学　位　論　文　内　容　の　要　旨

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学　位　論　文　題　名

Influence of dynamic mechanical properties of subgrade soil in cold climate on fatigue life of road pavement
(寒冷気候下の路床土の動的力学特性が道路舗装の疲労寿命に及ぼす影響)

Current Japanese design guide uses mechanical-empirical criteria to predict the failure loading number against cracking and rutting. These criteria have some limitations that variant base and subgrade layer moduli with fluctuating water contents, freeze-thaw history, stress states are not considered. However, in snowy cold regions such as Hokkaido, a northern island in Japan, pavement structures suffer annually freeze-thaw cycles as the zero degrees Celsius isotherm may penetrate deep into the pavement. Freeze-thaw action deteriorates pavement structures in two ways as frost-heave and thaw-weakening. Swelling of soil during freezing conditions caused by an increasing presence of ice lens finally leads to cracking in asphalt-mixture layer. Thaw-weakening means a drop of base and subgrade layer strength and stiffness caused by suddenly rising water content, which comes from the inflow of snowmelt water or the thawing of ice lenses, and deteriorates uniformity of particle skeleton structure after freeze-thaw action. A detailed understanding of the mechanical behavior of the base/subgrade materials during freeze-thaw is essential to develop a mathematical model of the mechanical response of the base/subgrade layer in cold regions and incorporate it into the theoretical design method for pavement structures. To achieve such understanding, it is necessary to quantitatively capture the deformation-strength characteristics of unbound granular base course and subgrade materials subjected to cyclic freeze-thaw actions under various compaction conditions and water contents through laboratory element tests with high-precision under sufficiently controlled experimental conditions. As the results, a significant loss of stiffness from frozen to thawed and an increase in the recovery period are observed in both in-situ bearing capacity test for frozen and thawed pavement structure and laboratory element test for frozen, thawed, and recovered base/subgrade material.
However, partly due to the apparatus limitation and different research topic, the synergistic effects between water content and freeze-thaw on the resilient modulus, which is the key factor of base/subgrade layer as it associates with the elastic modulus used in the design calculation for pavement structures applying the multi-layer elastic theory or finite element method, have not yet been quantitatively evaluated and modelled in these tests. Besides, rutting failure criterion used now provides no indication of the behavior of rutting over time and the effect of principal stress axis rotation on rutting development is also not captured.
To overcome such limitations, this study firstly examines the effects of freeze-thaw actions and the concurrent seasonal fluctuations in water content, named as climate effect in this study, on the resilient modulus of subgrade materials to evaluate their mechanical behavior in cold regions. A series of suction-controlled resilient modulus tests on subgrade materials with variant freeze-thaw, wheel loads,

and water contents conditions were conducted using a newly developed test apparatus. Test results were used to construct a simple model to estimate the climate effect on the resilient modulus by considering the synergistic effects between water content and freeze-thaw. This model is also proved to be valid when estimating the resilient modulus of base course material subjected to complex moisture content and freeze-thaw action. Then, constant base course and subgrade layer elastic modulus used in current Japanese design guide are replaced to resilient modulus related to stress states and complex climate conditions. Secondly, rutting failure criterion used in current Japanese design guide is revised referring to widely used Mechanical-Empirical Pavement Design Guide model. Besides, the effect of principal stress axis rotation is examined based on previous test results obtained through multi-ring shear apparatus, which could apply axial stress and shear stress simultaneously to simulate the principal stress axis rotation. Effect of principal stress axis rotation on rutting is also used to modify the rutting failure criterion. Applicability and accuracy of modified Japanese design guide are proved to be high on the failure loading prediction especially on the flexible pavement in cold regions by comparing predict fatigue life to long-term measured performance of test pavements built in Hokkaido. Chapter 1 introduces the background, objective, and organization of this study. Chapter 2 gives the detail of test apparatus, like freeze-thaw triaxial apparatus and medium-size triaxial apparatus, and test material used for resilient modulus test used in this study. Chapter 3 describes the test methods and experimental conditions of resilient modulus test under complex combination of matric suction, freeze-thaw action, and wheel loads. Chapter 4 presents the resilient modulus test results obtained in this study. A modified constitutive model is proposed to capture the synergistic effect between water contents and freeze-thaw action on resilient modulus of subgrade material. Chapter 5 discussed the effect of principal stress axis rotation on permanent deformation of specimen based on previous multi-ring shear test. Chapter 6 gives a modified pavement design guide comes from laboratory element test results shown in Chapter 4 and 5. Predicted fatigue life through modified design method is compared with long-term performance observation data to check the applicability. Chapter 7 summarizes the conclusion obtained in this study.