Evaluation of bamboo material structure and its influence to mechanical behavior in sand soil mixture under static loading

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ABSTRACT

Bamboo is a kind of natural resource that has ability to grow in varying conditions. Besides its high water absorbability as the main advantage of bamboo, effect of bamboo material structure can be utilized to improve characteristic of loose and poorly graded sand soil under saturated condition. This type of soil is very susceptible to liquefaction. An understanding of production process influence to the performance of bamboo materials type, influence of cement addition in the mixture and curing time to the mechanical behaviour were observed by static triaxial CU test. In addition, SEM (Scanning Electron Microscopic) analysis was also conducted to understand the particle interaction in mixture. This study can be developed as one of the proposed ideas in the utilization of environmental friendly materials in geotechnical field.

Keywords: bamboo material structure, static triaxial test, SEM analysis, environmental friendly material

1 INTRODUCTION

Bamboo is a kind of natural resource that has ability to grow in varying conditions, especially in tropical and sub-tropical countries. Bamboo has been utilized in various applications. Ref. [1] concluded bamboo product statistics, i.e. raw materials, charcoal, housing, pulp, paper, cloth, panels, flooring, weaving products, crafts, fuel, shoots, furniture, culture, protects steep slopes, soils and water ways, prevents soil erosion, provides carbon sequestration, and many other ecosystem benefits. In the form of bamboo chips combined with cement, Ref. [2] and Ref. [3] investigated bamboo utilization to improve the soft ground with low bearing capacity and to increase erosion resistance, respectively. Moreover, [4] 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.

2 MATERIAL AND EXPERIMENTAL PROGRAM

2.1 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 Ref. [5]. 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, εmax = 0.953, εmin = 1.352. This sand is at a relative density (Dr) of 35%.

2.2 Bamboo Material

Bamboo materials are made from bamboo culm produced by using rubbing and cutting machine. Bamboo materials are obtained from Nouken Sangyou Co. Ltd. in Itoshima, Japan. In this study, there are two types of bamboo material based on production process.

Fig. 1. Particle size distribution curve of the liquefied soil in several sites in Indonesia (modified after [5]).
In accordance with the name of machine, rubbing machine, as shown in Fig. 2(a), uses rubbing process for producing bamboo flakes, whereas cutting machine shown in Fig. 2(b) uses cutting process in bamboo chips production. Size of bamboo chips can be maintained by replacing cutting tool as the required size. In this study, bamboo chips used are 6 mm and 10 mm bamboo chips based on the longest size of chips. Types of bamboo materials used in this study can be seen in Fig. 3.

Physical characterization of bamboo materials by elongation and flatness ratio was performed. Elongation ratio is a ratio between intermediate and shortest length of bamboo material particle, whereas flatness ratio is the ratio between shortest and longest length. Particle length measurement was conducted by using a digital caliper.

Water absorbability test of bamboo material 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 material is about 0.2 gram/cm³. A simple procedure of the absorbability test was conducted by connecting the bamboo material cylinder with biuret contains distilled water. Water flowed to the bottom of bamboo material. At the same time, upper part of bamboo material 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 material 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 among three types of bamboo material.
Absorbed water index is ratio between the decreasing water in biuret and volume of bamboo material.

2.3 Test Method and Procedure

In this paper, specimen is mixture of 35% D₂ Toyoura sand, variation of bamboo materials type and cement content. 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 1. Water addition of 20% was decided based on the preliminary trial considering the workability reason. The percentages of bamboo materials, cement, and water are referenced to dry mass of Toyoura sand. Specimen was prepared by mixing soil, cement, and bamboo materials in dry condition into a homogeneous color mixture then pour water into the mixture. Compaction was conducted in acrylic cylinder. The specimens were cured for 3, 7 and 14 days. After curing, acrylic cylinder was removed.

<table>
<thead>
<tr>
<th>Cement content</th>
<th>Bamboo material</th>
<th>Mixture code</th>
<th>Curing time and type of test</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>1% bamboo flakes</td>
<td>TB₁</td>
<td>7 days Triaxial CU</td>
</tr>
<tr>
<td>0%</td>
<td>1% 6mm bamboo chips</td>
<td>TB₁</td>
<td>7 days SEM test</td>
</tr>
<tr>
<td>0%</td>
<td>1% 10mm bamboo chips</td>
<td>TB₀₁</td>
<td>7 days SEM test</td>
</tr>
<tr>
<td>2%</td>
<td>1% bamboo flakes</td>
<td>TC₂B₁</td>
<td>3, 7 and 14 days Triaxial CU</td>
</tr>
<tr>
<td>2%</td>
<td>1% 6mm bamboo chips</td>
<td>TC₂B₀₁</td>
<td>3, 7 and 14 days Triaxial CU</td>
</tr>
<tr>
<td>2%</td>
<td>1% 10mm bamboo chips</td>
<td>TC₂B₀₁</td>
<td>3, 7 and 14 days Triaxial CU</td>
</tr>
<tr>
<td>4%</td>
<td>1% bamboo flakes</td>
<td>TC₄B₁</td>
<td>7 and 14 days Triaxial CU</td>
</tr>
<tr>
<td>4%</td>
<td>1% 6mm bamboo chips</td>
<td>TC₄B₀₁</td>
<td>7 and 14 days Triaxial CU</td>
</tr>
<tr>
<td>4%</td>
<td>1% 10mm bamboo chips</td>
<td>TC₄B₀₁</td>
<td>7 and 14 days Triaxial CU</td>
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<tr>
<td>0%</td>
<td>T</td>
<td></td>
<td>0 days Triaxial CU</td>
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</tbody>
</table>

Consolidated-undrained method of triaxial test with the pore water pressure measurement during loading was conducted based on ASTM 4767-02. 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. In addition, for determining the particle interactions in the mixture, SEM (Scanning Electron Microscopic) test was conducted.

3 RESULT AND DISCUSSION

3.1 Bamboo Material Properties

3.1.1 Bamboo Structure

Bamboo consists of roots, culm, and leaves. Part of bamboo that is processed into bamboo materials in this study is bamboo culm. Bamboo culm consists of nodes and internode. Based on [6] and [7], as a dominant part of bamboo culm, internode is divided into three main sections, including outer, middle, and inner parts indicated by the number 1, 2, and 3, respectively, in Fig. [6]. Outer part consists of cortex which is densely packed cells, often cutinized and with wax coating. This section keeps the moisture and bamboo culm to spoil due to water. These properties causes the outer part of bamboo culm has hydrophobic properties. Middle part of bamboo culm consists of 50% parenchyma, 40% fibers, and vascular bundles. Fibers have good technical properties for providing strength of bamboo culm structure.

Fig. 6. Structure of bamboo culm [6].

Besides its structure, chemical constituent in bamboo culm also has influence on the performance of bamboo materials in mixture. The dominant content is cellulose. This substance has a tendency to absorb water (hydrophilic). Another chemical constituents are hemicelluloses, lignin which has the properties to maintain rigidity of bamboo culm, silica, and starch as the most important part of the plant as fortifying component. Silica has a capable of maintaining a material to against degradation, but in the bamboo culm, its small amount has no impact against biodegradation [6] and [7].

3.1.2 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. 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. 7 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.

![Fig. 7. Elongation and flatness ratio of (a) bamboo flakes, (b) 6 mm, and (c) 10 mm bamboo chips.](image)

3.1.3 Water absorbability
As an important parameter, absorbability of bamboo materials was investigated. The absorbability of bamboo materials provides potential to decrease the excess pore water pressure of soil mixture in undrained condition during loading. Fig. 8 shows the tendency of bamboo materials absorbability. Based on the test result, absorbed water of bamboo flakes is the highest for the first 60 minutes, but the value significantly decreases under absorbability value of bamboo chips after this point. It proves that structure of bamboo materials affects the tendency. It can be approved that the rubbing process in production of bamboo flakes causes the outer surface of bamboo culm is exfoliated. Thus, bamboo flakes can easily absorb water and saturated in a short time. Analogous to this, the cutting process in the production of bamboo chips do not change the structure of bamboo culm, but only cut into a smaller pieces. It causes the outer part of the bamboo culm still exist and provides longer duration to absorb water. In addition, the comparison between the two types of bamboo chips is also shown in Fig. 8. Water absorbability of 6 mm bamboo chips is about 25% higher than 10 mm bamboo chips at the same time test. In the larger size, water requires longer time to saturate. This result proves that size factor also has effect to the water absorbability.

3.2 Mechanical behavior of specimen under static triaxial test
In ASTM 4767-02, “failure is often taken to correspond to the maximum principal stress difference (maximum deviator stress) attained or the principal stress difference (deviator stress) at 15% axial strain, whichever is obtained first during the performance of a test”. Based on this definition, this study utilized failure point to compare some variation results. Failure point was chosen at 15% axial strain as its maximum deviator stress \(q_{\text{max}}\). Fig. 9 shows one of static triaxial results.

![Fig. 8. Absorbed water index of bamboo material in 90 minutes.](image)

3.2.1 Effect of Bamboo Materials Type
As previously mentioned, production process of bamboo materials has significant effect to its structure. Furthermore, the structure of bamboo materials will
also affect its performance in the mixture.

![Stress-strain relationship and pore water pressure of mixture with 4% cement and 1% bamboo flakes (TC\textsubscript{4}B\textsubscript{1}).](image)

3.2.2 Effect of Cement Content

Interaction between bamboo material and cement was observed and presented in Fig. 12. A consistent increasing \(q_{\text{max}}\) was occurred in bamboo flakes addition along with cement content addition. However, unique result was shown by bamboo chip addition. In the 2\% cement addition, \(q_{\text{max}}\) of bamboo chips mixture decreased. It can be explained by SEM test result in Fig. 13. Fibers structure of bamboo flakes provides void that can be filled by cement paste for sticking all particles in mixture, whereas bamboo chips was less reliable with small amount of cement content. Intact structure of bamboo chips provides higher effect in the mixture with 4\% cement addition than fibers structure of bamboo flakes.

3.2.3 Effect of Curing Time

Curing time effect was observed to determine interaction between bamboo material and cement in view point of time dependency. In Fig. 14, for both 2\% and 4\% cement addition, 10 mm bamboo chips and bamboo flakes provide highest and lowest \(q_{\text{max}}\) in three curing time variations, respectively. Each type of bamboo material also shows different performance in increment of \(q_{\text{max}}\) shown in the Fig. 15. After 7 days curing time, bamboo flakes provided highest increment of \(q_{\text{max}}\) referenced by 3 days curing time. For short period, it shows good interaction between cement and bamboo flakes due to its fibers structure.

![Comparison of maximum deviator stress of cement content variation in 1\% content of bamboo materials.](image)

![Result of SEM analysis of non-cemented specimen with addition of (a) bamboo flakes, (b) 6 mm, and (c) 10 mm bamboo chips.](image)

![Comparison of maximum deviator stress of bamboo materials type variation.](image)
In the mixture with 2% cement addition, consistent increment was presented by bamboo chips addition, whereas bamboo flakes addition showed slight increment after 7 days curing time. In the 4% cement addition, consistent tendency was shown by all bamboo material type addition that significant increment was reached in the short time. Thus, for short term application, high content of cement with bamboo flakes can be relied. However, for long term, bamboo chips is more suitable although with the small amount of cement.

4 CONCLUSIONS

Based on some tendencies, this study proves that addition of bamboo material improves loose and poorly graded sand strength in undrained and saturated condition. Based on physical, mechanical investigation, and microscopic analysis, following factors affect the performance of bamboo material in the mixtures: a. production process of bamboo material that formed physical characteristics and its water absorbability as main properties of bamboo, b. bamboo material size, c. cement content as additive materials to increase interaction of particles.

For further comprehensive analysis, variation of cement content and curing time were required to obtain proposed mix design.

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REFERENCES