Japan Society of Civil Engineers Concrete Committee, Investigative Research Subcommittee on Frost Resistance of Concrete Structures (359 Committee)

## 1. Introduction

Data on frost damage are continuously accumulated through survey results and exposure test results of concrete structures in cold regions. Furthermore, new technologies for improving the frost damage resistance of concrete structures are being researched and developed. These technologies include hollow microspheres made of resin that relieve the expansion pressure associated with freezing and thawing and chemical admixtures that can entrain fine bubbles even when admixture materials are used. On the other hand, while the JIS has standardized the evaluation and design method of frost damage resistance of concrete structures and the freeze-thaw test for internal damage, there is no test or design method for surface damage. Against this background, a JSCE concrete subcommittee, the Investigative Research Subcommittee on Ensuring Freezing Damage Resistance of Concrete Structures (359 Committee, Chairman: Shunsuke Hanehara, Professor Emeritus Iwate University, Vice-Chair: Ichiro Iwaki, Professor of Nihon University), was formed in May 2019 and was active until October 2021. Recognizing the need to manage performance over the life cycle of a concrete structure, the subcommittee organized the findings from both the latest research results and the current state of practice.

## 2. Outline of research

### (1) Mechanism of frost damage in actual structures

Regarding the mechanism of frost damage in concrete, the committee investigated in detail salt-scaling studies from the last few years. The investigation showed that the deterioration mechanism is affected by the concentration of the antifreeze solution and the minimum temperature. Also investigated was frost damage in existing structures, mainly road bridges and railway bridges, which are structures where frost damage is likely to occur. Examples of countermeasures were reported.

### (2) Test method and durability design

A test method is required for evaluating the freeze-thaw resistance to internal and surface damage (scaling). The JIS only specifies JIS A 1148, which assesses resistance to internal damage. However, the results of the relative dynamic elastic modulus test may be unreliable if the specimen is damaged. On the other hand, JIS has not established a test method for evaluating resistance to scaling. Therefore, the subcommittee collected test data and information from previous studies and overseas test standards. This report organizes that data and information and presents the results.

Regarding the durability of concrete structures against frost damage, the JSCE Concrete Standard Specification [Design] divides the inspection into internal damage and scaling. However, a method for quantitatively determining the design value and the limit value does not exist to verify scaling. As a result of research into predicting scaling on concrete structures in Hokkaido, a method has been proposed that determines the maximum value of the water-cement ratio according to the environmental action shown in Table 1.

(3) Construction

Changes in the amount of air and the distribution of air bubbles in fresh concrete are significant factors in the effect of the construction of concrete structures on frost damage resistance. Therefore, the subcommittee evaluated how changes in the amount of air, the bubble spacing coefficient, and the bubble diameter distribution in fresh concrete due to the pumping and compaction of concrete affect the frost-damage resistance of concrete. An overview of the findings of various studies shows that pumped concrete tends to have fewer fine bubbles, while overly compacted concrete tends to have fewer coarse bubbles. Different concrete materials and types of chemical admixtures were also studied to determine their effects on the frost-damage resistance of concrete structures. The hollow microspheres of the new technology shown in Table 2 and various data on the improvement of frost damage resistance of concrete structures and the influence of the freshness and strength characteristics of concrete and the construction method were included in the studies. Although these studies confirmed the effectiveness of hollow microspheres, it is necessary to continue standardizing the design and construction methods of concrete structures using hollow microspheres.

(4) Maintenance

Actual concrete structures were investigated for deformation of the appearance, the state of the concrete, and the environmental action. For example, 3D scanners and digital cameras were used for quantitatively and accurately evaluating the depth and amount of scaling in concrete structures. As a result of these investigations, a method for visualizing cracks inside the structure has been proposed. Moreover, a device has been developed to measure the distribution of bubbles in concrete on-site. This device measures the amount of air and the bubble spacing coefficient without collecting a core sample. This new technology allows for more accurate life cycle management by evaluating the state of the structure and using the data in laboratory tests and durability design.

## 3. Conclusion

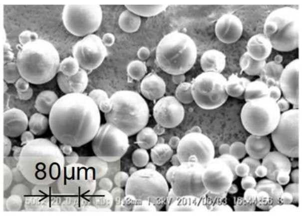
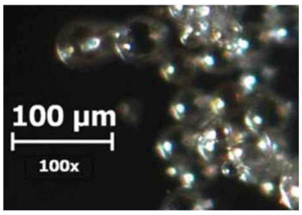
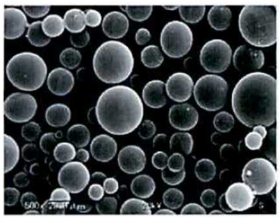
The 359 Committee has organized data and other information about the current state of technology related to frost-damage resistance of concrete structures and clarified issues for future study. It is hoped that this work will improve the durability and the life-cycle management of concrete structures regarding frost damage.

Table 1. Water-cement ratio required to keep the average scaling depth within 2 mm after 100 years

<table>
<tr><th rowspan="2">Freezing damage risk</th><th rowspan="2">Freezing damage risk value</th><th colspan="2">Ordinary Portland cement</th><th colspan="2">Blast furnace cement type B</th></tr>
<tr><th>Anti-frost damage agent Spray less than 50 times/year</th><th>Anti-frost damage agent Spray 50 times/year or more</th><th>Anti-frost damage agent Spray less than 50 times/year</th><th>Anti-frost damage agent Spray 50 times/year or more</th></tr>
<tr><td>0</td><td>0～200</td><td rowspan="5">55%</td><td>55%</td><td rowspan="2">55%</td><td>54%</td></tr>
<tr><td>1</td><td>201～500</td><td>54%</td><td>49%</td></tr>
<tr><td>2</td><td>501～800</td><td>52%</td><td>51%</td><td>46%</td></tr>
<tr><td>3</td><td>801～1100</td><td>50%</td><td>48%</td><td rowspan="4">45% or less▲</td></tr>
<tr><td>4</td><td>1101～2000</td><td>49%</td><td>46%</td></tr>
<tr><td rowspan="2">5</td><td>1401～2000</td><td>53%</td><td>47%</td><td rowspan="2">45% or less▲</td></tr>
<tr><td>2001～2500</td><td>51%</td><td>46%</td></tr>
</table>

・One outbound trip + one inbound trip is defined as 'one spraying.'
・Spraying 50 times / year is equivalent to 7.3t / km / year
・The amount of air is 4.5%
・▲ is used in combination with moisture contact suppression measures

Table 2. Hollow microspheres

| Principal component | Photo | feature | remarks |
|---|---|---|---|
| ① Acrylic resin system |  | ・Special admixture for frost damage countermeasure concrete<br>・Particle size: 10～100 μm (Average particle size: 80 μm)<br>・True density: 0.13 g/cm$^3$ | KIND AIR<br>(Denka Co., Ltd.) |
| ② Acrylonitrile-based polymer |  | ・White wet powder<br>・density: About 0.2 g/cm$^3$<br>・Standard addition amount: 1.5～4.0 kg/m$^3$ | MasterAir 150MHK<br>(Pozzolith Solutions Ltd.) |
| ③ AN-based copolymer |  | ・Very lightweight with an actual specific density of 0.02 to 0.04 g/cm$^3$<br>・Average particle size: 30-60 μm<br>・Wet plastic micro balloon with a solids content of about 10% | Matsumoto Microsphere<br>(Matsumoto Yushi-Seiyaku Co., Ltd.) |