Geo-environmental and Liquefaction Potential Assessment on Poorly Graded Sandy Soil Improved by Bamboo Materials

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（竹材によって改良された均質な粒度をもつ砂質土の液状化抵抗性と地盤環境評価に関する研究）

区　　分　：甲

論　文　内　容　の　要　旨

Poorly graded sandy soil is a soil type with high potential of liquefaction. Liquefaction is defined as the phenomenon of the strength loss of saturated and cohesionless soils due to the increasing pore water pressure under dynamic loading. Increasing liquefaction resistance can be achieved by mixing method using stabilizer material such as cement that is widely used and applied in field. The utilization of cement is the last alternative since other methods are more costly. However, soil improvement by cement is still considered as an expensive material, especially in developing countries. In addition, to the environmental point of view, cement production is an important concern. Based on Synthesis Report of Climate Change 2014 by Intergovernmental Panel on Climate Change (IPCC), cement production contributes 34.8GtCO_2/year annual CO_2 emission together with fossil fuel combustion and flaring. Since 1970, these activities have tripled. Therefore, cement replacement materials were studied by researchers. Concerning the environmental issue, utilization of natural material as the environmental-friendly and high sustainability material was considered to be studied.

Bamboo is a kind of natural resource that has ability to grow in various conditions, especially in tropical and sub-tropical countries. By its abundance, bamboo has high potential to be utilized in geotechnical application. In the previous study, bamboo chips and bamboo flakes were reliable in improvement of soft ground, erosion resistance, and high water content of excavated mud. In addition, bamboo leaf ash (BLAsh) which has high pozzolanic content was investigated to replace cement in high plasticity soil improvement. However, the combination among bamboo flakes, bamboo chips, and BLAsh in cemented poorly graded sandy soil under saturated condition has not been investigated yet. In this study, analysis based on the experimental study was conducted on aiming at (1) investigation of bamboo material effect in improvement of liquefaction resistance, (2) investigation of the environmental impact by this proposed method, and (3) recommendation of application system in field. The brief discussion of this study is presented into seven chapters as follows:

In Chapter 1, environmental problem of cement production and mechanical problem of poorly graded sandy soil as the research background were introduced. The availability of bamboo potential and its advantages as a high sustainable material were reviewed as the motivation to solve the problem. Research objectives, limitations, contributions, and outline structure of this study were also explained.

In Chapter 2, utilization of bamboo flakes and bamboo chips in geotechnical field was reviewed. In order to determine the optimum type between bamboo flakes and bamboo chips, water absorbability test apparatus was developed. In the constant volume of bamboo flakes and bamboo chips, relationship between water absorbability and elapsed time was determined using this simple test apparatus. In addition, physical characteristic, mechanical properties, and microscopic analysis of bamboo material addition in cemented sandy soil improvement were examined by elongation-flatness ratio, static triaxial test, and Scanning Electron Microscopic (SEM) test, respectively. It was found that cutting machine produces intact structure of bamboo

chips, whereas rubbing machine produces fiber structure of bamboo flakes. The form of structure affects the water absorbability and mechanical properties of bamboo material in cemented sandy soil. Based on the comparison, intact form of bamboo chips provides higher performance compared to bamboo flakes by the consistent water absorbability and the higher shear strength in cemented sandy soil mixture.

In Chapter 3, investigation of bamboo chips effect to the permeability and dilative behavior of cemented sandy soil was highlighted. The negative tendency to the permeability and dilative behavior was shown by bamboo chips-sandy soil mixture compared to cemented sandy soil. Conversely, the addition of bamboo chips in cemented sandy soil provides positive tendency. It can be concluded that bamboo chips is reliable as the reinforcement material in cemented sandy soil instead of cement replacement. Furthermore, 6 mm bamboo chips provided optimum result on the improvement of permeability and dilative behavior compared to 10 mm bamboo chips.

In Chapter 4, effect of BLAsh utilization in cemented bamboo chips-sandy soil mixture was investigated. Investigations to determine chemical compound, mechanical properties, liquefaction resistance, and impact to the environment were conducted by Energy Dispersive X-Ray (EDX) test, static triaxial test, cyclic triaxial test, and measurement of pH value and heavy metal content, respectively. Content of BLAsh was evaluated in the constant total amount of cement and BLAsh content in the mixture. Based on the relationship among content of CaO, SiO_2, and the normalized maximum deviator stress (q_{max}) of mixture, it was concluded that BLAsh is able to replace cement totally. It was shown by same strength of totally cement replacement by BLAsh with the cemented bamboo chips-sandy soil mixture (without BLAsh). However, small amount of cement provided higher strength because CaO content in cement generates more $Ca(OH)_2$ as the result of cementation reaction and as the reactant in secondary pozzolanic reaction by BLAsh at once. Static and cylic triaxial test provide consistent result of the optimum amount of BLAsh. 75% of BLAsh content in replacing cement was the optimum mixture design in improving q_{max} and liquefaction resistance. In addition, positive effect of BLAsh addition to the environment was also presented by the decreasing pH value and heavy metal content.

In Chapter 5, application of proposed mixture in factual problem in field, i.e. liquefaction occurrence after Yogyakarta Earthquake, Indonesia, on May 2006 was presented using Japan approach of liquefaction potential analysis. The assessment requires blow-count of Standard Penetration Test (N_{SPT}) value as the practical parameter in field. This chapter proposed the assessment by converting the result of undrained triaxial test as undrained shear strength (S_u) to N_{SPT} value following the empirical equation suggested by reference. The proposed mixture applied in this assessment is the optimum mixture found in the previous chapter, i.e. 75% cement replacement by BLAsh. Based on the result, decreasing liquefaction potential was shown significantly by the proposed mixture.

In Chapter 6, life cycle assessment (LCA) of BLAsh utilization in liquefiable soil improvement was conducted. In addition, application system of bamboo material utilization was generated. Based on the system, reducing bamboo leaf waste was calculated, equation to calculate total cost of system was proposed, and life cycle CO_2 ($LCCO_2$) of BLAsh production was presented. By $LCCO_2$, high CO_2 emission was shown in BLAsh production. However, the high carbon sequestration of bamboo trees was proposed to solve this problem. Regarding the concern to maintain the sustainability of bamboo forest itself, bamboo selection and harvesting time management were recommended in applying this method in field.

In Chapter 7, conclusions of each chapter and recommendations for future works were presented.