Permeation of Ultra-Fine Particle Cement Grout into Sandy Ground

Yasuyuki Nabeshima
National Institute of Technology, Akashi College/Civil Engineering, Akashi, Japan
Email: nabesima@akashi.ac.jp

***Abstract*— This paper describes study on permeation of ultra-fine particle cement grout into sandy ground. The cement grouting method was one of the improvement methods to strengthen the sandy ground. However, the conventional cement grout was difficult to permeate into sandy ground. The purpose of this study is to clarify the permeation of the ultra-fine particle cement grout into dry and saturated sands. The author conducted both column and model ground injection tests to examine the permeability of ultra-fine particle cement grout. As a result, ultra-fine cement grout had high permeability against finer sand regardless of dry and/or saturated conditions and the stabilized area was wider.**

***Index Terms*—ultra-fine particle cement, ground improvement, cement stabilization method, sandy ground, penetration behavior**

I. Introduction

Large liquefaction disasters were reported in recent big earthquakes such as, the 2011 Tohoku earthquake (Bhattacharya et al., [1]) and the 2018 Hokkaido Iburitobu earthquake (Serikawa et al., [2]). In the liquefaction disasters, many houses were damaged due to the unequal settlement and the lateral slide of ground. Large area ground improvement was carried out in Urayasu city after the 2011 Tohoku earthquake to restore the damaged ground (Sato, [3]). The cost of ground improvement is too expensive for the personal expense. Therefore, the effective and economical ground improvement techniques were eager to develop.

The cement grouting method is one of the ground improvement methods, the injectability of cement grout is restricted by the size of voids in sandy soil because the grout material contains particles of cement. Ultra-fine particle cement is one of the grout materials that permeates well into sandy ground and has excellent strength. Although the ultra-fine particle cement has the smaller particle size than that of normal Portland cement, its permeation behavior and the shape of the cemented mass in the ground are unknown. Therefore, in this study, the author carried out a series of column penetration tests and small size injection tests into the sandy model ground. The permeation behaviors of ultra-fine particle cement and the shape of cemented mass are compared with different size of sandy ground.

Manuscript received November 23, 2020; revised March 3, 2021; accepted May 8, 2021.

II. Permeation of Ultra-Fine Particle Cement Grount

A. Cement Grouting

Cement grouting fills cracks or voids in soil and rock, and permeates granular soils to create a cemented mass as shown in Fig. 1. The popular uses of cement grouting were to create barriers to groundwater flow, underpin foundations, provide excavation support, stabilize and strengthen sandy soils. The cement grouting was also known as slurry grouting, it fills voids in sandy soils with flowable cement grouts. The grout particle size of cement grout and void size of soil must be matched properly to allow the cement grout to permeate (see in Fig. 1(b)). Depending on the ground conditions, normal Portland cement or fine cement grout is injected under pressure at strategic locations. The cemented soil mass has a high strength/stiffness and reduced permeability.

Cement grouting sometimes has an economic advantage for underpinning applications over alternative approaches such as removal and replacement or piling, and it can be applied in cases of difficult access and limited spaces. The cement grouting is expected as the liquefaction countermeasure (Gallagher and Mitchell, [4]). Since the effectiveness of cement grouting is independent of structural connections, this technique is readily adaptable to existing foundations of buildings and can typically be accomplished without disrupting underground installations. Also, the cement grouting is applicable for the living houses without removal and relocation works. Therefore, the cement grouting is expected as the liquefaction countermeasure for personal houses, because of the low cost and the high applicability.

B. Ultra-Fine Particle Cements

In this study, two types of cements, normal particle size cement (average particle size bigger than 10 μm) and ultra-fine particle cement (average particle size 1.5 μm), were used to compare the penetration performance due to the difference in cement particle size. Fig. 2 shows electron microscope photographs of particle size of normal Portland, fine particle and ultra-fine particle cements. The average particle size of normal Portland cement is from 10 to 20 μm. In Japan, there is no specific classification of cement types by particle size, but cement with an average particle size of about 8 μm is often used

doi: 10.18178/ijscer.10.3.92-97

as fine particle cement, and cement with an average particle size of about 4 μm or less is often used as ultra-fine particle cement.

There are few practical examples of ground improvement using ultra-fine particle cement for the sandy ground (Koizumi et al., [5]), and the advantage of ultra-fine particle cement was that it can penetrate even small cracks (Yoneda et al., [6], [7]). The main use cases are water sealing material in tunnels, ground reinforcement, and various grouting materials for dams. The injectability of the cement grout into the sandy ground has been dramatically improved by the development of a cement with a small particle size such as ultra-fine particle cement. Since the ultra-fine particle cement grout can inject into small void, the application range of cement grout has been expanded, and it has become possible to apply to the ground containing fine sandy ground.

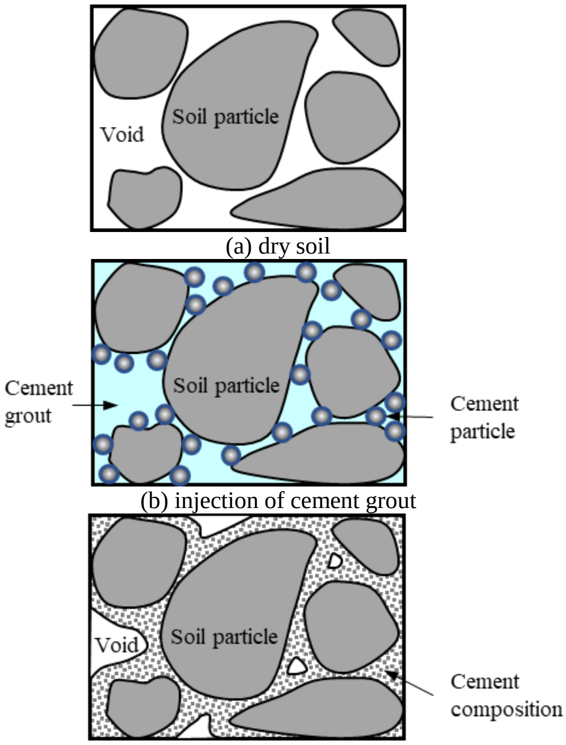
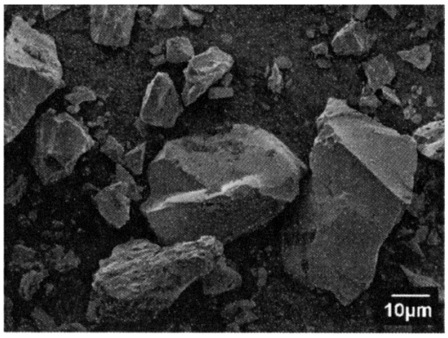


Figure 1. Cement grouting into sandy soil.

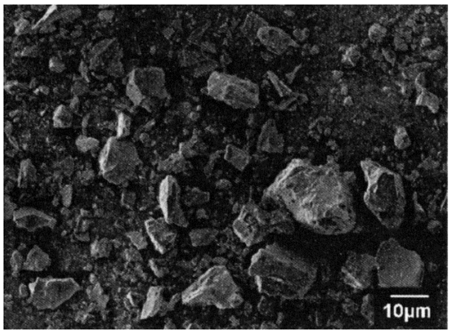
III. Column Permeation Tests

A. Test Conditions of Dry Model Sand

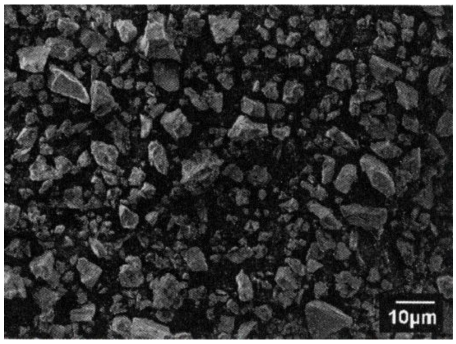
A series of column permeation tests were carried out to compare the permeation depth of cement grouts with different size of cements such as normal Portland cement and ultra-fine particle cement. The column, which has 50 mm in inner diameter and 500 mm in length, was made of acrylic cylinder. The model dry sands of 500 g were filled in the column, by the air pluviation method with filter coarse sand as shown in Fig. 3.



(a) Normal Portland cement



(b) Fine particle cement



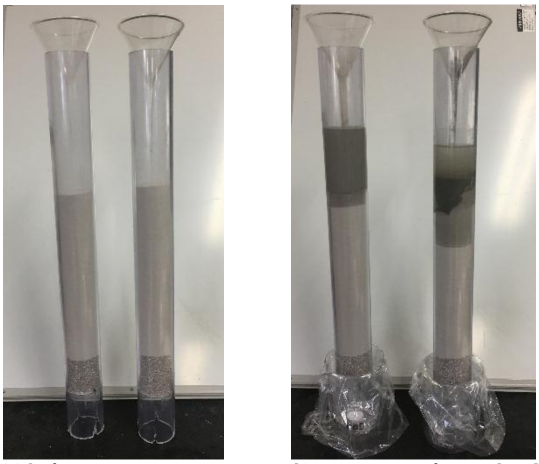
(c) Ultra-fine particle cement

Figure 2. Particle size of normal Portland, fine particle and ultra-fine particle cements.

The length of model sand was about 25 cm in the column, therefore, the density of model sand was almost equal in the all column permeation tests. The average particle size of model sands was listed in Table I. Four kinds of silica sands with different particle size were used in this study. The water-cement ratio of the cement grout was 800%. Normal Portland cement and ultra-fine particle cement were compared in the column permeation tests. The 1.5% cement dispersant was used in the cement grout. Many kinds of cement dispersants were proposed, the polycarboxylic acid type cement dispersant was employed in this study according to the preliminary experiment result. Cement, water and cement dispersant were mixed by the hand-mixer for 180 seconds with high speed. The cement grout was permeated from the top of column into dry sand without air pressure as shown in Fig. 3. The permeation depth of cement grout was measured by the liner scale with elapsed time, judging from the front of the cement grout permeation. After the column permeation tests, the cemented sand mass was observed.

TABLE I. AVERAGE PARTICLE SIZE OF MODEL SANDS

Sand	Average particle size (mm)	Porosity (%)
Silica sand No.6	0.32	51.6
Silica sand No.7	0.18	52.8
Silica sand No.8	0.11	55.2
Silica sand No.9	0.03	59.3
Filter coarse sand	0.90	44.9



(a) before penetration test

(b) penetration of normal and ultra-fine particle cements

Figure 3. Column permeation tests for dry sands.

B. Test Conditions of Saturated Model Sand

Another series of column permeation tests were carried out for the saturated model sand. The ultra-fine particle cement grout is expected as one of the useful countermeasures for the liquefaction of sandy ground. The permeation behavior of the ultra-fine particle cement grout into the saturated sand was investigated. First, a basic saturation method was adopted as shown in Fig. 4. The columns which were filled by dry silica sand No.6 were set in the water tank and saturated by increasing water depth gradually. The water level was kept in the equal height with the top of sand model for 90 minutes.

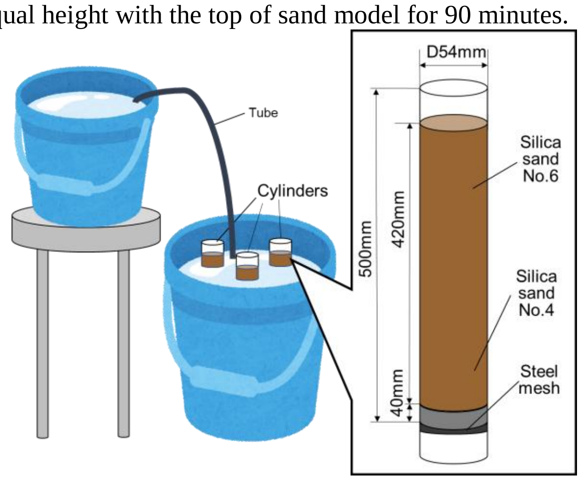


Figure 4. Saturation method of sand model.

In this saturation method, it was confirmed that the degree of saturation of model sand was almost 100 %. After the saturation, the column with saturated sand was closed up by the plates and sealed by silicon rubber as shown in Fig. 5. The ultra-fine particle cement grout with the water-cement ratio of 800% was horizontally permeated into the saturated sand from a constant height as shown in Fig. 6. The permeation distance of cement grout was measured by the liner scale with elapsed time. After the column permeation tests, the soil hardness of the cemented sand mass was measured by a portable soil hardness tester as shown in Fig. 7. The soil hardness was evaluated by the penetration resistance of the cone of the tester.

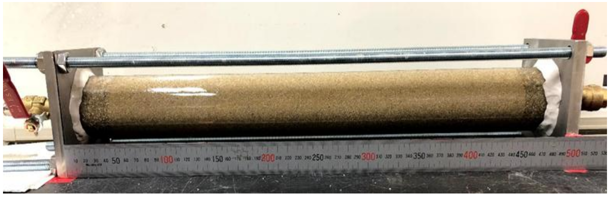


Figure 5. Column with saturated sand.

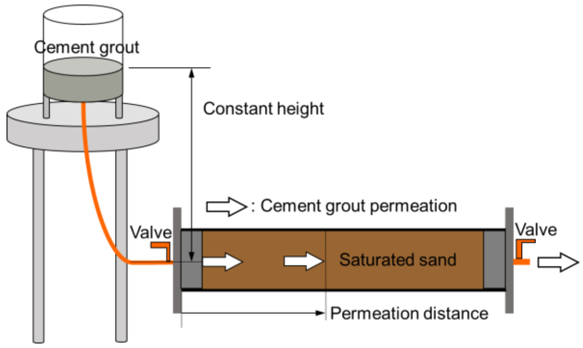


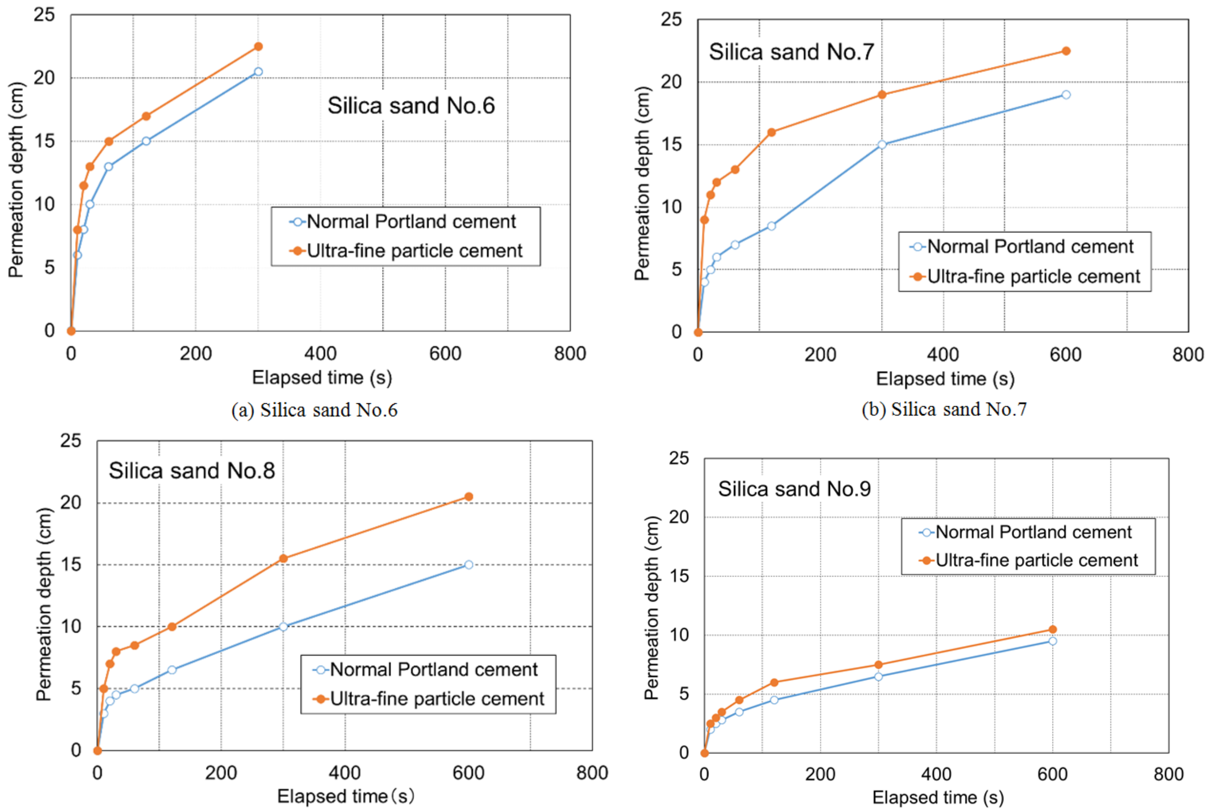
Figure 6. Column permeation test for saturated sand.

Figure 7. Portable soil hardness tester.

IV. TEST RESULTS OF COLUMN PERMEATION TESTS

A. Test Results for Dry Sand

Fig. 8 shows the permeation depth with elapsed time for different sands. Very fast permeation behaviors can be observed in silica sand No.6 as shown in Fig. 8(a). Even normal Portland cement could permeate 20cm into model sand with 300 seconds, ultra-fine particle cement could permeate at the end of model sand in the same time. It was because that the void of silica sand No.6 was very large. The difference of permeation behaviors between normal Portland cement and ultra-fine particle cement was not so larger. The difference of permeation behaviors between normal Portland cement and ultra-fine particle cement was clear in silica sand No.7 and No.8 as shown in Figs. 8(b) and 8(c). The permeation of ultra-fine particle cement was faster than that of normal Portland cement. In cases of normal Portland cement, the bleeding of cement grout, which was the separation of cement and water, was observed. Although the difference of permeation behaviors between normal Portland cement and ultra-fine particle cement was small in Fig. 8(d), the permeation of ultra-fine particle cement is faster than that of normal Portland cement. The void of silica sand No.9 was too small to permeate cement grout into model ground. Therefore, the permeation behavior of ultra-fine particle cement depends on void size of sand. In this test cases, the difference of permeation behavior of normal Portland and ultra-fine particle cements clearly appeared in silica sands No.7 and No.8. Consequently, ultra-fine cement grout had high permeability against finer sand and the stabilized area was wider.



(a) Silica sand No.6

(b) Silica sand No.7

(c) Silica sand No.8

(d) Silica sand No.9

Figure 8. Cement grout permeation test results into dry sands

Fig. 9 shows the cemented sand mass after column permeation test of the ultra-fine particle cement. As shown in this figure, the cemented sand mass was well stabilized by the ultra-fine particle cement. The ultra-fine particle cement uniformly permeated fine sand. The specimen for unconfined compression test, which has 3.5cm in diameter and 9cm in height, could be made from the cemented sand mass in cases of silica sand No.7. The unconfined compression strength of cemented sand after 7days was 488.3kN/m^2. The specimen could not be trimmed from the column test of the normal Portland cement because the continuous cemented sand mass as shown in Fig. 9 could not made. Since the unconfined compression strength of cemented sand by fine particle cement was 429.5kN/m^2 in comparative study, the strength of the cemented sand by ultra-fine particle cement was estimated higher than that of normal Portland cement.

Figure 9. Cemented sand mass after column permeation test.

B. *Test Results for Saturated Sand*

Silica sand No.6 was used in this test because the permeability was the best among the permeation tests of dry sands as shown in Fig. 8. The permeation tests for the saturated sand finished in a few minutes because the cement grout could not permeate. It was because that the cement grout was clogged in the saturated sand.

The soil hardness was measured by the portable soil hardness tester, which was shown in Fig. 7, at 4, 10, 16, 22, 28, 34, 40 cm of permeation distance. The soil hardness was measured at 5 points in one cross section at every permeation distance. Figure 10 shows an average value of the soil hardness measured at five points with red line and maximum and minimum values of the soil hardness at every permeation distance with black line. Average values of the soil hardness decreased as the permeation distance increased. Also, the difference between maximum and minimum values increased as the the permeation distance increased. The phenomenon was assumed that the ununiform permeation of the cement grout occurred in the saturated sand. Figure 11 shows the cross section at 4, 10, 16, 22, 28, 34, 40 cm of permeation distance in the column test for the saturated sand. The color of every cross sections gradually changed from bluish-gray to brownish-gray as the permeation distance increased. The bluish-gray color showed the cement grout homogenously penetrated into saturated sand and the brownish-gray showed the cement grout unequally penetrated into saturated sand. From this figure, the phenomenon in Fig. 10 could be explained.

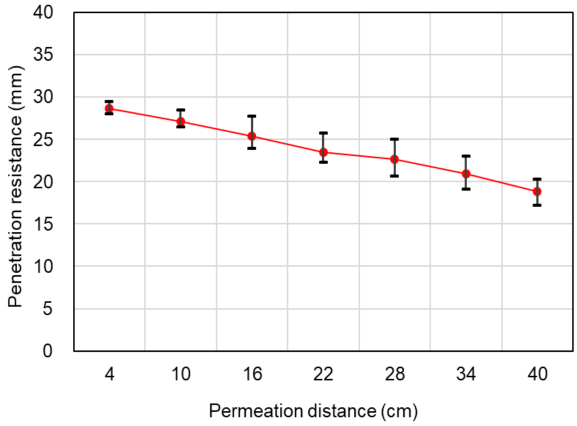


Figure 10. Soil hardness of cemented sand.

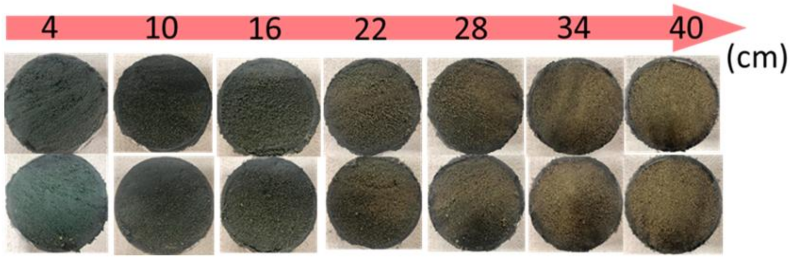


Figure 11. Cement grout permeation test results into saturated sand.

V. Conclusion

In this study, the author carried out a series of column penetration tests into dry and saturated sandy model ground. The permeation behaviors of ultra-fine particle cement grout are compared with different size of sandy ground and under dry and saturated conditions.

1) Ultra-fine cement grout had high permeability against finer sand and the stabilized area was wide under dry sand condition.
2) Strength of the dry sands improved by ultra-fine particle cement was higher than that by normal Portland cement.
3) The cement grout of ultra-fine particle cements was rapidly permeated into the dry sand, rather than the saturated sand.
4) The soil hardness of the cemented sand decreased as the permeation distance increased in the saturated sand. It was because of the ununiform permeation of the cement grout.
5) Ununiform permeation of the cement grout was observed by the color difference between cross sections in the column test for the saturated sand.

Conflict of Interest

Ultra-fine particle cement was provided by Nippon Steel Cement Co., Ltd., however, there are no conflict of interest with this company.

Author Contributions

The author conducted all experimental research works and approved the final version.

Acknowledgment

Ultra-fine particle cement was provided by Nippon Steel Cement Co., Ltd. Also, this corporation offers many references and important information about ultra-fine particle cement. This research work was financially supported by Grant-in-Aid for Scientific Research (C) No. 19k04609. Author expressed the profound gratitude for these supports.

References

[1] S. Bhattacharya, M. Hyodo, K. Goda, T. Tazoh, and A. C. Taylor, “Liquefaction of soil in the Tokyo Bay area from the 2011 Tohoku (Japan) earthquake,” *Soil Dynamics and Earthquake Engineering*, vol. 31, no. 11, pp. 1618-1628, 2011.

[2] Y. Serikawa, M. Miyajima, M. Yoshida, and K. Matsuno, “Inclination of houses induced by liquefaction in the 2018 Hokkaido Iburitobu earthquake, Japan,” *Geoenvironmental Disasters*, 2019.

[3] T. Sato, “Urayasu city liquefaction countermeasure project,” *Technical Report of Pacific Consultants*, pp. 1-4, 2017.

[4] P. M. Gallagher and J. K. Mitchell, “Influence of colloidal silica grout on liquefaction potential and cyclic undrained behavior of loose sand,” *Soil Dynamics and Earthquake Engineering*, vol. 22, no. 9, pp. 1017-1026, 2002.

[5] Y. Koizumi, T. Tanaka, J. Takeuchi, T. Kanazawa, and M. Nishigaki, "Development of grouting method of fine sand with ultrafine cement grout," *J Society of Material Science*, vol. 61, no. 1, pp. 52-57. (in Japanese), 2012.

[6] S. Yoneda, H. Kojo, Y. Terado, and K. Nakagawa, "Some penetrative behavior of cement suspension grout in fissured rock mass," *J Japan Society of Civil Engineers*, 480(VI-21), pp. 63-66. (in Japanese), 1993.

[7] S. Yoneda and K. Nakagawa, "Basic properties and penetration of cement suspension grouts with different grain sizes," *J Japan Society of Civil Engineers*, 462(VI-18), 101-110. (in Japanese), 1993.

Y. Nabeshima was born in Japan in 1965. He got B.Sc. in 1988, M.Sc in 1990 and Ph.D. in Civil Engineering, Osaka University, Japan in 1997. He was a research associate and an assistant professor in department of civil engineering, Osaka University from 1994 to 2006. He moved to National Institute of Technology, Akashi College. Now, he is a professor in department of civil engineering. His research area is in the ground improvement techniques for the liquefaction of sandy ground and countermeasures for the liquefaction. He has many scientific publications about soil mechanics and geo-environmental engineering.