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FROST RESISTANCE OF CONCRETE

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ABSTRACT

The article describes the factors affecting the frost resistance of concrete and the frost resistance of concrete, as well as the development of the theory of frost resistance of concrete, the causes of deterioration of concrete under the combined effect of water and cold.

Keywords: Concrete, cement, frost resistance, freeze-thaw cycle, porosity, strength.

Concrete has established itself as an effective material for creating a wide range of unique structures for various purposes due to its high physical and mechanical properties, fire resistance and strength. It is necessary to further expand the knowledge of concrete in order to identify new opportunities for improving the efficiency, reliability and frost resistance of concrete and reinforced concrete structures.

Water expands by about 9% when it freezes. When water in wet concrete freezes, it creates pressure in the porous parts of the concrete. If the resulting pressure exceeds the tensile strength of the concrete, the voids expand and crack. The accumulation of successive freeze-thaw cycles and the breakdown of the bond between cement and aggregates can eventually lead to expansion, cracking and spalling of the concrete.

The harmful effect of freeze-thaw cycles on concrete is the main cause of concrete deterioration in cold areas. Freeze-thaw damage of concrete is a complex physico-chemical phenomenon that begins with the internal microstructure of concrete. For example, during the freeze-thaw cycle, the pore structure of concrete deteriorates, thereby increasing the permeability of the concrete, and freeze-thaw damage is accelerated by the ingress of external water and erosive media. Surface erosion of concrete occurs due to freeze-thaw cycles and increases the risk of reinforcement corrosion. The main condition for improving the frost resistance and service life of concrete is to understand the deterioration mechanism in the freeze-thaw environment.

Many researchers have studied the damage mechanism of concrete in the freeze-thaw environment. Building on previous freeze-thaw theoretical studies, recent research suggests that concrete damage in freeze-thaw environments is not a single factor, but rather a combination of crystallization pressure, ice expansion pressure, and low-temperature suction.

There are many advances in the performance and micromorphology of concrete during freeze-thaw cycles, which are divided into macro and micro damage at different research scales. On the basis of macroscopic studies, damage to concrete is studied with the help of experimental indicators such as the surface condition of the material, mechanical property testing, ultrasound, acoustic and resistance. In mesoscopic studies, nuclear magnetic resonance and computer tomography methods are mainly used to determine the crack propagation and pore parameters of concrete. The development of microcracks and porosity in the sample is studied using a parameterized damage model. At the micro-level, most of the studies analyze the microscopic pore structure of cement-based materials using scanning electron microscopy and mercury intrusion porosimetry.

The development of the theory of concrete's frost resistance is characterized by many hypotheses about the causes and mechanisms of concrete failure under the combined influence of water and cold. The role of water expansion during freezing is also taken into account in modern hypotheses, but this physical phenomenon alone cannot fully explain the concrete failure process. In this regard, the works carried out in the 1930s and 1960s in the development of the theory of frost resistance of concrete are of great importance.

Summarizing various hypotheses, including the basis of the theory of moisture migration in porous bodies, it should be noted that the mechanism of structural damage of concrete in a state of alternating freezing and thawing in a water-saturated state is very complex.

According to the state standard, the number of freezing and thawing cycles is regulated as the number of temperature transitions from 0 °C. Frost resistance of concrete is primarily determined by the structure of its pore space. Three main types of pores are formed in concrete: cement gel pores with sizes in the range of (15...40) $\cdot 10^{-10}$ m, capillary pores (0.01...1 mm) and conditionally closed pores (10...500 µm). Relatively large pores are formed even when the concrete is not reinforced.

Capillary pores formed by excess water are the main defect in the structure of concrete, which negatively affects its resistance to cold. Conditionally closed pores include air bubbles in cement stone and concrete.

Total pore volume, size, and specific surface area can be controlled by incorporating air-entraining or gas-generating additives. The air voids obtained as a result of the introduction of air-permeable additives into the concrete mix significantly change the structure of the concrete. The number of air pores in 1 cm^3 of cement stone can reach one million, and the surface of these pores is 200...250 cm^2. Through this surface, excess water enters the pores and moves out of the capillaries when the concrete freezes. Only sufficiently small air holes of less than 0.5 ... 0.3 mm are considered to have a protective effect.

Water in most capillary pores freezes at temperatures down to -15°C. With a further decrease in temperature, water freezes in thinner pores, and almost all water freezes at temperatures of -70...-80 °C. Comparative determination of concrete's frost resistance by freezing at -17 and -50°C showed that in the second case, the deterioration of concrete is accelerated by 6...10 times.

The volume of open pores, which affects the volume of frozen water, depends on the water-cement ratio (W/C) and the degree of hydration of the cement (the percentage of cement that has chemically reacted with water after a certain setting time). With an increase in the water-cement ratio, both the total volume of open pores and their average size increase, which also has a negative effect on frost resistance. When designing frost-resistant concrete, it is common practice to limit W/C depending on the working conditions of the concrete in the structures. In order to ensure high frost resistance of concrete, it is recommended to have W/C in the range of 0.4...0.5, and water consumption should not exceed 160 kg/m^3.

The degree of hydration of cement depends on the activity of cement, the intensity of its growth over time, and the duration of concrete hardening. The period of cement storage has a significant effect on its resistance to cold. The presence of shells of hydrated minerals on cement grains is one of the main reasons for reducing the durability of concrete.

The frost resistance of concrete is significantly affected by the interaction of fillers and their water demand. From the point of view of frost resistance, the properties of fillers are important, which determines their adhesion to the cement stone and the modulus of elasticity.
Plasticizing additives increase the frost resistance of concrete due to the reduction of water demand and, accordingly, capillary porosity and specific gravity. The air-tight admixture increases the frost resistance of concrete. Air-tight additives are prepared as concentrated solutions, thick pastes or dry, easily soluble powders. Wood resins, oil products, vegetable oils and other raw materials are used for the preparation of additives. Most often, additives based on wood resin are used as air-permeable substances. They are added to concrete mixtures in the amount of 0.01 ... 0.02% by weight of cement. At the same time, the volume of added air is 30...60 l/m^3. The frost resistance of concrete increases several times with air-entraining additives. With air-tight additives, the frost resistance of concrete increases several times.

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