Effect of Bamboo Chips in Cemented Sand Soil on Permeability and Mechanical Properties in Triaxial Compression

Sito Ismanti, Noriyuki Yasufuku

***Abstract*—**Cement utilization to improve the properties of soil is a well-known method applied in field. However, its addition in large quantity must be controlled. This study presents utilization of natural and environmental-friendly material mixed with small amount of cement content in soil improvement, i.e. bamboo chips. Absorbability, elongation, and flatness ratio of bamboo chips were examined to investigate and understand the influence of its characteristics in the mixture. Improvement of dilation behavior as a problem of loose and poorly graded sand soil is discussed. Bamboo chips are able to improve the permeability value that affects the dilation behavior of cemented sand soil. It is proved by the stress path as the result of triaxial compression test in the undrained condition. The effect of size and content variation of bamboo chips, as well as the curing time variation are presented and discussed.

***Keywords*—**Bamboo chips, permeability, mechanical properties, triaxial compression.

I. Introduction

BAMBOO is a kind of natural resource that has ability to grow in varying conditions, especially in tropical and sub-tropical countries. In the form of bamboo chips combined with cement. References [1] and [2] investigated bamboo utilization to improve the soft ground with low bearing capacity and to increase erosion resistance, respectively. Moreover, [3] studied bamboo chips and flakes utilization in high water content of excavated mud. However, the combination between pozzolanic content of cement and high water absorbability of bamboo chips in the poorly graded sand under saturated condition has not been investigated yet.

Characteristic of loose and poorly graded sand in saturated condition has been investigated in some studies. In undrained condition, sand has three main behaviors in monotonic triaxial test, i.e. dilative, limited/partially-contractive, and fully contractive [6]-[11]. In this case, contractive behavior can also be interpreted as a static liquefaction phenomenon. Liquefaction is a destructive phenomenon subjected to either cyclic or monotonic loading. The main concept of this phenomenon is the generation of high pore water pressure that affects shear strength significantly.

There are some conditions and properties that affect the dilation behavior of sand. One of them is the coefficient of permeability. Reference [4] conducted some simulations using numerical analysis on liquefaction phenomenon. They concluded about the importance of soil permeability coefficient to predict the pore pressure and displacement. Moreover, [5] showed the sensitivity of loose and poorly graded sand behavior due to permeability value. The higher the soil permeability, the weaker the soil dilation. But, if the coefficient of permeability becomes too high, the excessive pore pressure is significantly reduced.

Dilation tendency of sand might be studied using a triaxial compression test to understand the mechanism. The effective stress path as result of the test shows the tendency. The dilation is shown by "elbow" shape that is formed by reaching the maximum deviator stress then together with the strain softening emerged at a certain stage of shear to a minimum deviator stress before turned and ascended along the failure line [6]-[11]. The elbow is observed in this study as comparison of dilation tendency.

II. Material and Experimental Program

A. Soil Sample

Liquefaction phenomenon was occurred in several sites in Yogyakarta City in Java Island, Indonesia after Mid Java Earthquake on May 27, 2006. Japanese Geotechnical Society (JGS) survey team investigated on geotechnical issues. Selection of soil type in this paper is based on this investigation result in [12]. Toyoura sand is fine sand used in this study. There are compatibility properties of Toyoura sand with liquefied soil in several sites. Fig. 1 shows that the grain size distribution curve of Toyoura sand is located among the other curves. The index properties of Toyoura sand are Gs = 2.64, D50 = 0.17 mm, Uc = 1.75, emax = 0.953, emin = 1.352. This sand is at a relative density (Dr) of 35%.

B. Bamboo Chips

Bamboo chips are made from bamboo rod produced by using cutting machine. In this study, there are two types of bamboo chips based on the longest size of chips, i.e. 6 mm and 10 mm. In addition, there is physical characterization of bamboo chips performed by elongation and flatness ratio. Elongation ratio is a ratio between intermediate and shortest length of bamboo flakes particle, whereas flatness ratio is the ratio between shortest and longest length. Particle length measurement was conducted by using a digital caliper.

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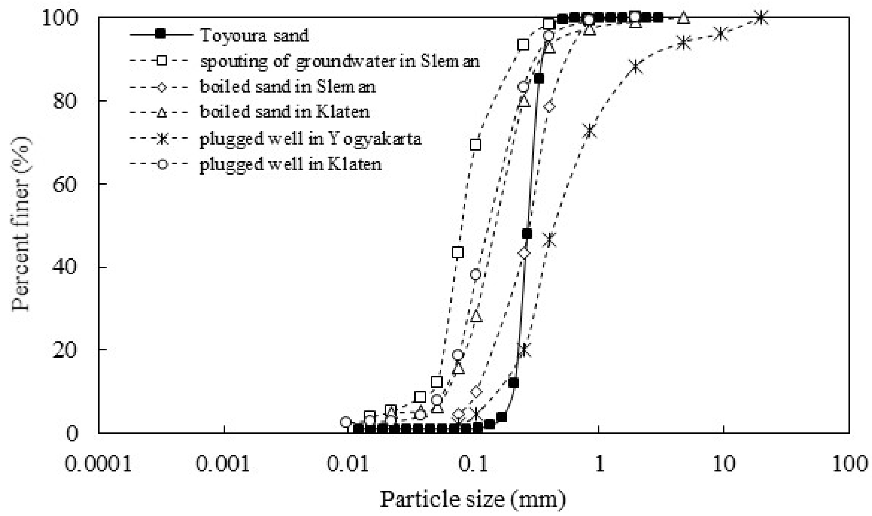


Fig. 1 Particle size distribution curve of the liquefied soil in several sites in Indonesia (modified after [12])

(a) (b)

Fig. 2 Bamboo chips (a) 6 mm and (b) 10 mm

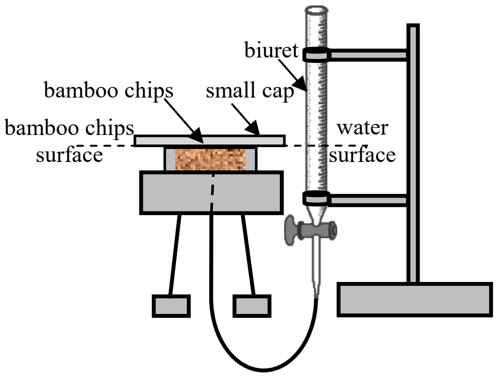


Fig. 3 Concept of absorbability test apparatus

Water absorbability test was conducted to obtain absorbed water in a constant volume of cylinder sample. The dimensions of sample are 6 cm diameter and 1.5 cm height. The initial water content was kept less than 5%. Bulk density of the bamboo chips is about 0.2 gram/cm^3. A simple procedure of the absorbability test was conducted by connecting the bamboo chips cylinder with biuret contains distilled water. Water flowed to the bottom of bamboo chips. At the same time, upper part of bamboo chips was detained in order to keep the volume by using small cap to avoid the over pressure. Pressure of the cap is 0.03 kPa. Water surface in biuret was maintained as high as bamboo chips surface during the test. The decreasing water in biuret is the absorbed water volume. Tests were conducted for 90 minutes. Result of this test provides the absorbability tendency in short term. Calculation of absorbed water index was conducted to provide understanding and comparison between both of the bamboo chips types. Absorbed water index is ratio between the decreasing water in biuret and volume of bamboo chips.

C. Test Method and Procedure

In this paper, specimen is mixture between Toyoura sand with 35% of D_r, and variation of bamboo chips and cement. The dimensions of specimen are 50 mm diameter and 100 mm height in cylinder. Cement used in this study is Ordinary Portland Cement (OPC). The variations are presented in Table I. Water addition of 20% was decided based on the preliminary trial considering the workability reason. The percentages of bamboo chip, cement, and water are referenced to dry mass of Toyoura sand. Specimen was prepared by mixing soil, cement, and bamboo chips in dry condition into a homogeneous color mixture then pour into the mixture. Compaction was conducted in acrylic cylinder. The specimens were cured for 7 and 14 days. After curing, acrylic cylinder was removed.

TABLE I
SPECIMEN VARIATIONS

Type of the test	Curing time (days)	Specimen variations
	0	Toyoura sand (T)
Triaxial, constant head permeability	7, 14	T:1% 6 mm bamboo chips (TB_61)
		T:2% 6 mm bamboo chips (TB_62)
		T:1% 10 mm bamboo chips ($TB_{10}1$)
		T:2% 10 mm bamboo chips ($TB_{10}2$)
		T:4%OPC (TC4)
		T:4% OPC:1% 6 mm bamboo chips ($TC4B_61$)
		T:4% OPC:2% 6 mm bamboo chips ($TC4B_62$)
		T:4% OPC:1% 10 mm bamboo chips ($TC4B_{10}1$)
		T:4% OPC:2% 10 mm bamboo chips ($TC4B_{10}2$)

(a) (b)

Fig. 4 Specimens with 2% of (a) 6 mm bamboo chips (TB_62) and (b) 10 mm bamboo chips ($TB_{10}2$)

Permeability and triaxial test were conducted by using constant head method (ASTM 2434-68) and consolidated-undrained method with the pore water pressure measurement during loading (ASTM 4767-02), respectively. In triaxial test, to obtain a high degree of saturation, deaired water was circulated in the specimen by using double negative pressure method. In addition, back pressure of 200 kPa was applied. B-values of more than 0.9 were observed in all. The test was performed at 50, 100, and 150 kPa of confining pressure. Strain was controlled after isotropic consolidation. The samples were executed by applying a monotonic axial load with a strain rate of 0.1%/min. Stress parameters p' and q are used for representing the effective mean principal stress, $p' = (\sigma'_1 + 2\sigma'_3)/3$, and the deviator stress, $q = \sigma'_1 - \sigma'_3$, respectively.

III. Result and Discussion

A. Bamboo Chips Properties

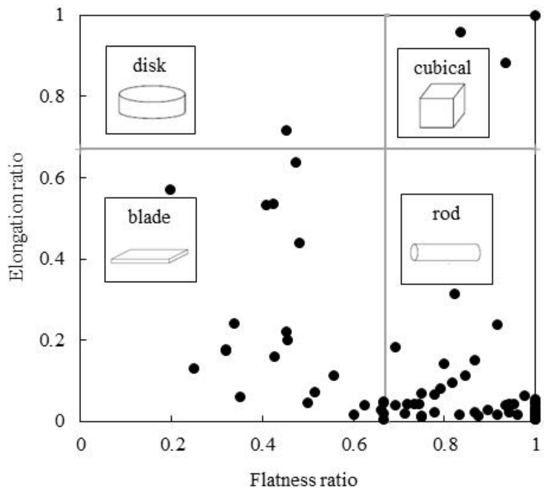
1. Elongation and Flatness Ratio

Based on the elongation and flatness ratio parameters, particles are divided to be four shapes, i.e. disk, cubical, blade, and rod. The limit of these shapes is 2/3 value of each parameter [13]. In the densification process, each shape of particle has typical characteristic in mixture. But, in compaction process, cubical is the best shape in the workability reason.

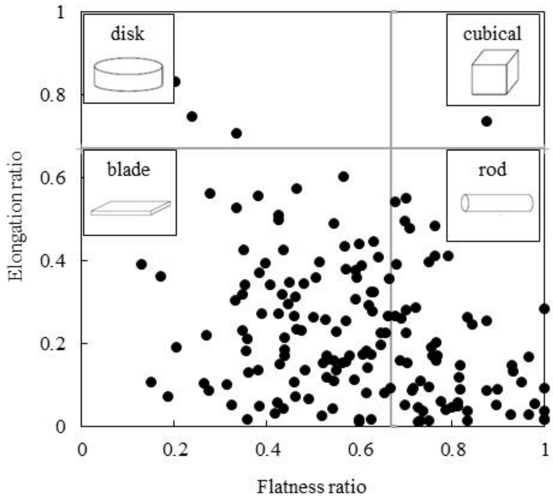
Both types of bamboo chips have same dominant shape, i.e. blade and rod. It can be seen in Fig. 5 that depicts the elongation and flatness ratio of bamboo chips. However, 6 mm bamboo chips have cubical shape and its size is smaller, so the compaction process of specimen with 6 mm bamboo chips content is easier.

2. Absorbability

As an important parameter, absorbability of bamboo chips was investigated. The absorbability of bamboo chips provides potential to decrease the excess pore water pressure of soil mixture in undrained condition during loading. Fig. 6 shows the tendency of bamboo chips absorbability. Based on the test result, absorbed water of 6 mm bamboo chips is higher than 10 mm bamboo chips. In the larger size, water requires longer time to saturate the bamboo chips. This result proves that shape factor has significant effect to the water absorbability.



(a)



(b)

Fig. 5 Elongation and flatness ratio of (a) 6 mm and (b) 10 mm bamboo chips

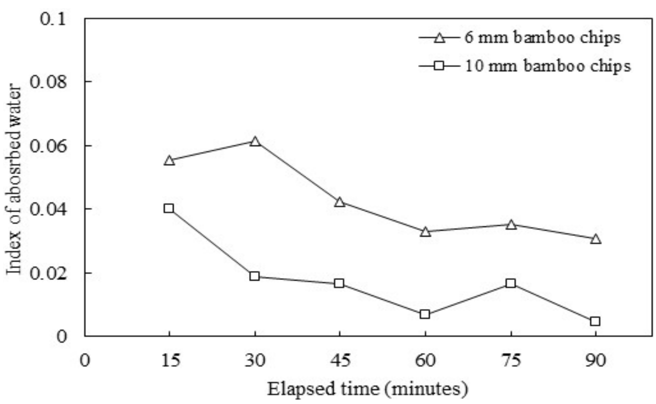
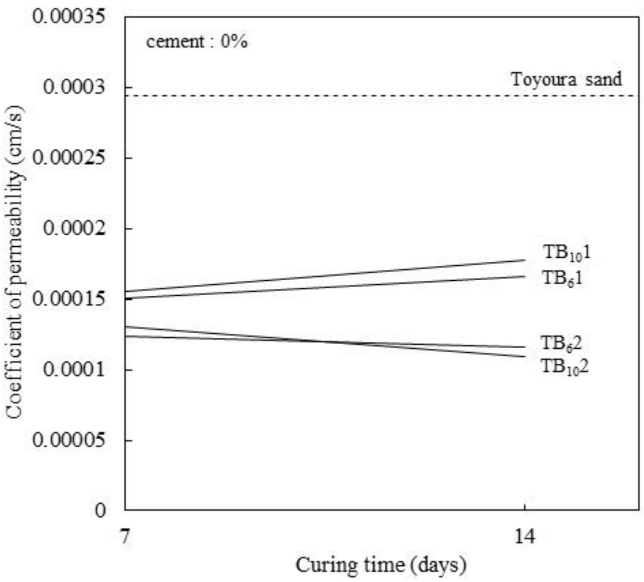


Fig. 6 Absorbed water index of bamboo chips in 90 minutes

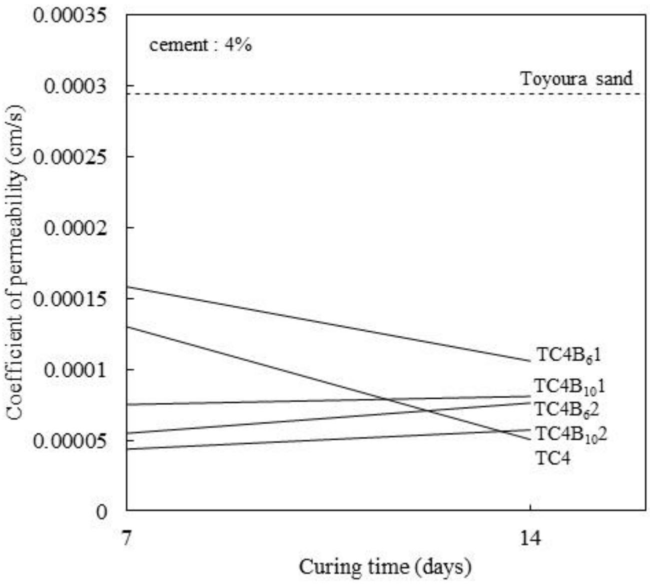
B. Coefficient of Permeability

In the mixture without cement, bamboo chips addition provides significant effect to the coefficient of permeability. Fig. 7 shows the decreasing of permeability coefficient about 47-58% and 40-63% of bamboo chips addition after 7 days and 14 days curing time compared to Toyoura sand, respectively. Based on this result, size factor of bamboo chips provides slight effect. It can be seen from adjacent lines between 6 mm and 10 mm of bamboo chips on the same percentage content in Fig. 7 (a). However, the quantity factor and curing time have an influence on the coefficient of permeability. This is indicated by the different slope of the curve between 1% and 2% of cement content in Fig. 7 (a). The higher content of bamboo chips, the lower of permeability coefficient. Based on the influence of curing time, there is also information that the addition of 1% of bamboo chips gives a negative effect over time. This is because small amount of bamboo chips allows water to saturate in a short time. There is intersected curve in the 2% of bamboo chips content. It might be due to the human error in the experimental stage during specimen preparation.

Pozzolanic content in cement presents different tendency. This information can be seen in Fig. 7 (b). The decreasing permeability of the cemented sand soil provides that cementation reaction was occurred. The decreasing void of sand is an effect of the bonding reaction between cement and water. Moreover, bamboo chips additions provide varying tendency. After 7 days curing time, permeability coefficient of the specimen with 1% and 2% content of 10 mm bamboo chips and 2% content of 6 mm bamboo chip are low compared to the cemented sand. Yet, after 14 days curing time, there are increasing tendency. It can be approved that cementation reaction might be hampered due to the presence of the bamboo chips as additive material in large quantities. Based on this result, factor of size and content of bamboo chips presents significant effect on the coefficient of permeability.



(a)



(b)

Fig. 7 Coefficient of permeability (a) without cement and b) with 4% cement in mixture

C. Undrained Monotonic Triaxial Compression Behavior

Dilation behavior of sand soil can be interpreted by using the stress path as a result of the monotonic triaxial test. Figs. 8 and 9 depict result of cemented sand soil test. Elbow shape in Fig. 8 that indicates the softening behavior is not fine. It can be approved that the cemented sand soil has dilative behavior. Based on this result, addition of the bamboo chips in the mixture has to be investigated to obtain the optimum type and content as proposed additive material in the cemented loose and poorly graded sand soil improvement

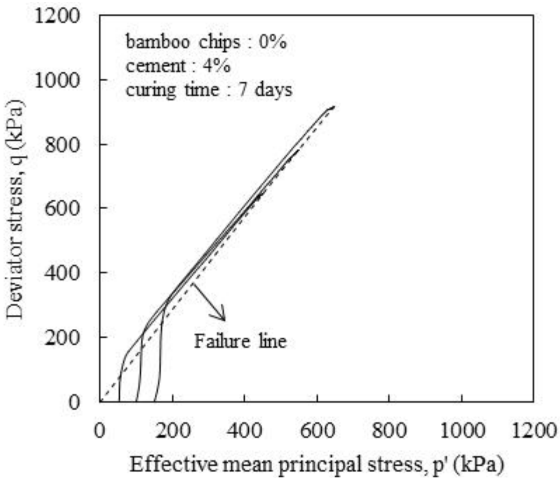


Fig. 8 Stress path of the cemented sand soil

In this study, the comparison of the properties contained in the specimen is presented only on the application of 100 kPa of confining pressure. This boundary provides focus discussion in order to provide understanding of each parameter effect. There are three parameters compared, i.e.

variation of bamboo chips size and content, curing time, and cement content. Observation is focused on the stress path behavior, especially on the elbow characteristic line that depicts the dilation behavior of specimen.

1. Effect of Bamboo Chips Size and Content

In the dilation behavior of cemented sand soil, factor of size and content of bamboo chips has main effect. Based on Fig. 10, after 7 days curing time, it can be seen that the highest stress path is reached by addition of 1% content of 10 mm bamboo chips. However, the upright curve is reached by addition of 2% content of 6 mm bamboo chips. It proves that 10 mm bamboo chips in small amount are able to improve the strength of the specimen using its form, while bamboo chips of 6 mm allow cement to react with water due to its small size. In accordance with the absorbability test, water can be easily absorbed by small bamboo chips. This can be concluded that cemented reaction is the main factor in addition of small bamboo powder.

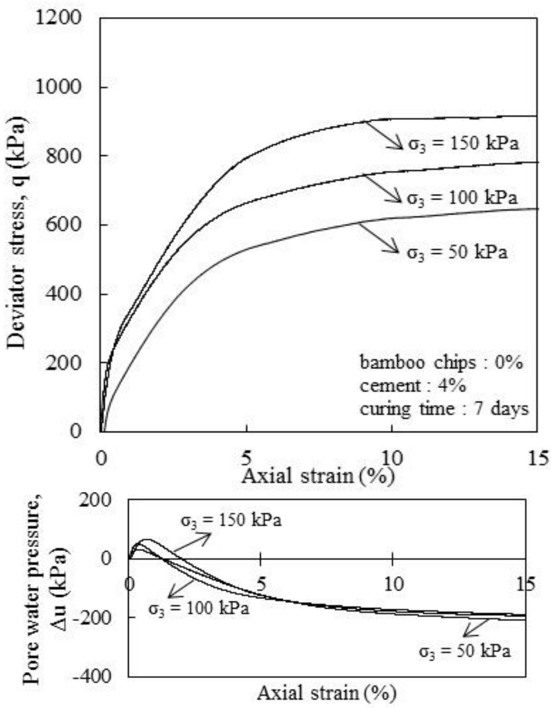


Fig. 9 Stress-strain relationship and pore water pressure of cemented sand soil

2. Effect of Curing Time

Variation of the curing time can be seen in Figs. 12-15. This information provides slight differences based on the adjacent curve. Based on observation of elbow shape and characteristic of stress path in Figs. 12 and 14, after 14 days curing time, improvement of specimen is shown by both types of bamboo chips. Positive tendency of the curing time is also shown in the stress-strain relationship curve in Figs. 13 and 15. This variation result shows that time dependency is also the main factor of this improvement of the loose and poorly sand.

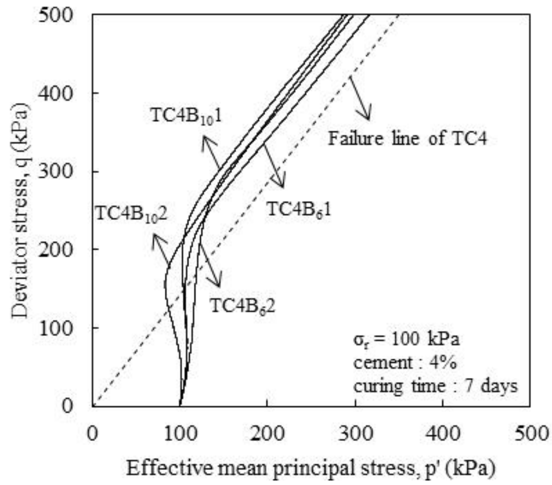


Fig. 10 Stress path in variation of bamboo chips size and content in cemented soil

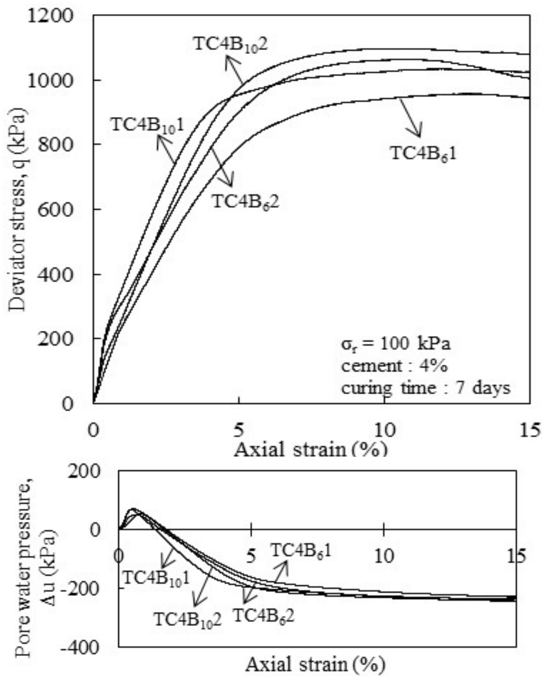


Fig. 11 Comparison of stress-strain relationship and pore water pressure in variation of size and content of bamboo powder

3. Effect of Cement Content

Variation of cement content is shown in Fig. 16. It shows that cement addition provides higher result compared to the utilization of bamboo chips only. This can be concluded that bamboo chips are not suitable as a substitute of cement material. However, addition of bamboo chips improves the strength of cemented sand. This statement is approved by the comparison of results that can be seen in Fig. 17. Curve in Fig. 17 is the comparison of deviator stress increment at 15% of strain between each specimen variation and cemented sand soil at the same curing time period. It shows that the higher content of bamboo chips, the higher strength of the cemented sand.

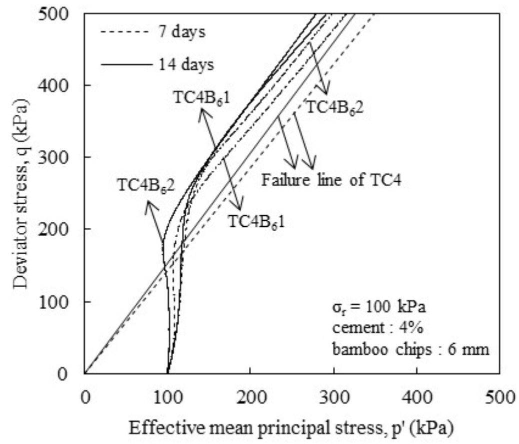


Fig. 12 Stress path in variation of curing time (6 mm bamboo chips)

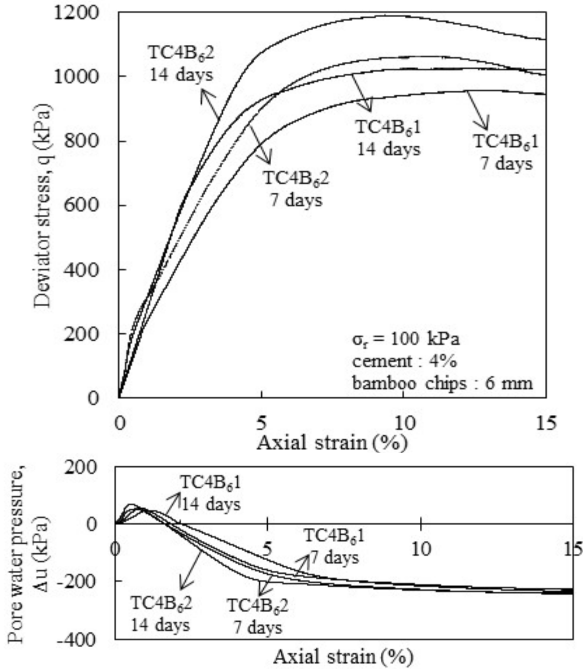


Fig. 13 Comparison of stress-strain relationship and pore water pressure in variation of size and content of bamboo powder (6 mm bamboo chips)

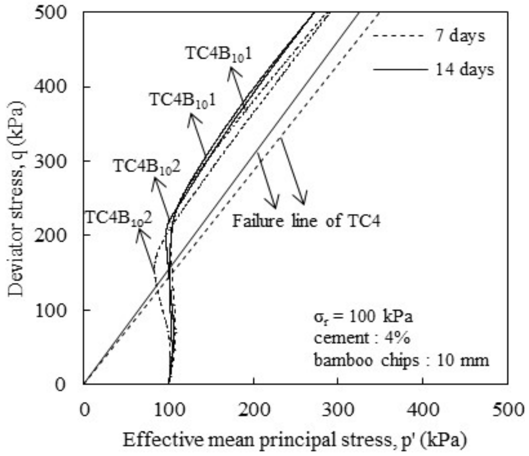


Fig. 14 Stress path in variation of curing time (10 mm bamboo chips)

IV. Conclusions

In environmental issues, restriction of cement utilization becomes the main focus in soil improvement. Cement replacement by bamboo chips is not the purpose of this study. Yet, the addition of bamboo chips as environmental-friendly material is proposed to be an additive material in cemented sand soil to provide positive tendency to its mechanical properties in order to reduce amount of cement content.

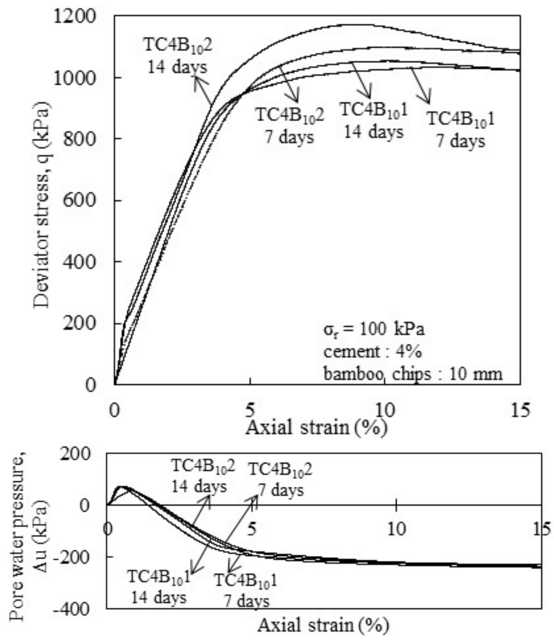


Fig. 15 Comparison of stress-strain relationship and pore water pressure in variation of size and content of bamboo powder (10 mm bamboo chips)

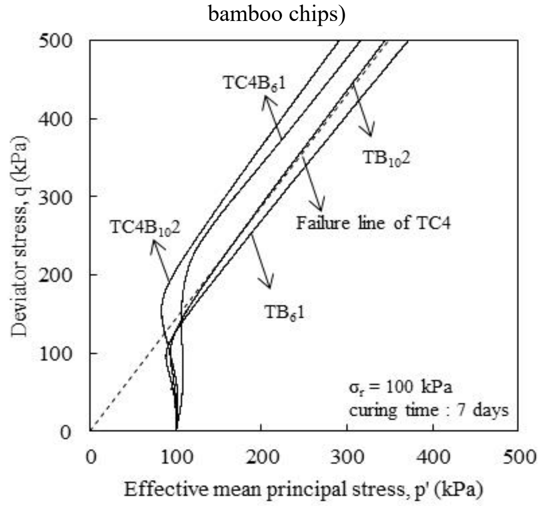


Fig. 16 Stress path in variation of cement

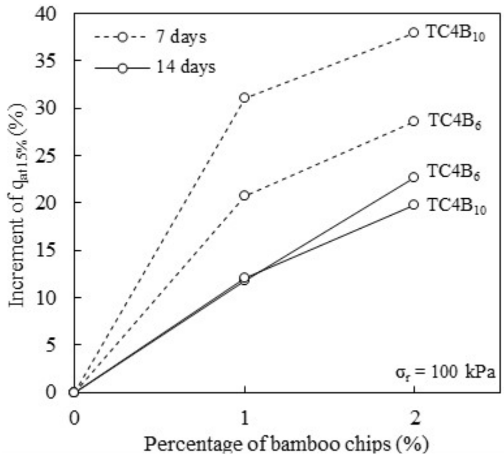


Fig. 17 Increment deviator stress at 15% of strain compared to cemented sand soil

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REFERENCES

[1] H. Huang, S. Jin, and H. Yamamoto, "Study on strength characteristics of reinforced soil by cement and bamboo chips", Applied Mechanics and Materials, vol. 71-78, 2011, pp. 1250-1254.

[2] K. Saki, R. Kitamura, T. Kawaji, and T. Yotsuda, "Erosion resistant properties of improved soil using bamboo chips for erosion prevention of Alameda in historic places", Disaster Mitigation of Urban Cultural Heritage Papers, vol. 7, 2013. (in Japanese)

[3] K. Sato, T. Fujikawa, and C. Koga, "Improved effect of the high water content clay using the water absorptivity of bamboo", Geosynthetic Papers, vol. 29, 2014. (in Japanese)

[4] A. Rahmani, O. G. Fare, and A. Pak, "Investigation of the influence of permeability coefficient on the numerical modeling of the liquefaction phenomenon," Scientia Iranica, Transactions A: Civil Engineering 19, 2012, pp. 179-187.

[5] J. M. Ramirez, "Influence of soil permeability on liquefaction-induced lateral pile response," Electronic Theses and Dissertations, University of California, San Diego, 2010.

[6] M. Hyodo, H. Tanimizu, N. Yasufuku, and H. Murata, "Undrained cyclic and monotonic triaxial behaviour of saturated loose sand," Soils and Foundation, vol. 34, no. 1, Japanese Society of Soil Mechanics and Foundation Engineering, 1994, pp. 19-32.

[7] Y. Jafarian, A. Ghorbani, S. Salamatpoor, and S. Salamatpoor, "Monotonic triaxial experiments to evaluate steady-state and liquefaction susceptibility of Babolsar sand," Journal of Zheijang University-SCIENCE A (Applied Physics & Engineering), ISSN 1673-565X (print); ISSN 1863-1775 (online), 2013.

[8] O. Igwe, K. Sassa, and H. Fukuoka, "Liquefaction potential of granular materials using differently graded sandy soils," Annuals of Disaster Prevention Research Institute, Kyoto University, no. 47 B, 2004.

[9] K. Ishihara, F. Tatsuoka, and S. Yasuda, 1975, "Undrained deformation and liquefaction of sand under cyclic stresses," Soils and Foundation, vol. 15, no. 1, Japanese Society of Soil Mechanics and Foundation Engineering, Mar 1975.

[10] R. Mohamad and R. Dobry, "Undrained monotonic and cyclic triaxial strength of sand," Journal of Geotechnical Engineering, vol. 112, no. 10, ASCE, 1986.

[11] L. B. Ibsen, "The mechanism controlling static liquefaction and cyclic strength of sand," Aalborg: Geotechnical Engineering Group, AAU Geotechnical Engineering Papers: Soil Mechanics Paper, vol. R9816, no. 27, 1998.

[12] J. Koseki, M. Yoshimine, T. Hara, T. Kiyota, R. I. Wicaksono, S. Goto, and Y. Agustian, "Damage survey report on May 27, 2006, Mid Java Earthquake, Indonesia", Soils and Foundations, vol, 47, no. 5, Japanese Geotechnical Society, Oct. 2007, pp. 973-989.

[13] J. S. Chen, M. K. Chang, and K. Y. Lin, "Influence of coarse aggregate shape on the strength of asphalt concrete mixtures," Journal of the Eastern Asia Society for Transportation Studies, vol. 6, 2005, pp. 1062-1075.