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LIQUEFACTION POTENTIAL OF NON-PLASTIC SILTY SAND

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Key words: soil liquefaction, non-plastic silty sand, Gel-Push sampler, fines content.

ABSTRACT

This paper is to introduce research progress on liquefaction potential of undisturbed high fines content non-plastic silty sand. A new sampling technique that was applied to the field allowing sensitive and high fines content silty sand material to be retrieved in sounding condition is described. Laboratory tests on the liquefaction resistance of non-plastic silty sand that emphasized on the influence of fines content percentages were conducted. It concludes that soil liquefaction would occur in non-plastic silty sand deposits even with high non-plastic fines contents. Both fines contents and void ratios have deterministic influences to the cyclic resistance of such silty sand material. Most importantly, disturbance effect would have great influence on cyclic resistances and post liquefaction volumetric strains of non-plastic silty sand. Results of this study is hoped to improve engineers' understanding on liquefaction potential of non-plastic silty sand.

I. INTRODUCTION

Engineering properties of non-plastic silty sand have attracted great interest on the research to soil liquefaction induced ground failures. During the 1999 Chi-Chi earthquake, serious soil liquefaction damages were observed in central Taiwan including Wu-Feng, Nan-Tou, and Yuen-Lin areas (Fig. 1). The post-earthquake study indicated that most soil liquefaction occurred in silty sand deposits with high fines content. Christchurch city and its vicinity area of New Zealand had also suffered from severe liquefaction damages during series of earthquakes in 2010 to 2011 (Fig. 2). Non-plastic silty sand again has been recognized as the major sources of

Fig. 1. Silty sand liquefaction at Wu-Feng during 1999 Chi Chi earthquake, Taiwan.

Fig. 2. Silty sand liquefaction at central business district of Christchurch during 2010-2011 Christchurch Earthquakes, New Zealand.

Fig. 3. Silty sand liquefaction at the seaside zone in the south of the Cemetery Park, Urayasu, Japan.

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Table 1. Fines content effect of liquefaction potential of soil.

Fines content effect	References
Inverse proportion	Chien *et al*. [4], Xenaki [18], Ueng [16], Papadoulou [12], Cubrinovski *et al*. [5], Lin [11], Youd [19].
Direct proportion	Kuerbis *et al*. [9], Vaid [17], Amini and Qi [1].
Low fines content was inverse proportion. And high fines content was direct proportion	Thevanayagam [14], Thevanayagam [15], Polito and Martin [13].

Fig. 4. Silty sand liquefaction at Hsin Hwa site during 2010 Jia Sian Earthquake, Tainan, Taiwan.

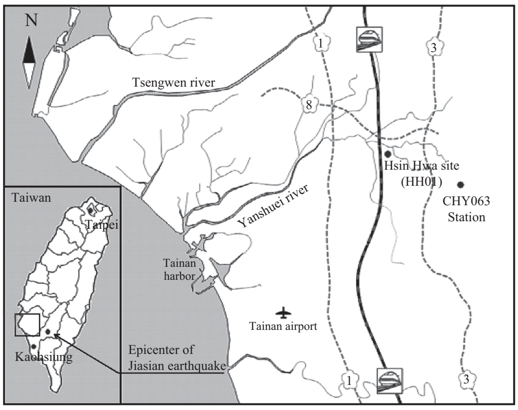


Fig. 5. Location of the Hsin Hwa test site (HH01).

soil liquefaction. Moreover, the Tokyo Bay area also suffered from serious soil liquefaction damage during the 2011 Great East Japan earthquake (Fig. 3). Preliminary reconnaissance also concluded that majority of liquefaction occurred in the reclaimed silty sand deposits.

Limited research progress was obtained because undisturbed sampling of high fines content silty sand was facing several technical difficulties in the past. The excessive friction generated during penetration of conventional sampler tends to cause serious disturbance to the specimens. Therefore, correlative researches only used remolded soil samples to investigate the fines content effect of the soil liquefaction potential, as shown in Table 1. In the present study, the authors adopted a recently developed "Gel-Push" sampling technique to obtain undisturbed samples of non-plastic silty sand. The Gel-Push sampler was designed to allow polymer lubricant to seep into the tube wall while the tube was penetrated into the soil. It could effectively reduce the wall friction so as to allow sensitive silty sand specimen to be recovered in good quality. The Gel-Push sampling technique was successfully applied to liquefaction sites located in southern Taiwan, Christchurch in New Zealand, as well as Urayasu area near Tokyo Bay, to retrieve undisturbed non-plastic silty sand specimen.

In this paper, one of the test sites, Hsin Hwa, was selected to show the application of Gel-Push sampler and laboratory tests in an effort to investigate liquefaction potential of non-plastic silty sand with various fines contents. Detailed sampling program and results were first introduced to illustrate advantages of using the developed sampler. Laboratory test program on both undisturbed specimens and remolded specimens with different fines contents were then introduced.

Purpose of the laboratory tests is to examine engineering features such as influence of fines content on liquefaction potential, influence of void ratio or particle packing state on cyclic stress resistance, effect of disturbance on dynamic engineering properties, and, finally, influences of fines content on post liquefaction volumetric strain.

In summary, the developed Gel-Push sampler has been proved to be an adequate tool to acquire good quality sample of non-plastic silty sand. Results of the cyclic triaxial tests verified that soil liquefaction would occur in non-plastic silty sand deposits even with high non-plastic fines contents. Both fines contents and void ratios have deterministic influences on the cyclic resistance of such silty sand material. Most importantly, disturbance effect would have great influence on cyclic resistances and post liquefaction volumetric strains of non-plastic silty sand. It is hoped that results of this study will improve engineers' understanding on liquefaction potential of non-plastic silty sand.

II. SITE INFORMATIONE

The high fines content silty sand exists extensively over central to southern parts of western Taiwan. Formation process of such unique geological material was recognized as a result of rapid weathering and abrading process (Huang *et al*. [6]). The studied site, Hsin Hwa City, Tainan, Taiwan, was selected because widespread soil liquefaction was observed during a magnitude 6.4 earthquake occurred in 2010 (Fig. 4). Fig. 5 indicates the location of the Hsin Hwa site (HH01). In total four boreholes were drilled. Gel-Push sampling was conducted in three boreholes, and conventional Shelby tube sampling was also conducted in one for comparison purpose. Fig. 6 summarizes the soil profile of the test site. As depicted

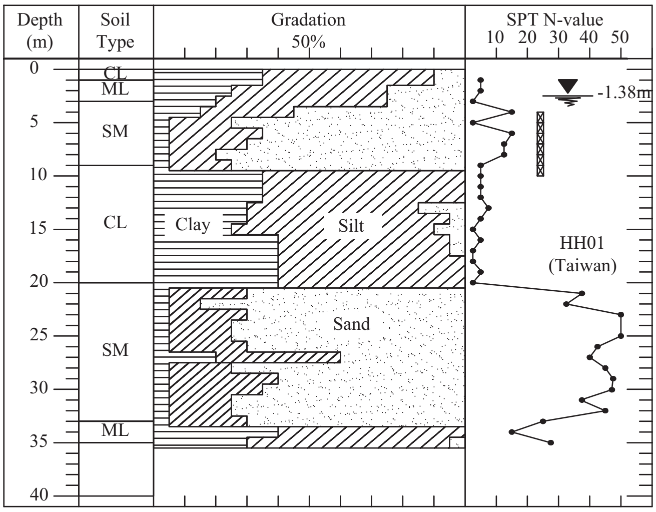


Fig. 6. Soil profile of the Hsin Hwa test site.

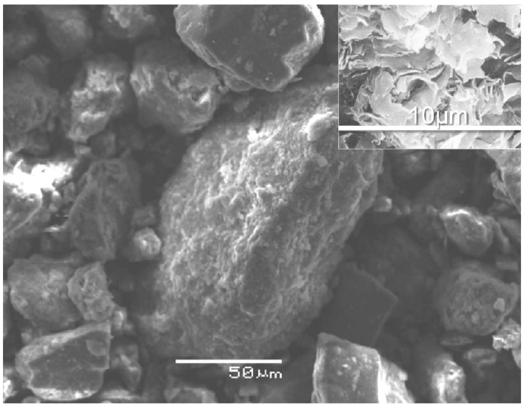


Fig. 7. Fines particles SEM image of studied silty sand.

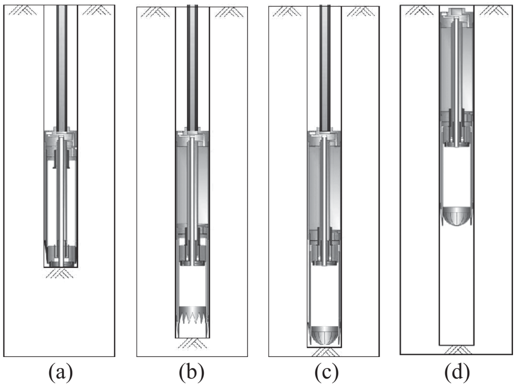


Fig. 8. Schematic drawings of Gel-Push sampling technique. (a) Fixed rod and sampler, (b) Push sampler into soil, (c) Close catcher, and (d) Move out Gel-Push sampler.

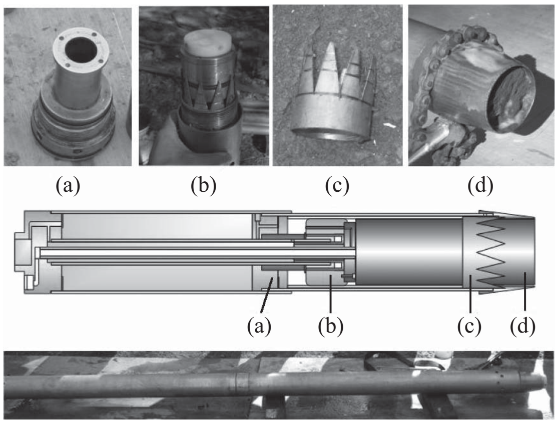


Fig. 9. Parts of Gel-Push sampler. (a) Transfer tube, (b) Piston, (c) Catcher, and (d) Thin wall tube.

in Fig. 6, silty sand layer locates between 2m to 10m below ground surface contains high fines content ranging from 10% to more than 50%. Fig. 7 shows the Scanning Electron Microscope (SEM) image of fines particles obtained from the studied site. As shown in the figure, fines particles of such silty sand material are in angular to sub-angular shapes, and have different particle shapes comparing to typical clay mineral. This evidence clearly indicates that almost no plasticity could be possibly exerted within such soils.

III. GEL-PUSH SAMPLING TECHNOLOGY

Undisturbed sampling of high fines content silty sand was facing several technical difficulties in the past. Conventional Osterberg's Shelby tube sampling technique has shortcomings in retrieving good quality high fines content silty sand specimens because the excessive friction generated during penetration tends to cause serious disturbance to the specimens. Therefore, the Shelby tube sampling techniques often results in incomplete soil sample and poor quality. Moreover, the ground freezing technique or tube freezing process, those generally were used for preserving sampled soil quality, would cause drifting of fines content and disturbance on sensitive micro structure during freezing and de-freezing process. Fines content loss would probably occur when such freezing methods are adapted.

The Gel-Push sampling technique was first developed by Kiso-Jiban Consultants Co. Ltd. to retrieve gravel material as an alternative replacing ground freezing method in Japan in 2004. This sampler was then modified and introduced to Taiwan by the authors, Lee and Ishihara, in 2006 in an attempt to obtain undisturbed high fines content silty sand during the forensic investigation of a subway construction failure (Lee *et al.* [10]). It was modified to accommodate the thin wall tube inside the sampler to become a triple tube system. The Gel-Push sampler was designed to allow polymer lubricant to seep into the tube wall while the tube was penetrated into the soil by hydraulic pressure. Fig. 8 shows the schematic drawings of the Gel-Push sampler at different stages of sampling process. As shown in the figure, the outer tube is designed to secure the borehole and to keep the penetration rod and piston fixed in alignment during penetration. The

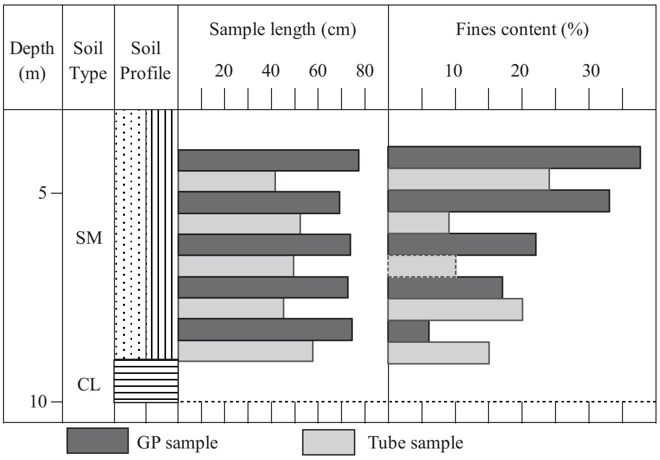


Fig. 10. Comparison of sampling results between conventional tube sampler and Gel-Push sampler.

middle tube acts as the guiding tube to push sampler into soil. Thin wall tube is secured inside the guiding tube for retrieving soil sample. Fig. 9 shows parts of the Gel-Push sampler. While sampling process starts, polymer gel is squeezed out from the chamber and seep into both outside of the guiding tube and inside of the thin wall tube. The sampler is also designed with a cutter attaching to the guiding tube to allow smooth penetration, and a catcher fixed at bottom of the thin wall tube to hold soil specimen from falling out during uplifting. The polymer gel would contaminate limited superficial portion of the specimen because very small amount of polymer gel is applied. However, it could effectively reduce the wall friction so as to allow sensitive silty sand specimen to be recovered in good quality.

Fig. 10 show the sampling results of both conventional Shelby tube sampler and Gel-Push sampler at Hsin Hwa site. The sampling depth is from 4 m to 9 m below ground surface where most non-plastic silty sand deposits locate. As depicted in the figure, Gel-push sampler had successfully recovered larger sample than the tube sampler. For completed sampling length, Gel-Push sampler also preserved more fines contents than tube sampler did. Tube sampler could only preserve clayey portion or coarse sand portion by comparing to soil samples retrieved using Gel-Push sampler. As shown in the figure, the length of conventional tube samples at depth of 7-9 m was shorter than that of GP samples, and it includes only clay layers. Fines content of conventional tube samples were higher than GP samples. Fig. 11 shows the silty sand specimen that was obtained using Gel-Push sampler. Specimens shown in the figure contains more than 25% of fines with water content higher than liquid limit. It was recognized as sensitive non-plastic silty sand material that was difficult to be retrieved in the past by using conventional tube sampler.

IV. LABORATORY TEST

Cyclic triaxial tests were conducted to investigate the dynamic properties of the non-plastic silty sand. Tests were performed on both undisturbed soil samples which obtained by the Gel-Push sampling technique and bulkily remolded samples. Effect of disturbance, fine contents (F_C) and void ratio (e) are three major factors for this study.

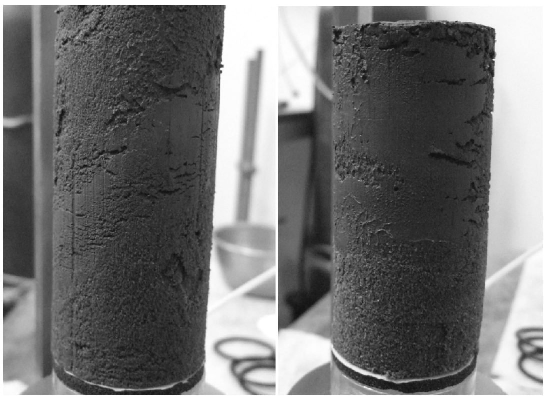
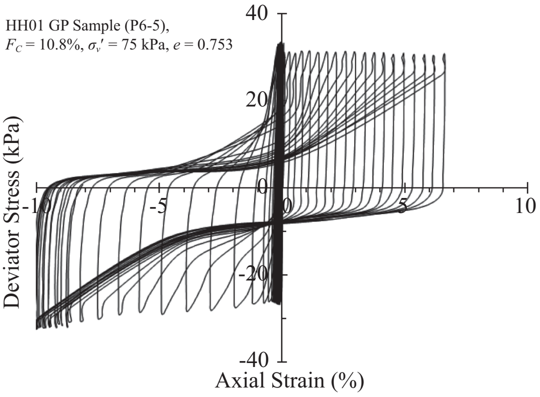
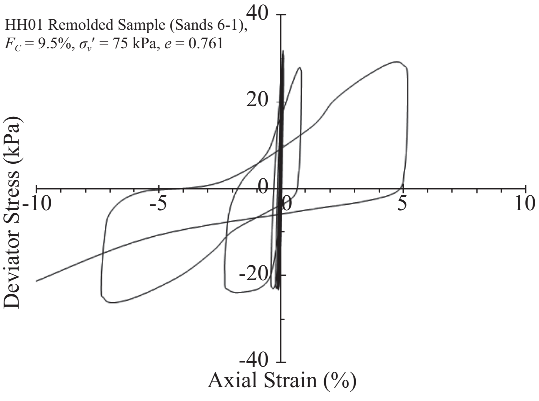


Fig. 11. Undisturbed sensitive silty sand specimens retrieved using Gel-Push sampling technique.



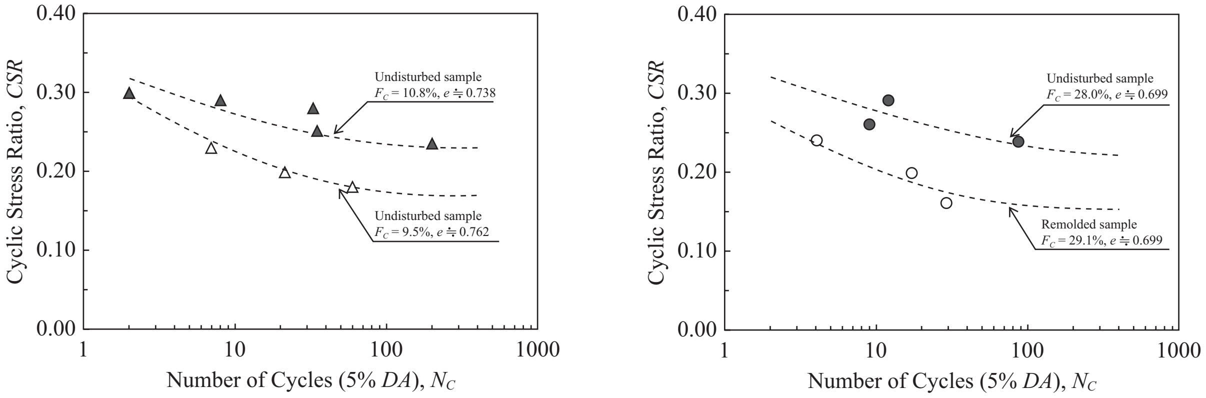
(a) Undisturbed



(b) Disturbed

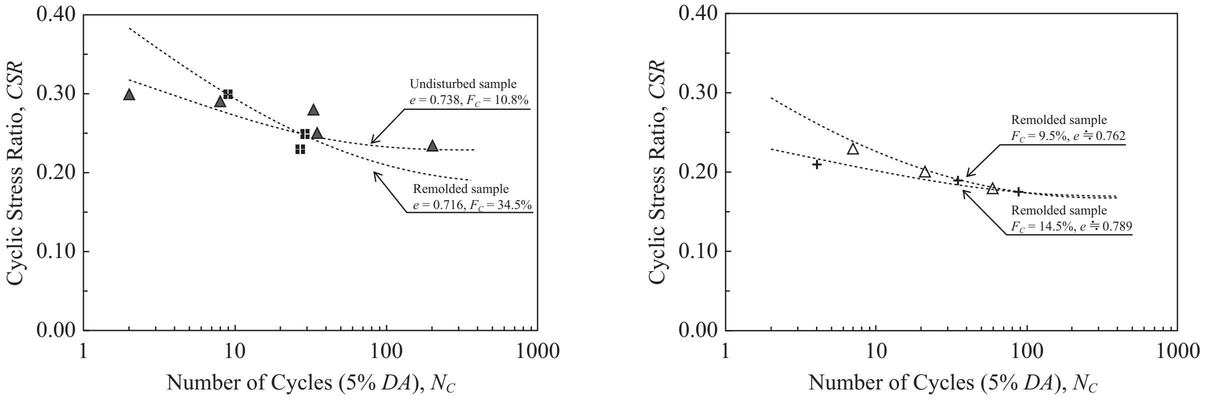
Fig. 12. Typical results of cyclic triaxial tests.

The C. K. Chan type of cyclic triaxial testing apparatus (Chan [2], Chan and Mulilus [3]) is used for this study. Ignition of liquefaction was set as double amplitude (DA), $DA = 2X_0$, where X_0 is the single amplitude, of axial strain



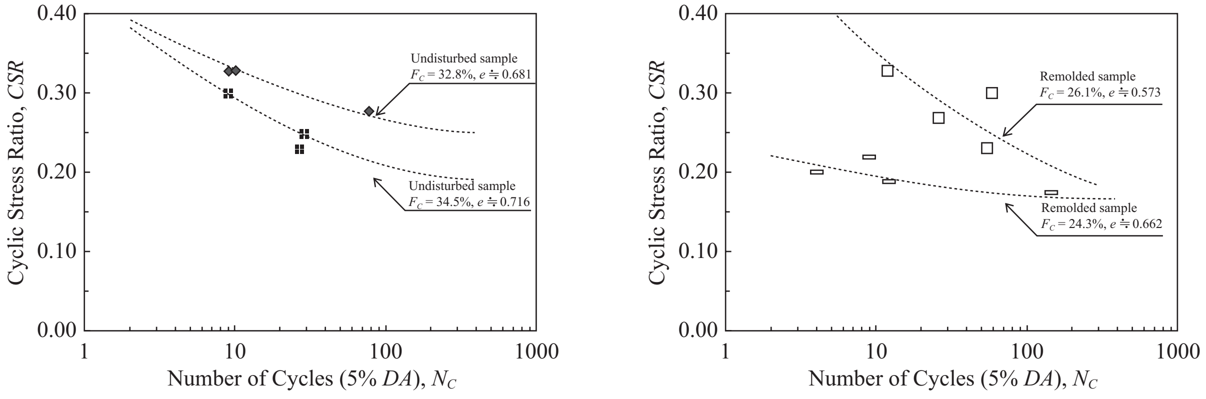
(a) Undisturbed sample *vs*. remolded sample, F_C = 9.5~10.8%, *e* = 0.738~0.762

(b) Undisturbed sample *vs*. remolded sample, F_C = 28.0~29.1%, *e* = 0.699



(c) Fines content effect for undisturbed sample, *e* = 0.716~ 0.738, F_C = 10.8~34.5

(d) Fines content effect for remolded sample, *e* = 0.762~0.789, F_C = 9.5~14.5%



(e) Void ratio effect for undisturbed sample, F_C = 32.8~34.5%, *e* = 0.681~0.716

(f) Void ratio effect for remolded sample, F_C = 24.3~26.1%, *e* = 0.573~0.662

Fig. 13. Results of cyclic triaxial tests under different conditions of samples.

exceeeding 5%. All remolded specimens were formulated to simulate field densities and fines contents obtained from undisturbed specimens. They were prepared using wet damping method to have better control of density and uniform mixture of fines content. During the preparation, fines were well mixed to account for uniform distribution of fines and to simulate total disturbance.

Fig. 12 shows typical test results from cyclic triaxial tests. As shown in the figure, the Gel-Push specimen is with high cyclic resistance and produces larger yielding strain than those of remolded specimen with the similar density and fines content under the same test condition. Results of major cyclic triaxial tests are shown in Fig. 13. Vertical axis is the cyclic stress ratio (*CSR*), $CSR = \sigma_d/\sigma_c'$, and horizontal axis is the number of cycles (N_C). As illustrated in the figure, undisturbed soil specimens have higher cyclic strengths than

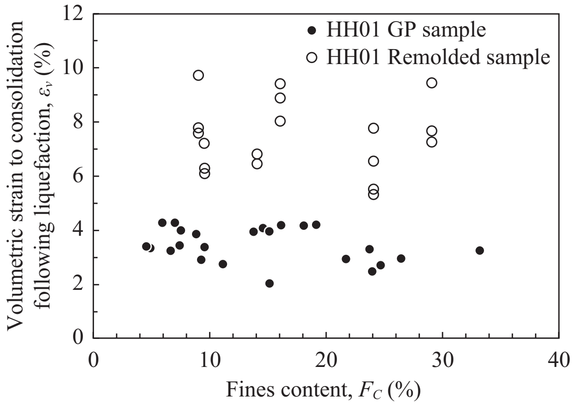


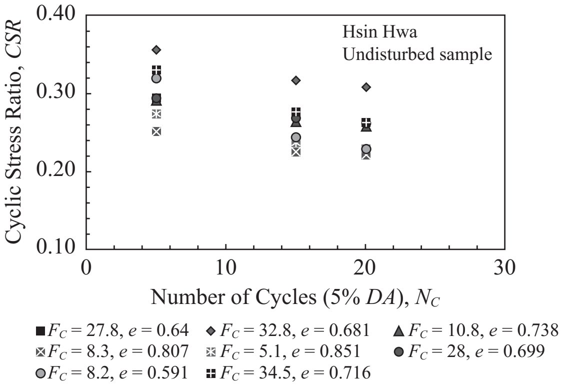
Fig. 14. Test results of post-liquefaction volumetric strains according to various fines contents.

those of remolded specimens with the same fines contents and the similar void ratios (Fig. 13(a) and (b)). Under the same void ratio condition, specimen with higher fines contents tends to have smaller cyclic strength (Fig. 13(c) and (d)). Under the similar fines content condition, specimen with higher void ratio tends to have smaller cyclic strength (Fig. 13(e) and (f)). Phenomenon a mentioned above becomes more noticeable for the remolded specimens.

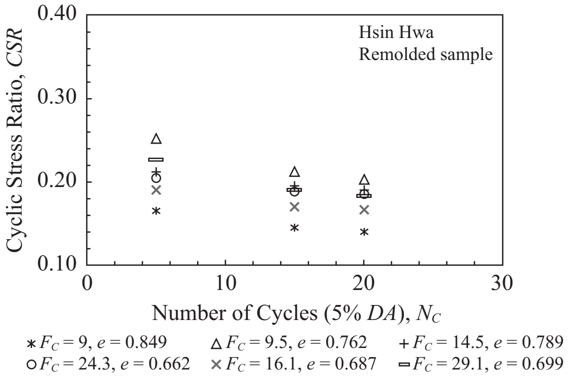
Fig. 14 summarizes test results of post-liquefaction volumetric strains (ε_V), $\varepsilon_V = \Delta V/V_0$, where ΔV is the post-liquefaction volumetric change, according to various fines contents. As shown in the figure, remolded specimens clearly possess larger volumetric strains than undisturbed ones. Volumetric strains of remolded specimens would be as high as 8 to 10%, whereas those of undisturbed specimens remain between 2 to 5%.

V. DICUSSIONS ON ENGINEERING PRACTICES

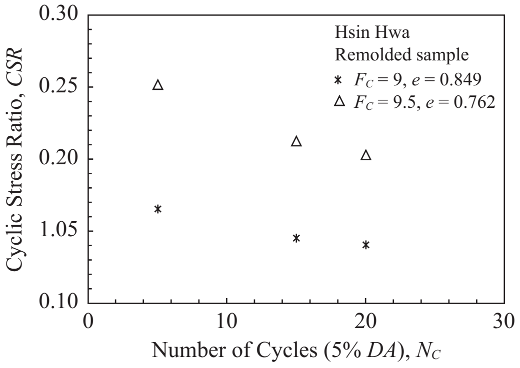
In summary, fines contents and void ratios appear to be the major factors of cyclic stress resistance of the non-plastic silty sand. Fig. 15 summarizes cyclic stress ratios according to 5, 15, and 20 number of cycles of loading for tested specimens. For specimens with similar fines contents, those specimens with higher void ratios have lower cyclic stress ratios (Fig. 15(c)). For specimens with similar void ratios, those specimens with higher fines contents have lower cyclic stress ratios (Fig. 15(d)). Attentions were also paid to the difference between undisturbed specimens and remolded ones. As shown in Fig. 15, undisturbed non-plastic silty sand specimens have cyclic stress ratio distributed from 0.22 to 0.30 when number of cycles equals to 15. However, cyclic stress ratios of remolded specimens with same fines contents and void ratios, distribute from 0.15 to 0.25 under the same cycles of loading. Main reason for such difference would be that microstructures of the undisturbed specimens probably possess better bonding between coarse grains and better particle packing



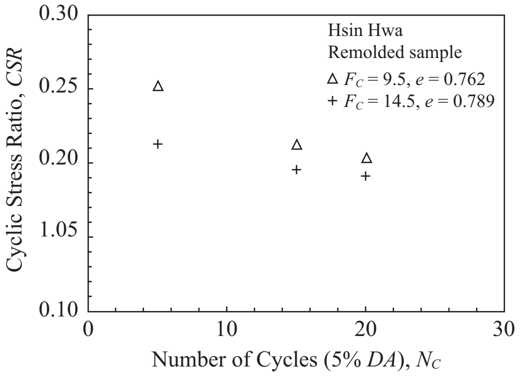
(a) Results of undisturbed samples



(b) Results of remolded samples



(c) Void ratio effect for remolded sample



(d) Fines content effect for remolded sample

Fig. 15. Cyclic stress ratios according to 5, 15, and 20 cycles of loading for undisturbed and remolded specimens.

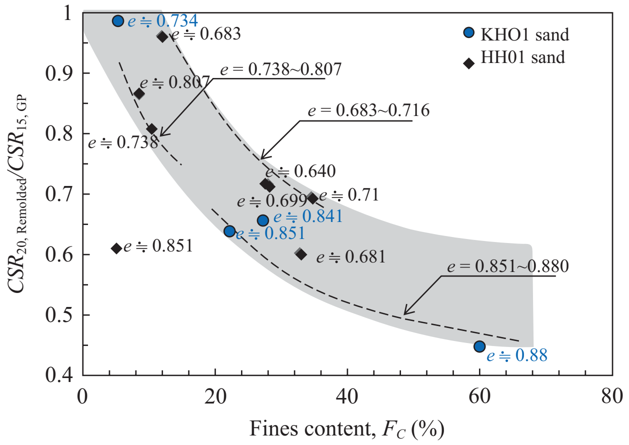
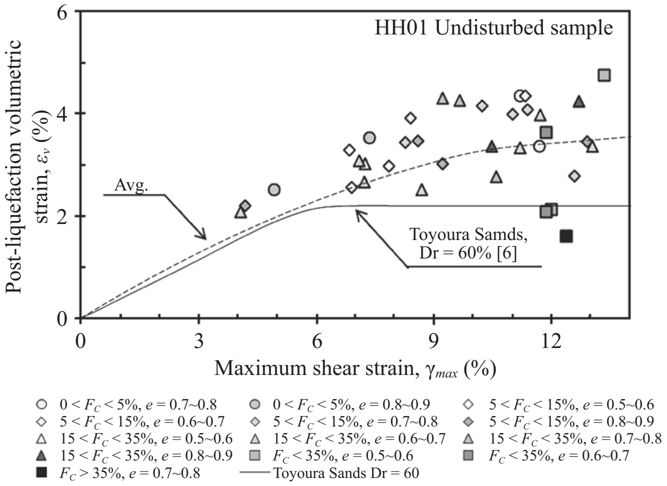


Fig. 16. **Summary of fines content influence and disturbance effects on cyclic stress ratio of non-plastic silty sand.**

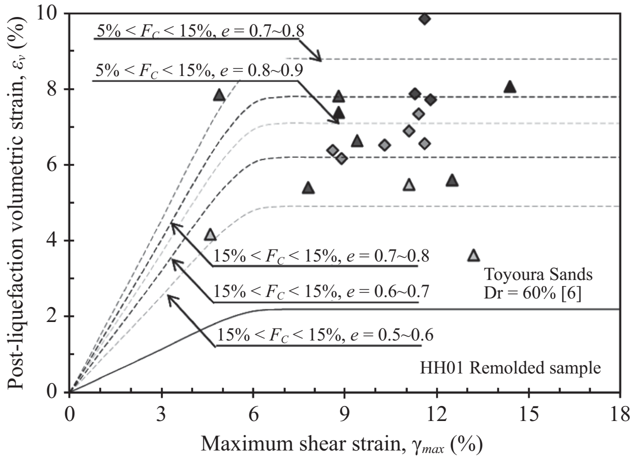
resulting from natural sedimentation and consolidation process. Another possible reason for such differences could be the existence of clay pockets within the undisturbed specimens. These clay pockets within the specimens would probably result in high cyclic stress ratios during laboratory tests, yet they would have less effect on overall liquefaction potential in the field. The clay material was removed when preparing the remolded specimens.

Fig. 16 summarizes both disturbance effect and influence of fines contents on liquefaction resistance for soils tested in this study. Vertical axial of Fig. 16 is the cyclic stress ratio deduction defined as the cyclic stress ratio of remolded specimens divided by those of undisturbed specimens at the same fines contents and void ratio. Horizontal axial of the figure is the fines contents. It was found that higher non-plastic fines content of silty sand would result in larger cycle stress ratio deduction. This trend would become more obvious when fines contents of non-plastic silty sand increased. The disturbance deduction could be as high as 40% for Hsin Hwa silty sand with approximately 25% of fines.

Fig. 17 summarizes relationship between volumetric strain and shear strain of non-plastic silty sand. Vertical axial is the volumetric strain to consolidation following liquefaction (ε_V), and horizontal axial is the maximum amplitude of shear strain (γ_{max}), $\gamma_{max} = 1.5\varepsilon_{d,\,max}$, where $\varepsilon_{d,\,max}$ is the maximum amplitude of axial strain. The post-liquefaction volumetric strain becomes greater as the maximum shear strain increases, and decreases with relative density increases. For the similar relative density, the post-liquefaction volumetric strain of silty sand is higher than clean sand [7], and remolded specimen is higher than undisturbed specimen. The above-mentioned phenomena might be attributed to the fineness and non-plasticity of silty sand particle. Non-plastic fines particle would migrate with excess pore water pressure dissipation at post-liquefaction compression phase. Moreover, the post-liquefaction volumetric strain of undisturbed specimen tends to stay constant as the maximum shear strain exceeds 8%, and it tends to stay constant as the maximum shear strain exceeds 11% for remolded specimen. These phenomena were in connection with the degree of drifting of non-plastic fines particle.



(a) Undisturbed



(b) Remolded

Fig. 17. **Summary of relationships between volumetric strain and shear strain of non-plastic silty sand.**

Fig. 18 summarizes liquefaction resistance of silty sand in Hsin-Hwa comparing to the semi-empirical chart proposed by Youd *et al.* [19], the vertical axial is cyclic resistance ratio (*CRR*), $CRR = \sigma_d/\sigma_c'$, and horizontal axial is corrected blow count $(N_1)_{60}$. In this figure, square and triangle points are cyclic triaxial test results of undisturbed specimens, that were converted into field cyclic resistance ratio by taking the cyclic stress ratios at number of cycle of 15, dotted lines are the research results proposed by Youd *et al.* [19]. This figure shows that some of *CRR* values of silty sand were smaller than Youd *et al.* [19] proposed; it means the method proposed by Youd *et al.* [19] might have overestimated the liquefaction resistance of silty sand.

Furthermore, Fig. 19 represents the analysis results of liquefaction potential of silty sand in Hsin-Hwa area, vertical axial shows sampling depth, and horizontal axial is fines

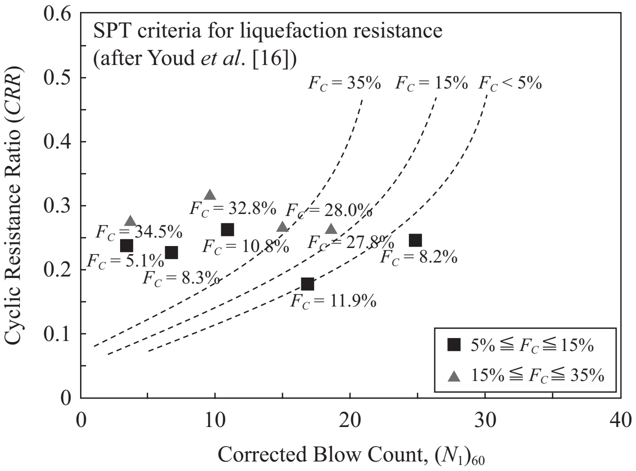
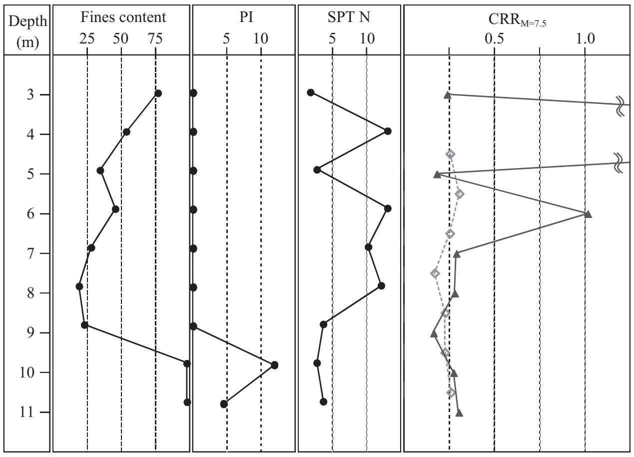


Fig. 18. Results of cyclic resistance ratio versus corrected blow count for non-plastic silty sand.



Note: ● In-situ test result, ▲ CRR value obtained by NJRA, ◇ CRR value obtained by triaxial test

Fig. 19. Cyclic resistance ratio of non-plastic silty sand.

content, plastic index (*PI*), SPT-N value, and the liquefaction resistance under the Richter magnitude (*Mr*) equal to 7.5 respectively. In the figure, triangle symbol shows the analysis results using the NJRA method [8], and diamond symbol indicates results of the cyclic triaxial tests obtains from undisturbed specimens. These *CRR* values were converted into field cyclic resistance ratio by taking the cyclic stress ratios at number of cycle of 20. It indicates that NJRA method [8] would estimate the liquefaction resistance of plastic soil layer accurately, but it overestimates the liquefaction resistance of non-plastic silty sand layer.

VI. CONCLUSION

The Gel-Push technique has been proven to be a better and more reliable sampling measure for retrieving the good quality non-plastic silty sand specimens. The triple tube system and polymer gel lining appear to be able to effectively reduce sampling disturbance due to the wall friction.

Results of cyclic triaxial tests on non-plastic silty sand indicate that, for specimens with the same void ratios, silty sand with higher fines contents tends to have smaller cyclic strength. This phenomenon becomes much more noticeable on the remolded soil specimens. Such non-plastic silty sand deposits have less liquefaction resistance when subjected to disturbance. Traditional assessment method of soil liquefaction would probably overestimate the liquefaction resistance of non-plastic silty sand.

In conclusion, void ratio, fines content, and disturbance effect are recognized as the three major influence factors on liquefaction potential of non-plastic silty sand. In this study, only general trends of effects of these factors were identified. In order to improve the liquefaction evaluation on non-plastic silty sand, more research efforts should be paid to further investigate combined effects of these factors.

REFERENCES

1. Amini, F. and Qi, G. Z., “Liquefaction testing of stratified silty sands,” *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 126, No. 3, pp. 208-217 (2000).
2. Chan, C. K., “An electropneumatic cyclic loading system,” *Geotechnical Testing Journal, ASTM*, Vol. 4, No. 4, pp. 183-187 (1981).
3. Chan, C. K. and Mulilus, J. P., “Pneumatic sinusoidal loading system,” *Journal of the Geotechnical Engineering Division, ASCE*, Vol. 102, No. GT3, pp. 277-282 (1976).
4. Chien, L. K., Oh, Y. N., and Chang, C. H., “Effects of fines content on liquefaction strength and dynamic settlement of reclaimed soil,” *Canadian Geotechnical Journal*, Vol. 39, pp. 254-265 (2002).
5. Cubrinovski, M., Rees, S., and Bowman, E., “Chapter 6: Effects of non-plastic fines on liquefaction resistance of sandy soils,” *Earthquake Engineering in Europe*, Springer, pp. 125-144 (2010).
6. Huang, A. B., Chang, J. W., Ho, Y. C., and Ye, C. Z., “Engineering properties of the Yunlin Mailiao silty fine sand,” *Sino-Geotechnics*, Vol. 67, pp. 66-68 (2007). (in Chinese)
7. Ishihara, K. and Yoshimine, M., “Evaluation of settlements in sand deposits following liquefactions during earthquake,” *Soils and Foundation*, Vol. 32, No. 1, pp. 173-188 (1992).
8. Japan Road Association, *Specifications for Highway Bridges: Part 5 Seismic Design*, pp. 132-149 (2002).
9. Kuerbis, R., Nequeeey, D., and Vaid, Y. P., “Effect gradation and fines content on the undrained response of sand,” *Geotechnical Special Publication*, No. 21, pp. 330-345 (1988).
10. Lee, W. F. (Editors), *The Complement the Geological Survey and Soil Tests of Kaohsiung MRT Orange Line CO1-Section SUO01 Station*, Assessment Report, Taiwan Construction Research Institute, Taipei, Taiwan (2007). (in Chinese)
11. Lin, C. W., *The Influence of Non-Plastic Fines on Liquefaction Resistance of Sandy Soils*, Master Thesis, Graduate Institute of Civil Engineering, National Cheng Kung University, Tainan, Taiwan (2006). (in Chinese)
12. Papadopoulou, A. and Tika, T., “I The effect of fines on critical state and liquefaction resistance characteristics of non-plastic silty sands,” *Soils and Foundations*, Vol. 48, No. 5, pp. 713-725 (2008).
13. Polito, C. P. and Martin, J. R., “Effects of nonplastic fines on the liquefaction resistance of sands,” *Journal of Geotech Geoenviron Engineering*, Vol. 127, No. 5, pp. 408-415 (2001).
14. Thevanayagam, S., “Effect of fines and confining stress on undrained shear strength of silty sands,” *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 124. pp. 479-491 (1998).
15. Thevanayagam, S., “Liquefaction potential and undrained fragility of

silty soils," *Proceedings of the 12th World Conference on Earthquake Engineering*, Auckland, New Zealand, Paper 2383 (2000).

16. Ueng, T. S., Sun, C. W., and Chen, C. W., "Definition of fines and liquefaction resistance of Mulou River soil," *Soil Dynamic Earthquake Engineering*, Vol. 24, pp. 745-750 (2004).
17. Vaid, Y. P., "Liquefaction of silty soils," *Ground Failures under Seismic Conditions, Geotechnical Special Publication*, No. 44, pp. 1-16 (1994).
18. Xenaki, V. C. and Athanasopoulos, G. A., "Liquefaction resistance of sand-silt mixtures: an experimental investigation of the effects of fines," *Soil Dynamic Earthquake Engineering*, Vol. 23, pp. 183-194 (2003).
19. Youd, T. L. and Idriss, I. M., (Editors), "Summary report," *Proceeding of the NCEER Workshop on Evaluation of Liquefaction Resistance of Soils*, Buffalo, pp. 1-41 (1996).
20. Yu, C. H., *The Influence of Low Plastic Fines on Dynamic Properties of Silty Sands*, (in Chinese), Master Thesis, Graduate Institute of Civil Engineering, National Cheng Kung University, Tainan, Taiwan (2007).