

A Case Study on Silty Sand Liquefaction

Wei F. Lee and Luo Y.N. Ge

Abstract Silty sand liquefaction has been of great interest of research in geotechnical earthquake engineering. This article presents preliminary results of a case study on nonplastic silty sand liquefaction. Influence factors such as fines contents and disturbance effects on dynamic properties of silty sand are carefully discussed in this paper.

Keywords Silty sand · Dynamic properties · Soil liquefaction · Fines contents · Sampling disturbance

1 Introduction

Nonplastic silty sand liquefaction has been of great research interests in geotechnical earthquake engineering. During the 1999 Chi-Chi earthquake, serious soil liquefaction damages were observed in central Taiwan including Wu Feng, Nan Tou, and Yuen Lin areas. Christchurch and its vicinity of New Zealand have also suffered from severe liquefaction damages during series of earthquakes from 2010 to 2011. Moreover, Tokyo bay area and Chiba prefect was suffered from serious soil liquefaction damages during the 2011 Great East Japan earthquake. For these destructive earthquakes, post-earthquake reconnaissance indicated that most soil liquefactions were taken place in silty sand deposits with high fines content. Preliminary reconnaissance also concludes that majority liquefaction occurred in the reclaimed silty sand deposits (Fig. 1; Lee et al. 2012).

However, it has been difficult to retrieve undisturbed samples of silty sand. Influences of fine contents, void ratio as well as sampling disturbance on liquefaction potential of silty sand containing nonplastic fines were not well studied in

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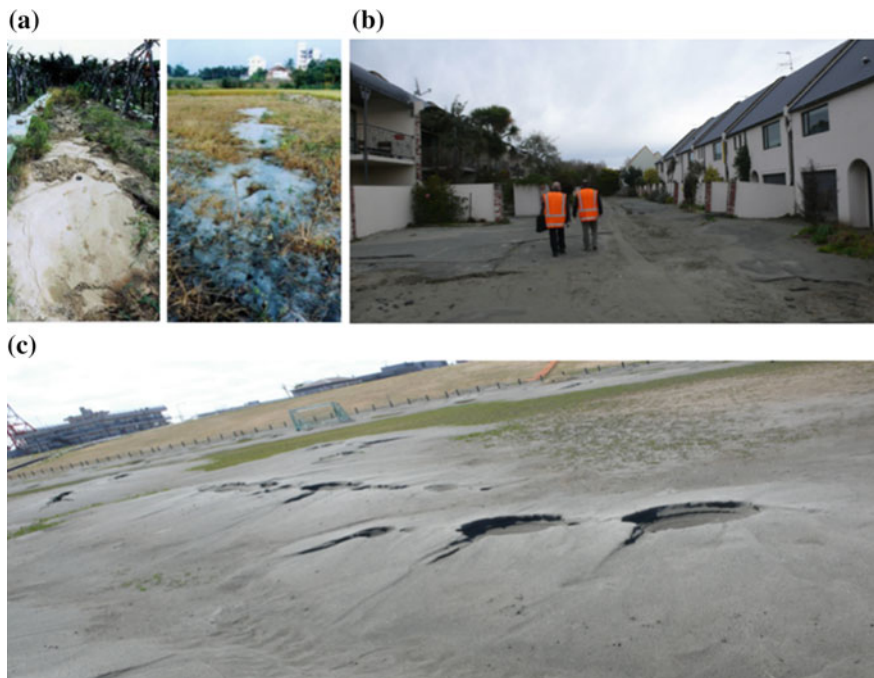


Fig. 1 Non-plastic silty sand liquefaction observed in **a** 1999 Taiwan Chi-Chi earthquake, **b** 2010–2011 New Zealand Christchurch earthquakes, and **c** 2011 Japan Tohoku earthquake

the past. A study site, Hsin Hwa, was selected as the study site, and it was suffered from soil liquefaction during the 2010 Jia Shan Earthquake in Taiwan. Dynamic triaxial tests were carried out on the undisturbed specimens obtained suing gel-push sampler (Lee et al. 2015) and remolded ones to examine the influences of sampling disturbance, fines contents, and void ratios on the dynamic behavior and liquefaction potential of nonplastic silty sand. Details and progress of such a research are presented as follows.

2 Hsin Hwa Liquefaction

Hsin Hwa is located in Tainan City, Taiwan (Fig. 2). This site was selected because massive soil liquefaction was observed during an earthquake of magnitude of 6.4 occurred in 2010. A peak ground acceleration about 385 gal was recorded during this earthquake. Total four boreholes were drilled, where gel-push sampling (Lee et al. 2015) was conducted in three boreholes, and conventional Shelby tube sampling was performed in the fourth one for the purpose of comparison. The soil profile including the SPT-N values of the test site is given in Fig. 3. As depicted in

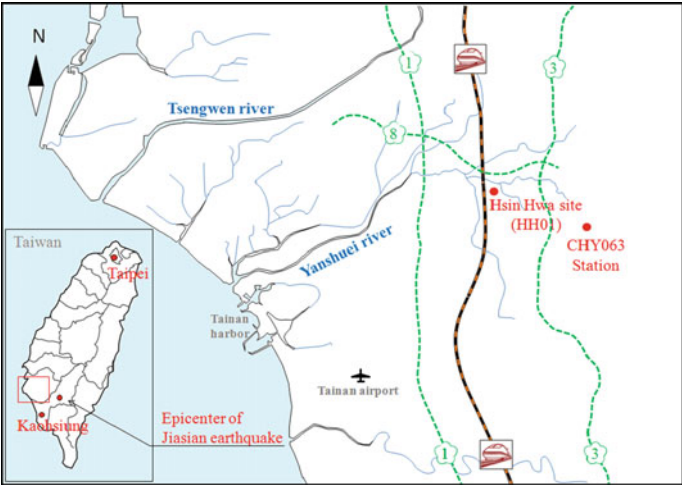


Fig. 2 Geographical location of Jia Sian earthquake

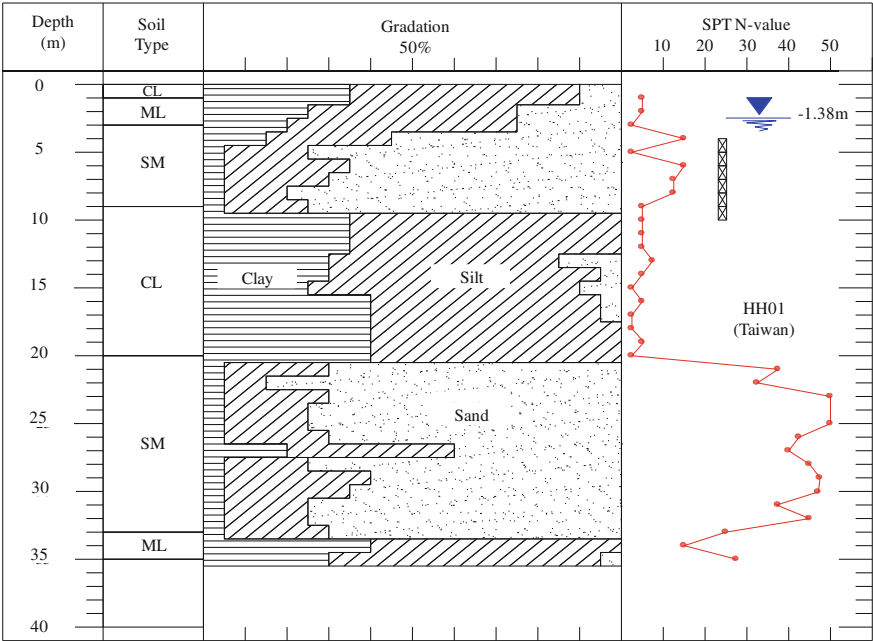


Fig. 3 Summarized soil profile at Hsin Hwa study site

the figure, a silty sand layer, which is located between 2 and 10 m below the ground surface, contains high fines content ranging from 10 % to more than 50 %.

3 Dynamic Properties of Silty Sand

Testing results of two representative specimen groups, categorized by fines contents near 10 and 28 %, respectively, were selected for comparative illustration. Each group contains undisturbed specimens and remolded specimens prepared under similar void ratios and confining pressure control for comparison. The remolded specimens were prepared using wet-damping methodology to effectively control the void ratio; and the undisturbed specimens were prepared from the gel-push sampler with minor trimming. Figure 4 shows the axial strain and pore water pressure excitation histories of two selected groups. The failure pattern of undisturbed specimens was similar to plastic deformation when the excess pore water pressure increased slowly and incrementally. For remolded specimens, the excess pore water pressure increased quickly, and brittle failure has occurred under the same testing condition. Figure 5 shows the strain–stress behaviors of tested specimens. The undisturbed specimen has stronger cyclic resistance and possesses a larger yielding strain than the remolded specimen with a similar density and deviator stress. For specimens with similar fines contents, the remolded ones appear to soften-up (yield) quickly while the undisturbed specimens still exert plastic behavior. For undisturbed specimens with different fines contents, specimens with 28 % fines deform less than those with 10 %, indicating that fines content plays an important role in stabilizing the micro structure of nonplastic silty sand. However, for remolded specimens, specimen with less fines content appears to yield much less than those with higher fines content.

Figure 6 summarizes the test results of post-liquefaction volumetric strains, where the post-liquefaction volume change was measured from the dissipation of excess pore water after liquefaction was identified in each cyclic triaxial test. As shown in the figure, remolded specimens clearly possess larger volumetric strains than undisturbed ones. Post-liquefaction volumetric strains of remolded specimens would be as high as 8–10 %, whereas those of undisturbed specimens remain between 2 and 5 %.

4 Discussion on Engineering Practice

4.1 Cyclic Stress Ratio

Figure 7 summarizes the relationships between the cyclic stress ratio (CSR) and the number of load cycles (N_c) at liquefaction of all tests conducted. As illustrated in

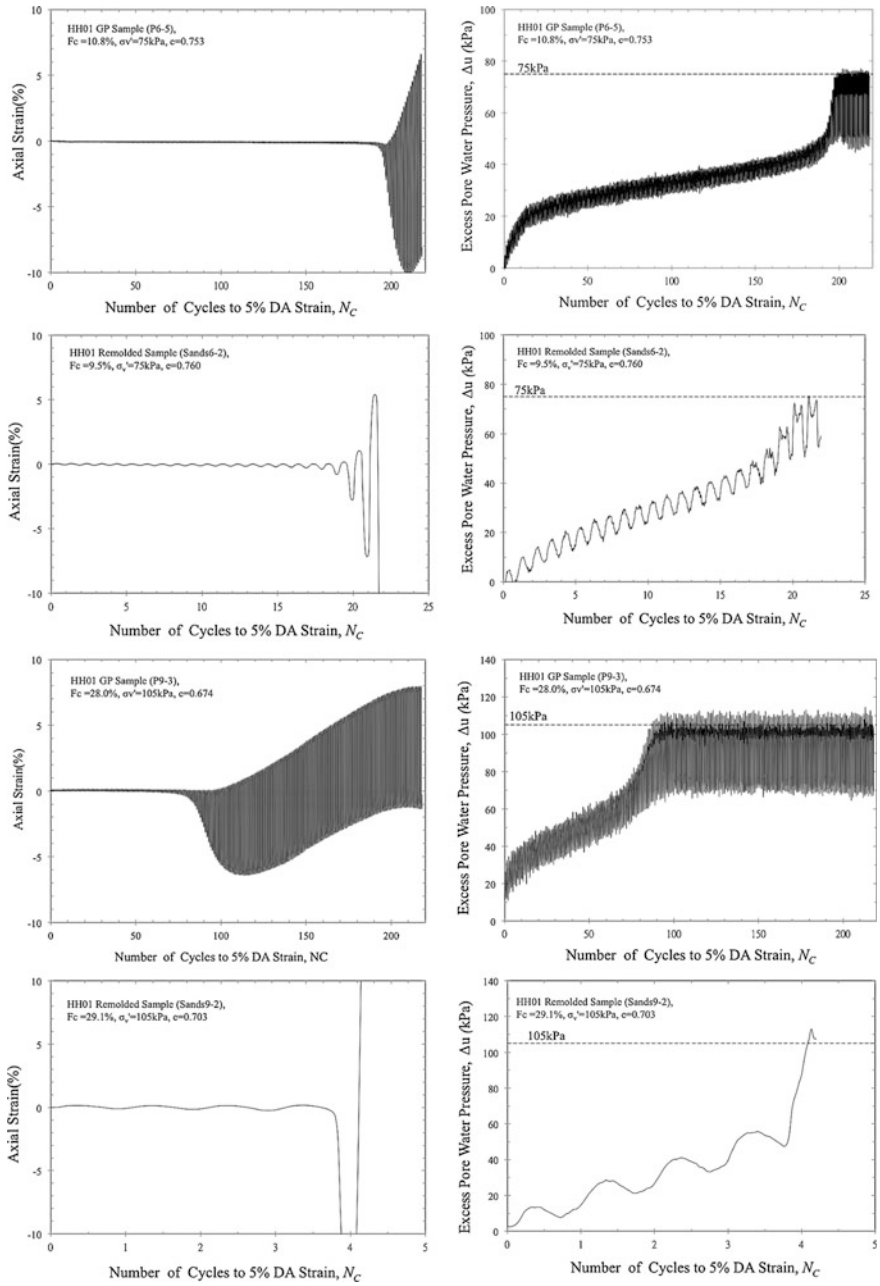


Fig. 4 Axial strain and excess pore water pressure histories of cyclic triaxial tests

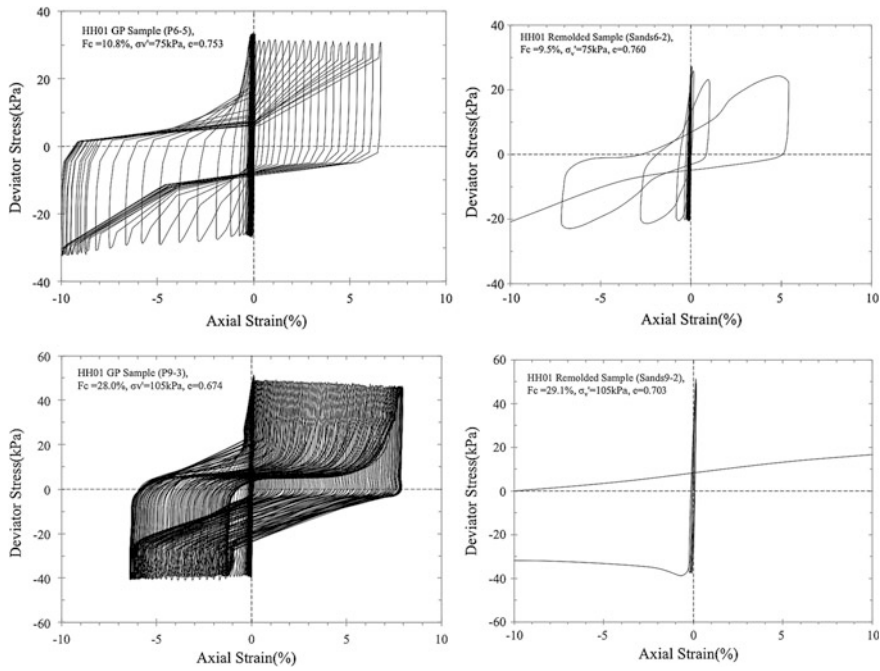
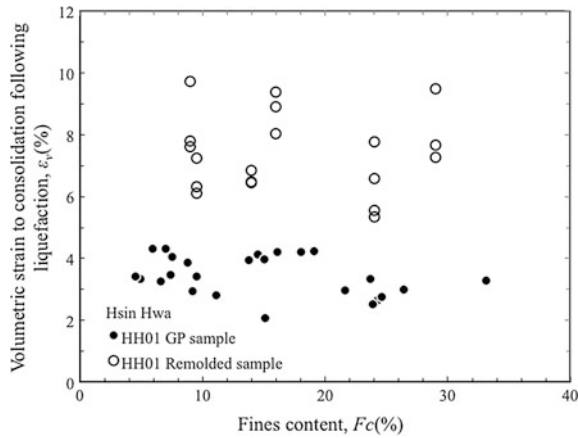


Fig. 5 Strain–stress behaviors of cyclic triaxial tests

Fig. 6 Test results of post-liquefaction volumetric strains according to various fines contents



the figure, undisturbed specimens have higher cyclic strengths than those of remolded specimens with the same fines contents and similar void ratios. It indicates that sampling disturbance could definitely influence the soil liquefaction resistance of nonplastic silty sand. Under the same void ratio condition, specimens with higher fines contents tend to have lower cyclic strengths. Under the similar

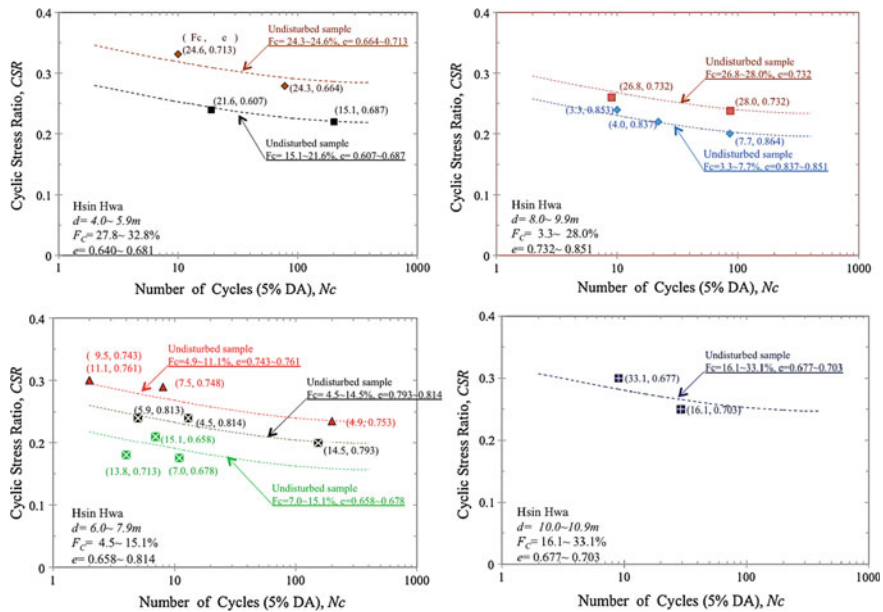
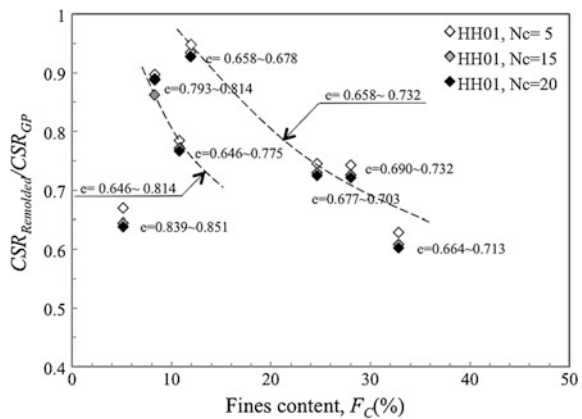


Fig. 7 Summary of results of conducted cyclic triaxial tests

Fig. 8 Influence of sampling disturbance to dynamic properties of nonplastic silty sand with various fines contents



fines content condition, specimens with higher void ratios tend to have lower cyclic strength. This behavior becomes more noticeable for the remolded specimens.

4.2 Influence of Fines Content and Void Ratio

Figure 8 shows the influence of sampling disturbance to dynamic properties of nonplastic silty sand with various fines contents. In the figure, the vertical axis is the

ratio of CSRs between remolded specimens and undisturbed specimens at the 5th, 15th, 20th load cycle (N_c). As shown in the figure, the more fines content the nonplastic silty sand has, more reduction in cyclic strength are observed. When the fines content of soil specimens was 30 %, there was a 40 % reduction in its cyclic strength.

4.3 Examination of Present Liquefaction Evaluation Method

The liquefaction potential evaluation of Hsin Hwa site is shown in Fig. 9, with a vertical axis showing depth, and horizontal axes of fines content, plastic index (PI), SPT-N value, and the liquefaction resistance ratio under the Richter magnitude (M_r) equal to 6.4, respectively. In the figure, red triangles and green circles show the analysis results using the NJRA and Seed’s methods, respectively. Blue $\times$ indicates the results of the cyclic triaxial tests on undisturbed specimens. Both NJRA and Seed’s methods would estimate the liquefaction resistance of plastic soil layer accurately. However, it seems to overestimate the liquefaction resistance in nonplastic silty sand layer, especially when fines content was higher. Hence, the present liquefaction evaluation methods in a nonplastic silty sand layer are probably inadequately applicable.

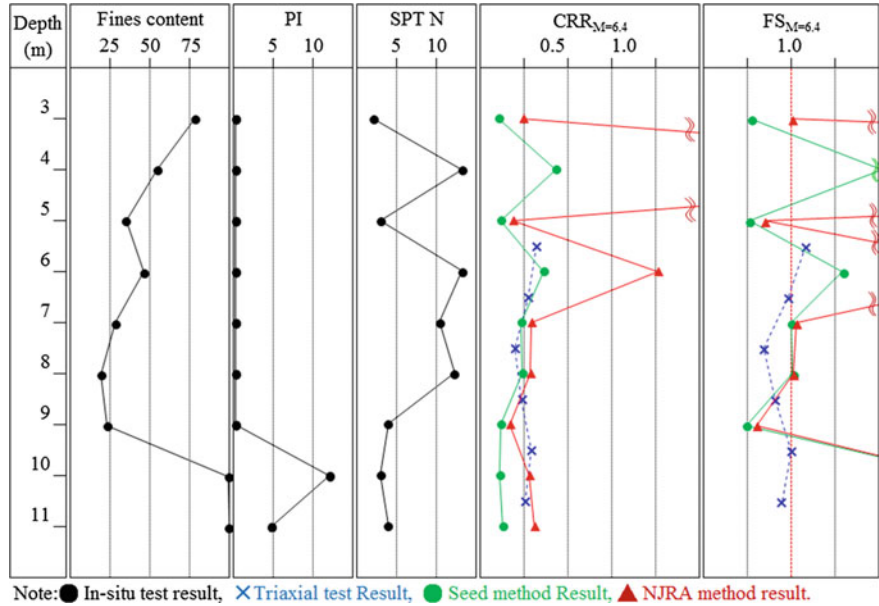


Fig. 9 Comparison of different liquefaction potential evaluations of nonplastic silty sand

5 Conclusions

Results of laboratory tests indicate that higher the void ratio and fines content of the nonplastic silty sand would have a larger cyclic strength reduction when disturbed. This phenomenon is considered to be very important in understanding time sequence of silty sand liquefaction. Void ratio (or relative density) would have deterministic effect on the silty sand liquefaction potential, so as the post-liquefaction volumetric strain. Results of tests on remolded specimens also show higher the fines contents, lower the liquefaction resistance. However, results of tests also imply no general trends of liquefaction resistance for intact specimens with difference fines contents. It is suggested that more efforts are needed to understand the combining effects of fines content, particle packing, aging, and sedimentation history, etc.

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