

## Optional reference method to determine frost resistance of concrete

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**Abstract.** The main purpose of this research is to create the new reference method to determine the freeze-thaw resistance of concrete that is characterized by small labor inputs, high efficiency and a wide scope application. The offered method is based on the measurement of long strength by a nondestructive method.

During this research, the theoretical analysis of concrete specimen dependence on freeze-thaw resistance and energy, which is emitted by a specimen during destruction, has been carried out. Freeze-thaw resistance of a specimen is calculated as the mathematical relation of these energies, and the freeze-thaw resistance of concrete is calculated as an arithmetic mean across specimens.

Correctness of the offered method is proved by experiments. The offered method doesn't demand long tests. It is highly efficient and has a wide scope, but special further laboratory test duration is needed.

**Key words:** frost resistance; concrete; long-term strength; dilatometric method; non-destructive loading; acoustic issue; relative tension set; durability of concrete

### *Introduction*

Although there is a variety of modern construction materials and technological research in this area, concrete remains the most convenient material. It is a multipurpose and widespread material which is used in construction of buildings and structures. The most important properties of concrete, which show themselves at the design stage of objects, are durability of concrete in terms of compression/tension, water resistance and freeze-thaw resistance. In climatic conditions of northern latitudes, where the North West region of Russia is located, the latter property is considered the most important one.

Freeze-thaw resistance of concrete is an ability of a water-saturated concrete specimen to withstand repeated standard thermal cycles without noticeable damage. Different types of water pressure cause freeze-thaw deterioration of concrete, such as hydraulic and osmotic pressure [1], capillary pressure [2] and other types of water impact according to the existing freeze-thaw resistance theory [3]. Decreasing strength of a construction material is caused by water freezing in it (for example, rock [4]). Water gets into the structure of porous bodies, separates particles and breaks bonds between them [5]. Porosity of a material is a crucial factor for frost resistance and, subsequently, durability [6, 7]. So, the strength of concrete could be represented as a porosity function [8]. In order to determine the composition of concrete mix, it is necessary to take into account freeze-thaw resistance.

### *1. Scope and Objectives of Project*

International experience offers some test methods to determine durability of concrete by freeze-thaw damage, such as Slab test [9], CDF [10], CIF-Test [11] and Cube-Test [12]. These test methods include the following steps: curing and preparing specimens, pre-saturation of specimens and their thermal cycling. The test liquid simulates a deicing agent and contains 3 % of NaCl weight and 97 % of (demineralized) water weight in case of the freeze-thaw test and deicing salt resistance and demineralized water to test the freeze-thaw resistance of concrete respectively. Scaling of specimens is measured after a well defined number of freeze-thaw cycles and resistance of the tested concrete against freeze-thaw damage is evaluated. Test methods, however, vary in terms of their procedures and conditions. Moreover, the CIF test determines internal damage by measuring the relative dynamic modulus of elasticity (by taking into account ultrasonic transit time) [13]. In addition, there are some models of labor concrete damage due to cyclic freezing and thawing, for example, interaction of load and freeze-thaw cycles with chloride exposure regime on surface scaling of concrete and internal cracking process [14].

There are two different standard types of methods to determine freeze-thaw resistance of concrete: basic one [15] and reference one [16] in the Russian Federation.

If freeze-thaw resistance of concrete is evaluated by the basic method, a considerable random dispersion of values of concrete strength (variation coefficient  $\rho = 15 \dots 20 \%$ ) [17] under invariable conditions of production and tests of specimens gives rise to a wide range of average values of strength, which requires a large volume test (quantity of test pieces 25 ... 50) as a proof that relative decreasing in strength of  $\Delta R/R = 0,05 \dots 0,15$  occurs as a result of freezing and defrosting.

Therefore, basic methods have two main weaknesses: high labour input and low operability. Determination of freeze-thaw resistance by basic methods takes long-term intervals (from 1 to 6 months), so reference methods are necessary.

One of the existing reference methods is the Dilatometric rapid method to determine freeze-thaw resistance of concrete [16]. This method is a prototype of the method which has been suggested by us. In this method freeze-thaw resistance of concrete is determined by the maximum relative difference of volume deformations of the tested concrete and standard specimens in accordance with the tables provided in a standard specification [15], which take into account the type of concrete, its form and size of specimens.

However, results from the tables provided in the federal standard specification are acceptable only for Portland cement concrete and slag Portland cement concrete without surface-active additives (PEAHENS). Today such types of concrete are used extremely seldom. Now a lot of new types of concrete are investigated, tested and used, for example, nano-modified concrete [18, 19, 20], high-strength concrete [21, 22], concrete on the basis of fine-grained dry powder mixes [23], concrete with recycled concrete aggregates [24], etc. In order to obtain new tables, long labour-consuming experiences, which imply using basic methods, are needed [25, 26]

This project is aimed at elaborating techniques to determine freeze-thaw resistance of concrete rapidly, decrease labour input and increase operability.

## 2. Suggested Method to Determine Freeze-Thaw Resistance of Concrete

A solution has been suggested which belongs to test methods of porous water-saturated bodies and is intended to define the type of concrete in terms of freeze-thaw resistance. The main goal has been reached in the prototype by producing a series of specimens from concrete mix and specimens sated with water, measure specimens, and freezing them down to the standard temperature. The suggested method includes the following important steps:

- measurement of relative tension set of a specimen  $\Theta_{ten}$  after one cycle of freezing and defrosting by dilatometer (a DOD-100-K dilatometer was used);
- measurement of the biggest nondestructive loading  $L_0$  of a specimen under stretching by acoustic methods for nondestructive testing of concrete [12] (an AF-15 AE-complex by Kishenevskiy was used) to determine the specimen's long-term strength  $R_{lt}$  under stretching;
- measurement of the short-term strength  $R$ .

At present, the concept of the biggest non-destructive loading  $L_0$  is usefully employed for express-monitoring of different kinds of long-term resistance, such as durability (mechanical and exogetical, remaining life of the product, longevity [27, 28], freeze-thaw resistance [29], cracking resistance, erosion behaviour [30], corrosion [31] and time-dependent deformation [32].

The damage of concrete that occurs during freezing is explained by subcritical cracks growth. In brittle solids, cracks start growing due to a shearing action [33] and they develop at a speed of no more than  $10^{-4}$  m/s [30, 34]. Therefore, in the conditions of freezing water, the filled crack in concrete captures the nearby closed pores. It stabilizes pressure in the water of the filled crack by about the value causing tensile stress in the material which equals to the long-term strength of a specimen under stretching [30]. If the temperature of the body changes from 78 K to 1493 K and the loading is the same as described above, the  $L_0$  value shifts inside its deviation determination, i.e. 1÷3 %. This fact allows using the  $L_0$  value obtained at a low temperature when the energy per unit of the specimen's volume that is disseminated in the course of freezing-defrosting is defined.

If  $L_0$  is determined, it is possible to calculate the long-term strength  $R_{lt}$  of the specimen in the conditions of stretching:

$$R_{lt} = \frac{2L_0}{\pi S}, \quad (1)$$

where  $S$  is the area of a specimen's section perpendicular to compression planes;  
 $L_0$  is the biggest non-destructive loading of a specimen under stretching.

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Definition of a relative tension set and long-time strength of a specimen allows evaluating the energy disseminated in the processes of destruction during  $W_{tc}$  freezing-defrosting by formula:

$$W_{tc} = \theta_{ten} R_{lt}, \quad (2)$$

where  $\theta_{ten}$  is a relative tension set of a specimen;  
 $R_{lt}$  is a long-term strength of a specimen under stretching.

Loading of a specimen in the conditions of monoaxial compression under extreme loadings, registration of these values of axial loadings and axial strain correspond to the loads that allow calculating energy per unit of the specimen's volume disseminated in the course of its compression under extreme loadings by numerical integration of dependence of axial loading on axial strain. The value of the energy disseminated in the unit of volume of a specimen under compression under extreme loads is in proportion to the square value of the short-term strength [35]:

$$W_{com} = \alpha R^2, \quad (3)$$

where  $R$  is a short-term strength;  
 $\alpha$  is a proportionality coefficient.

The logarithmation and differentiation of expression (3) allow calculating the specimen's freeze-thaw resistance  $F_{sam}$  by formula:

$$F_{sam} = 2[\Delta R / R] \cdot \frac{W_{com}}{W_{tc}}, \quad (4)$$

where  $[\Delta R / R]$  is a standard relative decreasing in terms of strength ( $[\Delta R / R] = 0,05 \dots 0,15$  [4]);  
 freeze-thaw resistance of concrete is found as average values of freeze-thaw resistance for specimens.

### 3. Implementation of the Method Suggested

This method is implemented as follows. First, specimens are made in the form of cylinders or cubes with edges of 10 cm from concrete mix of the demanded structure. After that curing specimens are sated with water, and measured. Further, the biggest non-destructive loading of  $L_0$  is defined for each specimen by non-destructive testing, for example, an acoustic emission method [36]. Without outreaching  $L_0$ , cracking of a specimen does not develop yet in the conditions of stretching.  $R_{lt}$  is calculated by formula (1). After the specimen is frozen and defrosted up to the standard temperatures and definition  $\theta_{ten}$  it is possible to calculate  $W_{tc}$  by formula (2).

Further, a specimen is squeezed in the conditions of monoaxial compression under extreme loadings, and current values of the axial loading and relative tension corresponding to a specimen are registered. Freeze-thaw resistance for a  $F_{sam}$  concrete specimen is calculated according to the received results by formula (4). Freeze-thaw resistance of concrete is found as an average value of freeze-thaw resistance for specimens. The confidential interval of freeze-thaw resistance of concrete is calculated according to dispersion of values of freeze-thaw resistance for a series of specimens.

In particular, this technique was implemented on 10 specimen cubes with the edge of 10 cm, aged 88 days and made of concrete mix of the following structure: Brand 400-1 Portland cement weight part, sand – 2 weight parts, granite rubble 5 ... 20 mm – 4.5 weight parts, waters – 0.6 weight parts. It is experimentally defined in two different ways for this concrete aged 88 days that after 105 freezing-defrosting cycles corresponding to this concrete type in terms of freeze-thaw resistance, the average relative decrease in strength makes 0.142 on a way [30] and 0.16 on the basic way [15], that both values lie within an error of the used ways. On average, relative decrease in strength amounts to 15 %.

Specimens were sated with water according to the item's federal standard specification, measured and registered volume. For each cube sated with water, splitting according to the item value of the biggest nondestructive load (without which excess of a crack in a specimen which has not developed yet is irreversible) has been defined. After each test the plane of compression of a specimen was changed for the perpendicular plane to previous compression. Definition of the greatest nondestructive loading is carried out by means of an acoustic emission way [37] with the use of an AF-15 AE-complex by Kishenevskiy. Acoustic sensors with the frequency of 20–200 kHz were installed on the edge of a specimen, parallel to the plane of compression. In order to create an axial loading, a hydraulic press was used. The value of the long-term strength of a specimen in stretching was defined by the received value of the greatest nondestructive loading corresponding to it. Then the average value of the long-term strength was defined, too. The results of calculation are given in the table.

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Water-saturated specimens were placed in the measuring camera of a DOD-100-K differential volume dilatometer and tested according to the standard [17]. According to the dependency diagrams of differences, relative volume tension set of a concrete and aluminum specimen was calculated. Energy per unit of specimen's volume disseminated in freezing-defrosting is defined by formula (2) for each specimen.

Further average value of long-term strength of the specimen being stretched was defined as arithmetic average  $R_{it}$  of long-term strength values in the conditions of stretching.

Axial compression of specimens at the speed of 400 kg/sec was carried out on a hydraulic press equipped with the graph plotter of dependence of axial loading on axial strain. By the dependence received on the graph plotter the area under it was determined, i.e. the energy disseminated per volume of a specimen in the course of its compression under extreme loads was received.

Then for each brand of a concrete specimen freeze-thaw resistance values were calculated, (table) as the number of freezing defrosting necessary to decrease its strength by 15 % is defined by formula (4).

Further, the average  $F_{15}$  for values of  $F_{15i}$ , and average square deviation of results of experience were calculated:

$$S = \frac{\sqrt{\sum (F_{15i} - \bar{F})^2}}{3}, \quad (5)$$

where S is an average square deviation of the experience results;

$F_{15i}$  is specimen concrete value in terms of freeze-thaw resistance at decreasing short-term strength of the specimen under compression by 15% was received in the suggested way; where i is changed from 1 to 10;

$\bar{F}_{15}$  is freeze-thaw resistance of concrete equal to the arithmetic mean value of freeze-thaw resistance for a series of concrete specimens at decreasing their short-term strength under compression by 15 %.

The average square deviation of  $F_{15i}$  values is equal to 16. Considering this, the divergence of the freeze-thaw resistance average value of concrete is considered to be 99.7 and the earlier experimentally found number of cycles is 105 (F15 brand) which is necessary to decrease R by 15 %. It is possible to consider these data casual, and the suggested way is correct.

**Table. Definition of the type of concrete in terms of the freeze-thaw resistance according to the suggested method**

№	$\bar{R}_t, \text{MPa}$	$\theta_{ten} \cdot 10^4$	$W_{tc} \cdot 10^4, \text{MPa}$	$W_{com} \cdot 10^4, \text{MPa}$	$[W] \cdot 10^2, \text{MPa}$	$F_{15i}$
1	1,5	2,7	4,05	0,9990	2,997	74
2	1,7	3,1	5,27	1,7215	5,165	98
3	1,8	1,8	3,24	1,2312	3,694	114
4	1,9	2,6	4,90	1,6796	5,039	102
5	2,0	2,5	5,00	1,4333	4,300	86
6	2,1	1,9	4,00	1,4364	4,309	108
7	2,2	2,6	5,72	2,2308	6,692	117
8	2,3	2,1	4,83	1,3846	4,154	86
9	2,9	1,8	5,22	1,6008	4,802	92
10	3,1	1,5	4,65	1,8600	0,558	120
Average	2,15	2,1	4,69	1,5577		99,7

## Conclusions

The suggested technique extends a list of technical means for the rapid method to determine freeze-thaw resistance of concrete. Duration of determining the freeze-thaw resistance of concrete is caused by a long time of the specimen's water saturation (4 days according to standard specification [17]). At present, there is a pending patent application for the suggested method. Detailed research and pilot experimental studies are necessary to get more data and create a new method to determine the freeze-thaw resistance of concrete in the future.

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