学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

Effect of moisture and wheel loads on resilient modulus and permanent strain of road subgrade in cold regions
(寒冷地における水分及び輪荷重が道路路床のレジリエントモジュラス及び永久ひずみに及ぼす影響)

Asphalt pavements, typically consisting of the asphalt layer, base course, and subgrade, endure cyclic loads from traffic, which generally leads to fatigue cracking and rutting damage, particularly affecting unbound granular materials. The current Japanese pavement design guide has some limitations such as the exclusion of moisture and freeze-thaw effects, the effect of stress state on elastic moduli, the behavior of rutting over time, the application of traffic loading, rate-hardening, the contribution of the non-subgrade layers to rutting, and principal stress axis rotation (PSAR), etc. To overcome these shortcomings, this study incorporated the concept of resilient modulus (M_r) and the rutting failure model of the Mechanistic-Empirical Pavement Design Guide (MEPDG) based on the previous study and further investigated the dynamic mechanical properties of unbound pavement materials such as subgrade soil and base course.

Resilient modulus (M_r) is a fundamental mechanical property vital for assessing the resistance of pavement structures to cyclic vertical loads. It has played a pivotal role in pavement design and has been instrumental in predicting pavement responses and fatigue life. The M_r of subgrade soil is affected by a multitude of factors, including stress, moisture, and temperature conditions, all of which interact to define the response of the soil. This study investigated the effect of complex climatic conditions on M_r with a particular focus on areas experiencing significant seasonal changes in snowy cold regions like Hokkaido, Japan. Previous studies have proposed predictive models for M_r, incorporating the concept of matric suction, to account for moisture conditions. However, these models have rarely considered hysteresis phenomena in the soil-water characteristic curve (SWCC) or the effects of wheel loading during different seasons. In this study, a series of M_r tests were conducted on two types of subgrade soil under various climatic and wheel loading conditions. The test results promise to enhance our understanding of the complex interplay of climatic and stress conditions on M_r of subgrade soil under suction hysteresis, particularly in regions with significant seasonal variations. Furthermore, three modified semi-empirical M_r predictive models incorporating Bishop's effective stress are combined with three χ estimation models and compared to find the appropriate determination method for χ and discuss their applicability to the wetting path of the SWCC.

On the other hand, cyclic axial loads generated by the traffic significantly affect the deformation characteristics of the base and subgrade materials, which becomes an important factor for the rutting damage of the pavement structure. For a fixed point in the pavement structure, the direction of stress constantly changes during the movement of the wheel load, defined as principal stress axis rotation (PSAR),

which also affects the deformation of the pavement structure. Mechanistic-Empirical Pavement Design Guide (MEPDG) proposed a model that combines resilient and permanent deformations to predict the rut depth of unbound granular materials. However, there are some disputes about whether the effect of PSAR has been considered. This study examined the behavior and relation of the resilient strain and permanent strain of crusher-run gravels under the effect of PSAR by multi-ring shear tests and further verified the validity and reliability of the MEPDG permanent axial deformation predictive model.

In this study, the contents are mainly divided into two parts: the estimation of resilient modulus and the estimation of permanent strain. Chapter 1 introduces the background, literature review, objective, and organization of this study. Chapter 2 gives the details of the test apparatus used in this study, including water retention test apparatus and unsaturated freeze-thaw triaxial apparatus. Chapter 3 describes the test materials and test methods used in the water retention tests and resilient modulus tests under different climatic and stress conditions. Chapter 4 shows the results of resilient modulus tests under various test conditions and discusses the effects of complex climatic and wheel loading conditions on Mr. Chapter 5 verifies and compares the applicability of suction stress-based M_r predictive models by combining different χ estimation models. Chapter 6 proposes a modified permanent axial strain predictive model with consideration of the effect of PSAR based on the MEPDG rut depth predictive model to estimate the rutting damage more precisely. Chapter 7 summarizes the findings obtained in this study and the possible assignments in the future.