PHYSICAL AND MECHANICAL BEHAVIOR OF TIRE DERIVED GEOMATERIALS AND THEIR MODELING USING ARTIFICIAL INTELLIGENCE

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(タイヤ由来の地盤材料の物理・力学特性と人工知能を用いたそれらのモデリング)

区　　分　: 甲

論 文 内 容 の 要 旨

The use of scrap tire derived materials (STDM) such as tire chips, shreds and powders has rapidly been adopted in civil engineering applications, with the objective of preserving our ecosystem and reducing construction costs. Considerable research has been devoted to explore the behavior of sand-STDM as a conventional tire derived geomaterials in geotechnical applications such as lightweight fills for embankments, backfills and liquefaction protection layers for residential houses. However, high compressibility and low stiffness of mixture may lead to differential settlements and inadequate bearing capacity. This may undermine the serviceability of geo-structures built on these materials and increase construction and maintenance costs. Gravel has low compressibility, high permeability (same as STDM) and stiffness and can be considered as a suitable alternative material for sand in soil-STDM mixture. However, so far, no study has been conducted to investigate the physical and mechanical behavior of gravel-STDM mixture as a new tire derived geomaterials. Modeling soil behavior plays a key role in successful numerical simulation of the behavior of geotechnical structures. Existing conventional material models are in capable of capturing the stress-strain behavior of the tire derived geomaterials. Therefore, there is a need for developing a new suitable material model that is capable of modeling complex behavior of tire derived geomaterials.

The purpose of this study is to (1) identify important parameters affecting physical and mechanical behavior of gravel-tire chips mixture (GTCM) using experimental programs, (2) evaluate the effectiveness of GTCM in mitigating the earthquake induced liquefaction, (3) develop a constitutive material model for the reinforced soil using Artificial Intelligence (AI) .

In experimental approach, a series of consolidated drained (CD) and consolidated undrained triaxial compression tests were conducted on gravel-tire chips mixture to evaluate the effect of different parameters such as tire chips size and mixing percentage of gravel-tire chips on physical properties, stress-strain, shear strength, and dilatancy behavior of GTCM. In addition, the evolution of dynamic characteristics and liquefaction potential were assessed by performing a series of CU cyclic triaxial tests on GTCM.

In numerical approach, artificial neural network (ANN) model was developed to simulate packing density of GTCM. Furthermore, support vector machine (SVM) and ANN machine learning techniques were employed to predict dynamic characteristics of GTCM using database obtained from experimental analysis. In this thesis, a new ANN based constitutive material model was also introduced to capture complex stress-strain behavior of GTCM using laboratory test results. The model then is validated against independent data base and used to generalize stress strain behavior of GTCM.

This dissertation comprises 8 chapters. The contents of each chapter are as follows:

Chapter 1 describes the research background and motivation. It highlights the environmental issues associated with scrap tires disposal. It discusses the existing challenges related to utilization of preceding reinforcing techniques such as sand-STDMs and sheds light on the importance of introducing alternative materials such as GTCM. In addition, it discusses drawbacks of existing material models for reinforced soil with STDMs and importance of developing new material model for these mixtures. The objective and originality of this research were also presented in the chapter.

Chapter 2 presents physical and chemical properties of materials used in this research. A series of maximum and minimum void ratio tests were conducted and a new empirical expression was introduced to determine the void ratio characteristics of binary mixture of GTCM in terms of particle size ratio and volumetric fraction of gravel (GF). Chemical composition of gravels was also examined using x-ray fluorescence spectrometer test.

Chapter 3 provides past research works on static behavior of soil-STDMs and examines mechanical behavior of GTCM using consolidated drained and undrained triaxial compression tests. The effects of volumetric fraction of gravel, particle size ratio of tire chips to gravel, relative density, and confining pressure on stress-strain and dilatancy behavior of GTCM were investigated. A new formula was proposed to estimate initial tangent modulus and dilatancy of GTCM. It was found that the parameters such as GF, particle size ratio of tire chips to gravel, and confining pressure have significant impact on shear strength and dilatancy of GTCM.

Chapter 4 provides a summary of the past research works related to the dynamic behavior of soil-STDMs mixture and examines the liquefaction resistance and dynamic characteristics of GTCM determined by laboratory cyclic triaxial testing. It was observed that shear modulus and liquefaction resistance are significantly influenced by the confining pressure and volumetric fraction of gravel in mixture.

Chapter 5 discusses issues associated with the mathematical modeling of void ratio characteristics of binary mixture comprises of stiff gravel and soft tire chips particles. A new model using ANN is developed to estimate maximum and minimum void ratio of GTCM. The results provided the evidence of ANN based model's capability to capture and generalize complex void ratio characteristics of GTCM. Furthermore, proposed model yielded better performance over the conventional mathematical models for estimating void ratio of binary mixture.

Chapter 6 discusses the limitation of current models for predicting dynamic properties of reinforced soil with STDMs. It proposes novel models for estimating dynamic characteristics of GTCM using ANN and SVM techniques. The models then are validated against independent testing datasets. It was observed that ANN based model yields better performance on generalization of dynamic properties of GTCM in comparison to that of SVM.

Chapter 7 presents a new ANN based approach for constitutive modeling of Geomaterials. The model was trained, validated and tested using database obtained from CD triaxial tests on GTCM specimens. Comparison between ANN based material model prediction, plasticity soil model and the independent experimental data revealed the exceptional capabilities of the proposed methodology in mapping the very complicated behavior of reinforced soil.

Chapter 8 concludes the results and achievements of the research and presents recommendation for the future studies.