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Research Paper

Study on effects of specimen size of unconfined compressive strength of improved soil

T. Himeno [1], K. Takatani [2], T. Hino [3], S. Mandhar [4] and S. Shrestha [5]

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ABSTRACT

Deep mixing method (DMM) is one of the countermeasures for long-term stability of the soft ground area, specifically highly applicable in coastal lowland. With the economic growth in ASEAN countries, this technology has become more popular in order to develop stable infrastructures through mega projects.

In this paper, discussions are carried out through conducted laboratory mixing tests by where samples were extracted from the site in order to maintain the quality of soil-cement column by using DMM based on designed methodology. In Japan, samples are extracted continuously from the vertical direction using a thin-walled sampler. It can be connected from considering characteristics of strength development of each depth grouped into three sections from the tube into upper, middle and lower portions. However, the case of non-uniformity and the total amount of sample taken from the site is not enough, there will be the possibility to encounter a difficult situation to conduct laboratory mixing test using standard specimen size of D 50 mm × H 100 mm. Therefore, the characteristics of strengths appeared in the standard size of D 50 mm × H 100 mm laboratory mixing test is compared and discussed with newly defined laboratory test of specimen size D 25 mm × H 50 mm.

1. Introduction

Deep mixing method (DMM) is one of the countermeasure for long-term stability of the soft ground area, specifically highly applicable in coastal lowland. With the economic growth in ASEAN countries, this technology has become more popular in order to develop stable infrastructures through mega projects. Thus it is imperative to understand the strengths of the DMM column in the laboratory and their size effects carefully.

Our laboratory researched about quality and quantity of soil cement column using DMM. In Japan, samples are extracted continuously from the vertical direction by using the thin-walled sampler. It can be connected from considering characteristics of strength development of each depth grouped into three sections from the tube into upper, middle and lower parts. Samples were collected from the site and conducted laboratory tests in order to ensure the quality of the soil cement column by the designed DMM. Since the amount of samples collected from the site in not enough, it will be difficult to conduct

[1] Doctoral student, Course of Environmental Science and Engineering, Graduate School of Science and Engineering, Saga University, Honjo 1, Saga, JAPAN, 16634010@edu.cc.saga-u.ac.jp
[2] Former under graduate student, Department of Civil Engineering and Architecture, Faculty of Science and Engineering, Saga University, Honjo 1, Saga, JAPAN.
[3] Deputy Director, Prof., Institute of Lowland and Marine Research, Saga University, Honjo 1, Saga, JAPAN.
[4] Head of Department, Assoc. Prof., Department of Disaster Risk Engineering and Management, Lumbini International Academy of Science and Technology, Lumbini Buddhist University, Lalitpur, NEPAL.
[5] Lecturer (Research Fellow), Institute of Lowland and Marine Research, Saga University, Honjo 1, Saga, JAPAN.
Note: Discussion on this paper is open until September 2019

Table. 1 Basic physical and chemical properties of sample

Water content (%)	167.1	ORP(mV)	-158
Density of particle ρ_s(g/cm³)	2.573	Ignition loss L_i (%)	11.3
Liquidity Limit, w_L(%)	137.1	Coarse sand (%)	1.0
Plastic Limit, w_p(%)	55.5	Medium sand (%)	2.2
Plasticity Index, I_p	81.6	Fine sand (%)	5.4
Salt concentration (%)	0.46	Silt (%)	17.2
Electric conductivity (mS/cm)	10.1	Clay (%)	74.2
pH	7.22	Activity A	1.10

necessary laboratory tests in the previously designed standard for detail investigation.

This is the reason why the miniaturization of specimen using laboratory mixing test was performed (Yamamoto and Miyake, 1982; Hayashi et al., 1997; Shogaki, 2012) The characteristics of strengths appeared in the standard size of D 50 mm × H 100 mm laboratory mixing test was compared and discussed with newly defined laboratory test of specimen size of D 25 mm × H 50 mm in this paper.

2. Previous researches

The research on the effects of specimen size on the strength characteristics of ground materials has a quite long history. Several studies on the size effects of improved soil have also been carried out.

The specimen shape and size influence the unconfined compression characteristics to natural sedimentary ground material.

According to Shogaki (Shogaki, 2012), it is advantageous to use smaller sized specimens to conduct necessary laboratory tests for design purpose because the total amount of the samples extracted from the site are insufficient on account of possibilities of presence of numerous cracks and develop heterogeneity. In addition, q_u and E_{50} of specimens size of D 15 mm × H 35 mm are equivalent to those of specimens size of D 35 × H 80 mm, and there is no superiority based on research results.

According to Yamamoto et al. (Yamamoto and Miyake, 1982), it is presumed that the compressive strength and Young's modulus will change with the change in specimen size even with the same improved soil when the specimen volume is changed with constant aspect ratio (h / d ≒ 2) was conducted. Based on this result, as the size of the specimen increased, the value of q_u became smaller and the value of E_{50} had a tendency to become larger. In addition, the progress of the strain obtained by the strain gauge attached to each specimen almost corresponded to the average strain, however, it is confirmed that the strain on the shear surface increases rapidly and the other face recovers just before the destruction.

3. Perspectives of laboratory mixing tests from design to construction

Amidst several countermeasures, DMM is one of the reliable techniques along the coastal lowlands. In the design and construction of the DMM of Japan, at first, samples are extracted through in the vertical direction by continuous sampling using a thin wall sampler. The obtained sample in the thin wall sampler is used for the required soil test at each depth with partitioning into three parts of upper, middle, and lower sections of the same specimen. In order to determine the soil layer that represents the improvement ground by grasping the results of the soil test and the geological composition. Afterwards, the characteristics of strength development were considered by laboratory mixing test and unconfined compression test (JIS A 1216 [4]) followed by JGS 0821-2009 [5]. Then the type and the amount of cement content for the soil-cement column were determined to satisfy the required strength. The formulation design determined by this laboratory mixing test also has an important meaning in terms of quality control at the site. Troubles on the site are prevented by estimating formulation design using the strength of laboratory mixing test qul and the strength of site quf after construction are set for the safety factor that the intensity ratio is considered in advance as, q_{uf} = (1 to 1/3) q_{ul} [6].

4. Experimental method

In the case of a specimen size of D 50 mm × H 100 mm which is widely used in improved soil specimens, it is necessary to use a soil sample having a maximum particle size of 9.5 mm or less. Furthermore, when prepared the smaller sized specimens, the particle size is set to be 1/5 or less of the diameter of the specimen (The Japanese Geotechnical Society, 2009). In this research, cohesive soil which had been sieved with a sieve of 2 mm in advance was used as a sample. This cohesive soil was collected from the Rokkaku River which is merging into the Ariake Sea Coastal Lowland,

and it is the natural state of water content. Table.1 shows the physical properties of the sample.

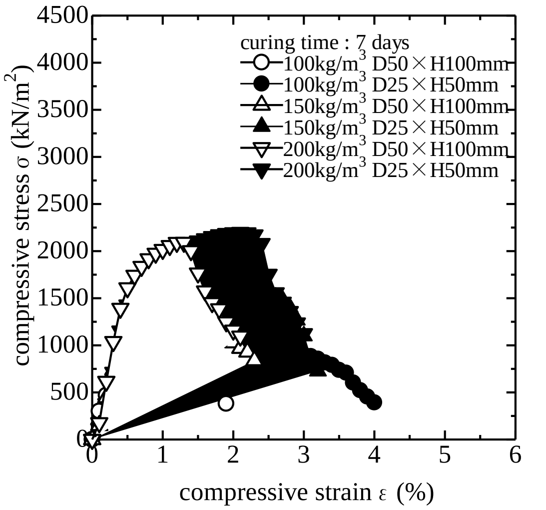

Fig. 1. Stress-strain curve of 7-days

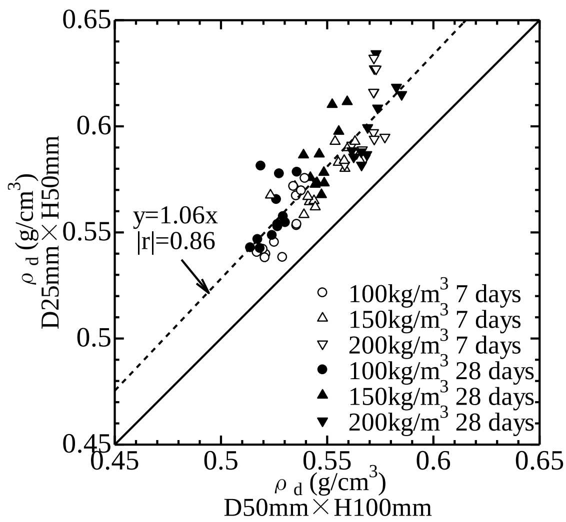

Fig. 2. Comparison of the ρ_d

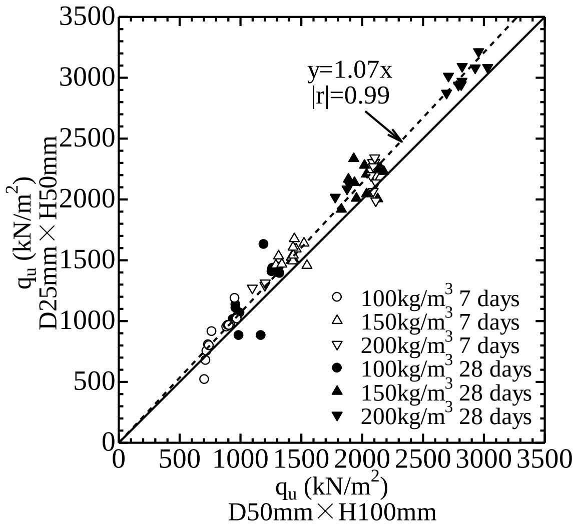

Fig. 3. Comparison of q_u

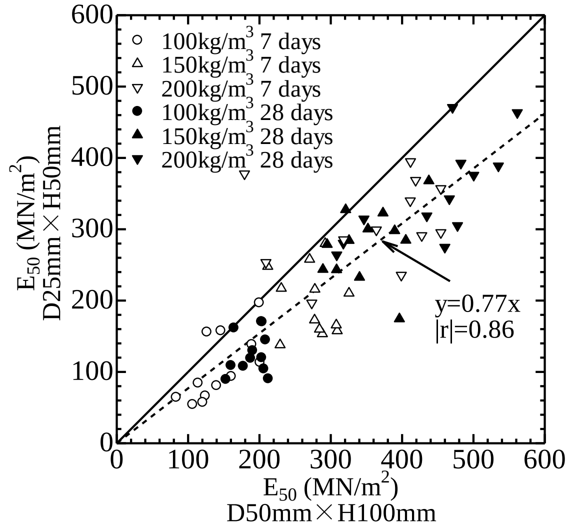

Fig.4. Comparison of E_{50}

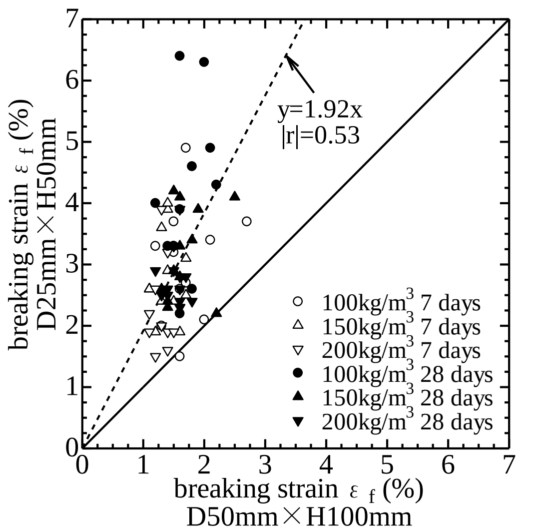

Fig. 5. Comparison of breaking strain ε_f

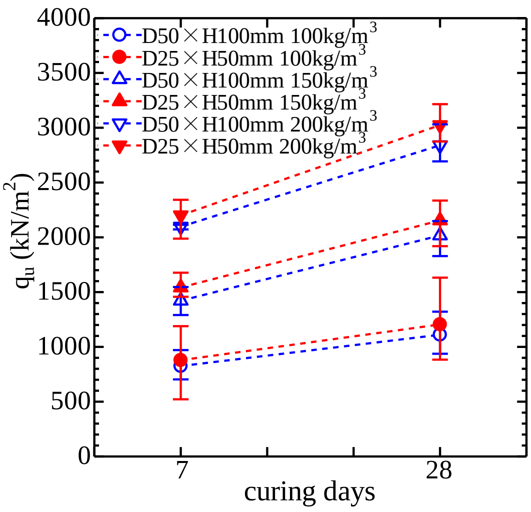

Fig. 6. Characteristics of strength development

The method for making specimens was conducted in accordance with JGS 0821-2009 (The Japanese Geotechnical Society, 2009). In order to investigate the influence of difference in size of specimen on unconfined compression strength, standardized D 50 mm × H 100 mm (h / d = 2) specimen (hereinafter referred to as O-specimen (ordinary specimen) (Shogaki, 2012) and miniaturized D 25 mm × H 50 mm (H / D = 2) specimen (hereinafter referred to as S-specimen (small specimen) [3]. A commercially available plastic molds were used for the former and a vinyl chloride pipes adjusted to the size of D 25 mm × H 50 mm were used for the latter. Each mold was filled with cement mixed soil by tapping method. For the solidified material, hexavalent chromium-less cementitious solidification material was used in a slurry state with water cement ratio W/C = 1.0 and mixed for 10 minutes using a soil mixer. Three specimens were prepared under the conditions of mixing amount of cement content 100 kg/m^3, 150 kg/m^3 and 200 kg/m^3 with curing days of 7 days and 28 days respectively. After that specimens were cured in thermostatic chamber room and conducted unconfined compression tests.

Moreover, specimens were made with using ceramic materials in order to investigate the influence of the particle size composition of the sample on the unconfined compression strength. In order to investigate the influence of the particle size composition, laboratory mixing tests were conducted at a ratio of cohesive soil and ceramic materials at a ratio of 7:3, 6:4, 5:5, 4:6 (cohesive soil:ceramic materials). For the solidified material and water cement ratio were the same as those in the above experiment. Also, the amount of the cement content was 150 kg/m^3 and O-specimens and S-specimens were made 3 times under conditions cured for 7 days and 28 days respectively.

5. Results

Figure 1 shows one of the results of the stress-strain curve of 7-days curing of the unconfined compression test with the size difference specimens. At each amount of cement mixing quantity, the S specimens show slightly higher unconfined compression strength q_u than the O-specimens. Also, the breaking strain ε_f of the S-specimens shows higher than the O-specimens and the value of S-specimens show a tendency to decrease with increase of the unconfined compression strength accompanying the amount of the cement content. This tendency is confirmed to be the same in the 7-day curing and 28-day curing specimens.

Figure 2 shows the comparison of the dry density ρd with the difference in size of the specimens. The slope of the straight line of the ρ_d group shows 1.06, which is slightly higher for the S-specimens but it can be said that the homogeneity could be maintained regardless of the size of the specimens.

Figure 3 shows a comparison of unconfined compression strength q_u with the size difference specimens. The slope of approximate straight line of the qu plots group is obtained 1.07. It's confirm that the q_u value of S-specimen slightly higher than O-specimen. Even from this viewpoint of view, almost equal results were obtained regardless of the size of the specimen.

On the other hand, Figure 4 shows a comparison of the Young's modulus E_{50} with the size difference specimens. The slope of the straight line of the E_{50} group shows 0.77, indicating that E_{50} of the S-specimens is lower.

Figure 5 shows the result of breaking strain εf. The value of S specimens is 1.92 which is larger than O-specimens. Figure 6 shows the characteristics of strength development of unconfined compression strength with curing days. The strength development of the unconfined compression strength qu obtained 1.3 times to 1.4 times uniformly for each amount of cement content.

Figure 7 shows one of the stress-strain curves of the specimens made by mixing cohesive soil and the ceramic material with the compounding ratio set at 7:3. Figure 8 also shows a comparison of q_u with the size difference specimens prepared by using the same methodology. In **Fig. 7**, the unconfined compression strength q_u and the breaking strain εf show the same tendency as the stress-strain curve in the case of specimens prepared using only cohesive soil as shown in **Fig. 1**. In **Fig. 8**, the slope of the qu group shows 0.96 which is slightly higher in the O-specimens than the S-specimens, but nearly equal results are obtained regardless of the size of the specimen. Also, comparing the unconfined compression strength qu and the Young's modulus E_{50} of specimens made using only cohesive soil as shown in Figs. 3 and 4. There is a tendency that the variation of q_u becomes larger by mixing ceramics material and similarly, the S-specimens show a tendency to become lower.

6. Discussion

Regarding the unconfined compression characteristics of specimens of improved soils, regardless of size differences, the value of qu is about 1:1. On the other hand, similar tendencies were not obtained for E_{50} and ε_f, indicating a tendency of large deformation in the S-specimens. Since homogeneity of each specimens are kept by the relationship of ρd and

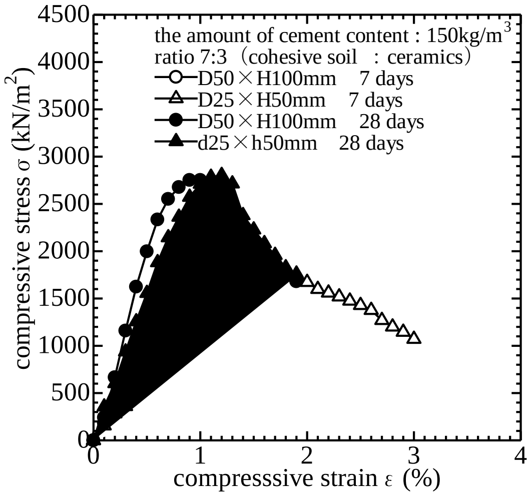

Fig. 7. Stress-strain curves

previous researches (Yamamoto and Miyake, 1982; Hayashi et al., 1997), as the size of the specimen smaller, the value of E_{50} becomes lower or the value of εf becomes higher. It has been confirmed that although the progress of the strain obtained from the strain gauge attached to each specimen corresponds approximately to the average strain, the shear plane of distortion increases sharply and the other face recovers just before the breakage in accordance with Yamamoto et al. (1982).This is imagined that the S-specimen was more affected by straining than the O-specimen, resulting in a decrease in E_{50} and an increase in ε_f even if the size of the specimen is varied. The strain generated in the shear plane is at the same level. On the other hand, in the case of the comparison under the condition that the ratio h / d of the height h of the specimen to the diameter d is different, the non-interlocking movement characteristics of a series of data may be accepted. In this study, there is similarity to miniaturization of the size of the specimen, and h / d of both sizes are the same, it is difficult to consider about their effects. In general, it is a well-known understanding that the height h of the specimen is kept from 1.8 times to 2.5 times the diameter d. However, in the case of improved soil of cohesive soil, it may be necessary to newly define the relationship between h and d as the size of the specimen becomes smaller. In the present situation, it can be said that it is safe to grasp by underestimating the q_u value to about 80% from the viewpoint of deformation coefficient on improved soil composed of cohesive soil even if the q_u value equivalent to the standard size is obtained as the specimen becomes smaller. Also, although it is possible to conduct the laboratory mixing test by the miniaturization even for samples with coarse particle size composition. It can be

the characteristics of strength appeared. Therefore, it's difficult to consider the effects of them. According to

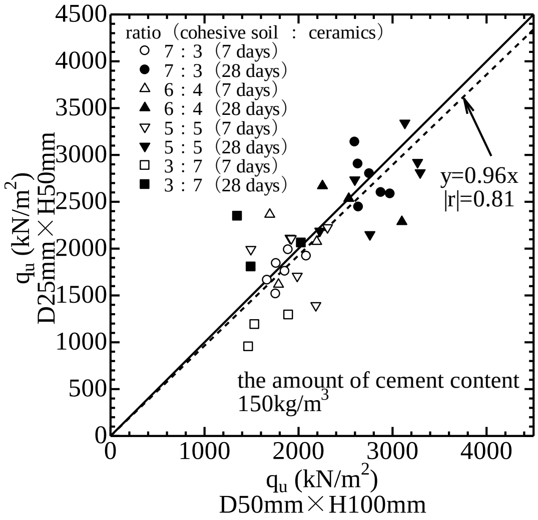

Fig. 8. Comparison of q_u

said that it is safe to grasp q_u by underestimation same as composed of only cohesive soil specimen.

7. Conclusion

Based on the investigation and laboratory test results, the following conclusion can be drawn.

1) The effects of specimen size about unconfined compressive strength cannot be found between O-specimen (D 50 mm × H 100 mm) and S-specimen (D 25 mm × H 50 mm).

2) For the fracture strain ε_f, it was confirmed that the value of the S-specimen (D 25 mm × H 50mm) is about twice the value of the O-specimen (D 50 mm × H 100 mm), and the value of the Young's modulus E_{50} is reduced to about 80%.

3) The effects of specimen size about the characteristics of strengths appeared with curing period cannot be found between O-specimen (D 50 mm × H 100 mm) and S-specimen (D 25 mm × H 50 mm).

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References

Hayashi, N., Ochiai, H., Yasufuku N. and Omine, K., 1997. Effect of cement stabilized soil on crack tensile strength and unconfined compression strength, Proceedings of the Annual Meeting of JSCE Western Branch, 468-469. (in Japanese)

Japanese Cement Association, 1999. Ground improvement manual with cementitious solidification material 2nd edition, 17-48.

Public works Research Center, 2004. Design and construction manual of deep mixing method in land, 57-62. (in Japanese)

Shogaki T., 2012. Geotechnical engineering for performance based design, Kajima Institute Publishing Company, 25-60. (in Japanese)

The Japanese Geotechnical Society, 2009. Japanese Standards and Explanations of Laboratory Tests of Geomaterials, 2 of 2 separate volumes, 426-434. (in Japanese)

The Japanese Geotechnical Society, 2009. Japanese Standards and Explanations of Laboratory Tests of Geomaterials, 2 of 2 separate volumes, 541-549. (in Japanese)

Yamamoto, T. and Miyake,M., 1982. Influence of Specimen Size on Unconfined Compressive Strength of Cement Treated Soil, The Society of Materials Science. **31**(341): 183-188. (in Japanese)