Mechanism of soil improvement in mitigating liquefaction by vertical and horizontal reinforcing inclusion using scrap tire chips

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https://doi.org/10.15017/1807004

出版情報：九州大学, 2016, 博士（工学）, 課程博士
バージョン：

（様式２）

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論文題名　：Mechanism of soil improvement in mitigating liquefaction by vertical and horizontal reinforcing inclusion using scrap tire chips.

(廃タイヤチップを用いた水平および鉛直補強による液状化対策の地盤改良機構に関する研究)

区　　分　：甲

論 文 内 容 の 要 旨

The disposal of scrap tires has been a long time problem in developing countries. Developed country such as Japan and the United States practiced thermal recycling in order to balance the stockpiling of the scrap tires. However, thermal recycling brought harmful side effects to the environment. Therefore, a more environmentally approach by utilizing scrap tires derived materials (crumbs, chips or shreds) in constructions is relevant to preserve the environment as well as to provide alternative ways of scrap tires disposal. On the other hand, the 1995 Hyogo-ken Nanbu earthquake and the 2011 Tohoku off the Pacific Coast earthquake had caused serious damage to many quay walls and residential areas due to soil liquefaction. Therefore, development of an economic liquefaction prevention method to protect infrastructures is necessary. This study was an attempt to integrate environmental protection and disaster mitigation issues by exploiting the compressibility and permeability of the tire derived material (tire chips) and utilize it as earthquake resistant material.

In this study, tire chips were utilized as part of construction material behind retaining wall and beneath shallow foundation. The tire chips were placed as vertical reinforcing inclusion behind the wall in the form of cushion and vertical drains. The purpose of installing the cushion is to prevent further tiltation of the wall during earthquake while the vertical drains are to ensure that no liquefaction occurs within the backfill. On the other hand, horizontal reinforcing inclusion made of tire chips-gravel mixture was placed underneath the foundation to prevent soil liquefaction. Numerical studies were conducted upon the models of retaining wall and foundation subjected to earthquake motion. The purpose of this research is to make clear the improvement mechanism of vertical and horizontal reinforcing inclusion made from tire chips in mitigating earthquake induced liquefaction. It was found that, by substituting part of the soil backfill with tire chips, less tiltation of the wall is observed and liquefaction inside the backfill is also able to be prevented. In the case of the horizontal inclusion was placed beneath the foundation, soil liquefaction is also able to be mitigated.

This thesis is organized into six chapters; the contents of each chapter are summarized as follows:

Chapter 1 highlights the background and driven factor of the research which covers the importance of solving the critical issues of reducing the stockpiling of waste tires and disposing it through environmentally friendly approach as well as mitigating soil liquefaction due to earthquake. In this chapter, the objectives of the research were introduced and the flowchart of the research was illustrated. Furthermore, the original contributions of this study were also presented.

Chapter 2 explains the numerical analyses conducted upon a retaining wall reinforced with vertical cushion made from tire chips. The vertical cushion was able to reduce the tiltation of the

wall compared to the conventional retaining wall. However, in the case where liquefaction occurs inside the backfill, the presence of cushion only was insufficient to prevent soil liquefaction. Therefore, the combination of cushion and vertical drains (also made from tire chips) to mitigate soil liquefaction inside the backfill was also simulated. The numerical analyses were performed using a finite element software program named PLAXIS. All the retaining wall models were subjected to earthquake load recorded during the 1995 Hyogo-ken Nanbu earthquake. The analyses reveal how the soil and structure response to the earthquake motion by comparing the response of the retaining wall, with and without the presence of the reinforcing inclusion. Through this study, it was confirmed that the failure of the retaining wall without any reinforcing inclusion was due to the tiltation of retaining wall and soil liquefaction which resulted to the settlement of the backfill. However, by replacing part of soil backfill with tire chips, the risk of liquefaction was reduced, and thus limited the wall tiltation.

Chapter 3 focuses on the application of horizontal reinforcing inclusion made from tire chips placed underneath shallow foundation. Parametric studies were conducted to verify the consequences of using a stand-alone material (either tire chips or geosynthetics) for soil reinforcement, the presence of gravel in the reinforcement, the effects of the reinforcement width, thickness of the inclusion as well as the distance from the reinforcing inclusion to bottom of the shallow foundation. It was found that the utilization of tire chips as a single material is unsuitable to reinforce the soil. Therefore, the mixture of tire chips with stiffer material such as gravel is proposed. The presence of geosynthetics layer is also found to be significant in reducing the settlement of the foundation. Placing the reinforcing inclusion of tire chips-gravel mixtures in between the geosynthetics layer is found to be the most advantageous configuration. The settlement reduction was due to the distribution of the load to a wider area of the surrounding soil compared to the case without any additional reinforcement where the distribution area is limited.

Chapter 4 mainly concentrates on the validation of the results obtained from numerical analyses with the data from laboratory tests conducted by other researcher. It was found that, most of the results obtained from the numerical analyses were similar to the results obtained through laboratory tests except for the case where the reinforcement inclusion was placed in between sand layers with different relative density. Huge difference in the result was found to be affected probably by the compaction works done during the laboratory tests, which in numerical analyses, this factor is not considered.

Chapter 5 simulated the effectiveness of the proposed technique of reinforcing bearing soil using tire chips and gravel mixtures. The case which gave the best result in mitigating soil liquefaction as described in chapter 4 is chosen to be simulated in an enlarged dimension. The enlarged model of the shallow foundation with horizontal reinforcing inclusion was subjected to the ground motion experienced during the 1995 Hyogo-ken Nanbu earthquake. The purpose of this simulation is to confirm the effectiveness and suitability of the propose placement against earthquake-induced damage. It was found that the reinforcing inclusion is not only able to protect the soil from liquefaction thus reducing the final settlement of the shallow foundation but also successful in sustaining higher magnitude of seismic motion.

Chapter 6 concludes the results and achievements obtained from the study and highlighted possible ideas for the future studies.