ABSTRACT

Title Improvement of Durability for Concrete Bridges in Cold Climate

Doctor Course in Civil Engineering Doctor of Engineering

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［Abstract］（1,000words，10points，single space）

Concrete, because of its good plasticity, versatility, and low cost is widely used in the construction of all kinds of infrastructures such as roads, bridges, dams, and tunnels. However, the durability of concrete structures in cold climates has always been the focus of attention. In the cold region of Japan, many existing reinforced concrete (RC) structures currently are suffering from multiple deteriorations such as frost damage, the chloride ion attack, alkali-silica reaction (ASR), and granulated concrete due to severe environment and climates, which seriously restricted its service life and function.

As we all know, in cold regions, road and bridge deterioration is a common phenomenon main related to frost attack. Deicing salt is widely used to ensure the driving safety of vehicles in winter. When the average temperature less than -3℃ in winter and the deicing salt was sprayed approximately 20 t/km per year according to the report in the Tohoku region of Japan. For this reason, the Tohoku Regional development bureau has published the manual for the countermeasure to frost damage of concrete structures under spreading deicing salt. This manual was proposed to increase the target air content of fresh concrete on site. That is to cover the decreasing of air content while the execution process of construction and to attain air content in hardened concrete. In the case of concrete structures under the most severe environment on frost damage risk, the W/B less than 45% and the target air content of 6% were requested. However, study on the deicing salt scaling resistance and the distribution characteristics of air voids during the entire construction execution phase are not clear yet.

Furthermore, maintenance management for extending the service life of the existing RC structures becomes particularly critical in recent years. Nevertheless, the increase in maintenance management will inevitably lead to an increase in maintenance costs, which seriously restricts the development of the modern social economy. In the Tohoku region of Japan, over 40% of bridges will reach a service life of more than 50 years by 2025, which means a large number of bridges would have potential risks on its performance, according to the Ministry of Land. In other words, the great majority of existing RC bridge structures are about to or have entered a large-scale rehabilitation and reconstruction period. Therefore, the fabrication of durable concrete is of great significance to green and sustainable development. This thesis focuses on improving the concrete durability for bridge structures in cold climate via the survey of surface air permeability of existing RC bridge substructures (Non-destructive testing, NDT), laboratory tests, tests of concrete frost resistance at various stages of the actual

construction process, and a novel exploration of curing method. Around this subject, the main research contents and conclusions are as follows:

(1) The influence of the initial curing on air permeability and the deicing salt scaling resistance of surface concrete were investigated. These results showed that concrete curing with sheet or permeability formwork was better than curing in air with in-creased of duration. Especially, utilizing the form of permeable sheet is greatly effective for the attainment of high surface quality and durable concrete. Simultaneously, focus on cold weather concreting, could evaluate the appropriate curing period including additional curing from combining with the surface air permeability and the deicing salt scaling resistance of concrete. It is also decided that the concrete has better deicing salt frost resistance, when the surface air permeability coefficient is less than $1\times10^{-16}m^2$.

(2) To obtain high-durability concrete suitable for cold climates, the deicing salt scaling resistance, alkali-silica reaction (ASR), restrained and free shrinkage, and the visual evaluation of RC bridge slab surface cracks were conducted in the laboratory and field. These results indicated that concrete with FB cement has a better deicing salt scaling resistance, however, it has little difference in terms of deicing salt scaling resistance regardless of cement types and W/B ratios, when the air content of fresh concrete reaches 6%. Concrete (especially for low W/B ratios) with BB cement has better resistance for ASR expansion, autogenous/drying shrinkage under re-strained/free conditions, and cracking.

(3) The air void system of RC bridge slabs of Mount Aobuna No. 1 Bridge and Shinyanagibuchi Bridge were studied. The results revealed that the air void frequency increase with W/B ratio decrease, especially the diameter 0-200μm. Confirming the air void in the range of 0-200μm was one of the significant factors for featuring the distribution of air void and the spacing factor. Moreover, the dosage of the expansive agent has little influence on deicing salt scaling resistance of concrete. PP fiber can improve the anti-scaling performance of concrete surfaces, however, the curing methods of fiber concrete would be one of the significant factors to determine the surface scaling resistance. It is proved that wet curing is helpful to the frost resistance of PP fiber concrete.

(4) The effects of the individual or hybrid addition of superabsorbent polymers (SAP) with varying dosages (0.1%, 0.2%, 0.3%, and 0.6%) and the lime-type expansive agent (KEA) on the length and mass change, compressive strength, and pore structures (MIP) of mortars were investigated. The results showed that the incorporation of SAP can effectively mitigate its autogenous shrinkage and the length change value of the mortar with SAP smaller than Ref until 49 d, regardless of the presence of KEA. The hybrid addition of SAP and KEA increase the initial expansion of the specimens as compared with individual addition of SAP, which is a beneficial effect on compensating for the shrinkage of the mortar under drying conditions. Moreover, the addition of SAP seems to delay cement hydration and increase the volume of macropores (greater than 100 nm), thereby reducing the compressive strength of the mortars. The introduction of KEA slightly promoted the formation of micropores, resulting in a slight increase in compressive strength compared with the samples without KEA. Furthermore, in our view, it promotes pore refinement, so as to re-duce moisture evaporation.

(5) The influence of different SAP incorporation methods and different SAP and KEA contents on internal curing effect the shrinkage behavior and compressive strength of concrete were studied. The results showed that the concrete with pre-soaked SAP, due to the clustering of pre-soaked SAP in the fresh concrete, it is difficult to uniformly distribute in the concrete matrix, resulting in the formation of larger pores in the hardened concrete.

However, the existence of these larger pores did not adversely affect the compressive strength of concrete. In addition, when the surface of concrete was exposed for 63 days under drying conditions, the wet residue range of the concrete samples with pre-soaked SAP was larger than that of the concrete samples with dry SAP powder. The combined effect of SAP and KEA is beneficial to mitigate the autogenous shrinkage of concrete and delay the drying shrinkage, regardless of the incorporation methods of SAP. The voids created by SAP and air-entraining agent have a negative impact on the compressive strength of concrete. The compressive strength decreases with the increase of SAP contents, regardless of the incorporation methods of SAP. In addition, when the SAP content is 0.3%, its compressive strength is greater than or close to the concrete samples with 5% air content.

To sum up, this work has tried to improve the durability of concrete in cold areas through laboratory and field research, thereby extending the service life of the RC structures and reducing subsequent maintenance costs. The research results and recommendations provide a little technical contribution for casting durable concrete in cold climate.

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