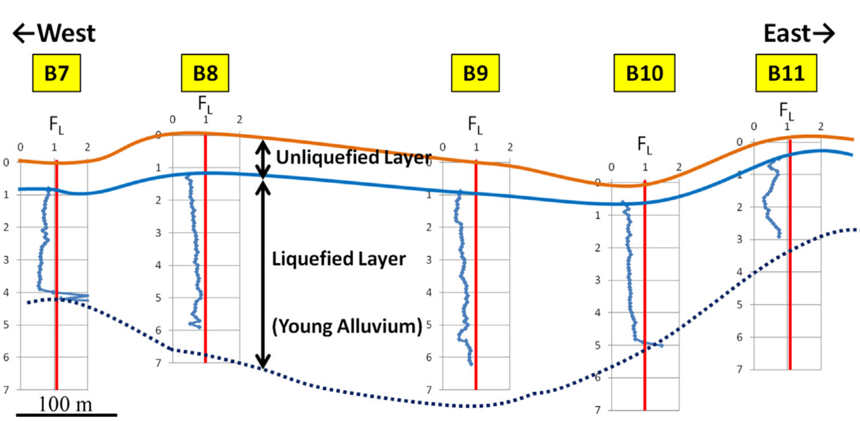

Fig. 3. The assessed cross section of the studied area in terms of factor of safety against liquefaction (200 Gal at surface, Recommendations for Design of Building Foundations by the Architectural Institute of Japan).