学　位　論　文　内　容　の　要　旨

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CONCRETE FROST RESISTANCE EVALUATION METHOD CONSIDERING MOISTURE INCREASE BY FREEZE AND THAW

(凍結融解による水分増加を考慮したコンクリートの耐凍害性評価方法)

Frost damage to concrete structures in cold regions has been a big problem. In recent years, there are two methods for evaluating the frost resistance of concrete. One widely adopted method in Japan is the accelerated freeze and thaw test based on the JIS A 1148 A (ASTM C 666), and the other is the critical degree of saturation test according to the RILEM CDC 3. In the critical degree of saturation test, cylinder specimens with different water contents are conducted with the freeze and thaw test and the critical degree of saturation Scr where obvious frost deterioration occurs is obtained. Furthermore, the single surface water absorption test at room temperature has also been conducted and the capability that the moisture in the single surface water absorption test reaches Scr is regarded as concrete frost resistance. The more difficult for the water absorption to reach the Scr is, the better frost resistance of the concrete specimens owe. Even though both tests are for the comparison between different concrete frost resistance, the results by the two tests sometimes do not correspond with each other. In particular, the critical degree of saturation test does not take the moisture content increase due to the freeze and thaw in the single surface water absorption test into account, which is one of the important factors for concrete frost deterioration. Therefore, the purpose of this paper is to propose a new method for evaluating the concrete frost resistance using the critical degree of saturation method considering the moisture increase due to freeze and thaw. Furthermore, concrete frost deterioration in the actual environment has been predicted by this method as well.

Firstly, the single surface water absorption test considering moisture content increase by freeze and thaw has been employed base on the critical degree of saturation test, and the results were compared with the critical degree of saturation Scr. However, the effect of the moisture content increase by this method was weak, and the moisture content Scap could not get to the Scr. Therefore, the accelerated freeze and thaw test has been adopted as a test owing a stronger moisture content increase effect. In the test, except for the general measurements of the length change, relative dynamic modulus of elasticity change (RDM) and the mass change, the mass moisture content of the specimen has also been calculated. The results were then compared with the critical degree of saturation test. As a result, the moisture content increased due to freeze and thaw, and it has been clarified that the mass moisture contents at the nickpoint where the obvious change appeared in the curve of the length and RDM change were equal to the mass moisture content of the critical degree of saturation Scr. The mass moisture content at the nickpoint was defined as the critical mass moisture content Wcr, and concrete illustrated apparent damage when the critical mass moisture content Wcr was exceeded. Moreover, the freeze and thaw cycle at the nickpoint of the accelerated freeze and thaw test was defined as the critical freeze and thaw cycle Nf, and Nf was proposed as a new concrete frost resistance criterion.

In order to predict concrete frost deterioration in the actual environment, it is necessary to clarify its influence factors. The greatest effect on frost damage is the lowest temperature during freeze and thaw. Hence, the accelerated freeze and thaw test with the lowest temperature -5 ℃ and -10 ℃ and the critical degree of saturation test were conducted in this paper. Furthermore, the results were compared with the standard accelerated freeze and thaw test with the lowest temperature -18 ℃ to figure out the effect of the lowest temperature on concrete frost damage. The results showed that the critical freeze and thaw cycle Nf increased as the lowest temperature increased, and the critical mass moisture content Wcr was not affected by the different lowest temperatures. In addition, a formula has been proposed to convert the Nf calculated by the test with different lowest temperatures to the Nf achieved in the standard accelerated freeze and thaw test with the lowest temperature -18 ℃.

It is reckoned that obvious frost damage occurs when the frost effect of the actual environment surpasses the Nf of concrete specimens. Therefore, the concrete specimens were subjected to the outdoor exposure test and the temperature and the relative humidity (RH) of the specimens have been measured. The frost effect of the outdoor exposure with different lowest temperatures has been converted to the freeze and thaw cycle Nf* by the formula proposed above. Concrete specimens are regarded as damaged when the frost effect Nf* exceeded Nf. Besides, the specimens after the outdoor exposure were conducted with the accelerated freeze and thaw test and it has been confirmed that the Nf decreased after the outdoor exposure. These results indicate the possibility of predicting concrete frost damage deterioration by Nf. In the future, it is necessary to clarify the influence of other influence factors (drying, outdoor exposure duration, etc.).

This dissertation is composed of five chapters. The outline of each chapter is listed as follows.

Chapter 1 is the introduction of the current stage for concrete frost resistance evaluation methods and the previous achievement on concrete frost deterioration. Besides, the detail of the accelerated freeze and thaw test and the critical degree of saturation test were explained. The problems of the two tests have been proposed and the purpose of this study was exhibited.

In Chapter 2, the single surface water absorption test considering moisture absorption by freeze and thaw has been conducted. Based on this, the relationship between the accelerated freeze and thaw test and the critical degree of saturation test were conducted. The mass moisture contents at the nickpoints of the length and RDM were similar to the mass moisture content of Scr. The freeze and thaw cycle at the nickpoint, which was a new concrete frost resistance criterion, was defined as the critical freeze and thaw cycle Nf and its mass moisture content was designated as Wcr.

Chapter 3 examined the effect of the lowest temperatures on the Nf. The Nf achieved by the accelerated freeze and thaw test with different lowest temperatures were compared with the Nf calculated by the standard accelerated freeze and thaw test. As a result, the relationship between the lowest temperature and its corresponding Nf was clarified, and the conversion formula was proposed.

In Chapter 4, the frost deterioration in the actual environment has been predicted by Nf. It is supposed that concrete specimens are damaged by freeze and thaw as the environmental frost effect reaches Nf. The temperature and the relative humidity of the specimens were measured for one year and its frost effect has been converted to Nf* by the formula proposed in Chapter 3. Moreover, the specimens after the outdoor exposure were conducted with the accelerated freeze and thaw test to verify the frost effect of the outdoor exposure.

Chapter 5 is the summary of the results obtained from Chapters 2-4 and presents further research challenges.