Environment. Technology. Resources, Rezekne, Latvia
Proceedings of the 10th International Scientific and Practical Conference. Volume I, 170-174

Accelerated method for the determination of freeze-thaw resistance of concrete

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Abstract. **Main purpose of this research is to create the new reference method of determining the freeze-thaw resistance of concrete that is characterized by small labor input, high efficiency and a wide application scope. The offered method is based on measurement of long strength by nondestructive method. During this research, the theoretical analysis of concrete's 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 value across specimens.**

To prove the method correctness it was realized on 10 concrete specimens. Age of specimens cosolidation is 88 days. Speciments of concrete mortar were prepared using a mix of portland cement 400 (12,3%), sand of dimentions 0.6-5 mm (24,7%), granite macadam of dimentions 5-20 mm (55,4%) and water (7,4%). Freeze-thaw resistance such mortar was determed earlier by method, approved national standard specification, it was equal 105 cycles. According dimentions by new offered method freeze-thaw resistance such mortar is equal 107 cycles and its confidence interval is equal 5,4 (probability P = 0,95). Therefore, spread of results could be casual and the offered method is correct.

Keywords: **concrete, freeze-thaw resistance, permanent set, durability, monitoring of strength, freese-thaw cycling.**

I INTRODUCTION

This Despite a variety of modern construction materials and technological research in this area, concrete remains more convenient material. It is a multipurpose and widespread material which is used during construction of buildings and facilities. The most important properties of concrete, which demonstrate themselves during the design phase of objects, are concrete's durability in terms of compression/stretching, waterproofing and freeze-thaw resistance. In climatic conditions of northern latitudes in which the North Western region is located as well, the last property is considered to be the most important one.

Freeze-thaw resistance of concrete is an ability of water-saturated concrete specimen to maintain repeated standard thermo cycles without noticeable damage. Different types of water pressure cause concrete's freeze-thaw deterioration, such as hydraulic and osmotic pressure [1], capillary pressure [2] and other types of water influence according to existing freeze-thaw resistance theory [3]. In order to determine the concrete mix composition, it is necessary to take into account freeze-thaw resistance.

II PROJECT SCOPE AND OBJECTIVES

In order to keep comfortable microclimate inside of structure [4] measurement of durability of concrete is of grave importance [5]. The Worldwide experience offers a vast number of ways for determination of durability of the concrete structures [6], but accordingly to the European standard [7,8] there four main methods to determine the concrete frost resistance: Slab test, CDF, CIF-Test and Cube-Test. These test methods contain the following steps: curing and preparing the specimens, pre-saturation of the specimens and their thermo cycling. The test liquid simulates a deicing agent nd contains 3% of NaCl weight and 97% weight of (demineralized) water 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 the specimens is measured after a well defined number of freeze-thaw cycles and leads to an estimate of the resistance of the tested concrete against freeze-thaw damage [9]. The test methods however differ in terms of their procedures and conditions [10]. Also CIF test shows determination of internal damage by measuring the relative dynamic modulus of elasticity (taking into account ultrasonic transit time) [11].

ISSN 1691-5402

DOI: http://dx.doi.org/10.17770/etr2015vol1.205

There are two different standard types of methods of determining the freeze-thaw resistance of concrete-basic [12] and reference [13] in the Russian Federation.

During the estimation of freeze-thaw resistance of concrete by the basic method, considerable random dispersion of values of concrete strength (variation coefficient ρ = 15 … 20%) [14] under invariable conditions of production and tests of specimens gives rise to a wide scatter of average values of strength and demands large volume test (quantity of test pieces 25 … 50) as a proof that relative decreasing in strength of ΔR/R = 0,05 … 0,15 as a result of freezing and defrosting.

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

One of the existing reference methods is a Dilatometric rapid method of determining the freeze-thaw resistance of concrete [13]. This method is a prototype for the method which has been offered by me. In this method concrete's freeze-thaw resistance is determined by the maximum relative difference of volume deformations of the tested concrete and standard specimens in accordance with tables provided in standard specification [12] taking into account concrete's type, its form and the size of specimens.

However, the results from the tables provided in state standard specification are acceptable only for Portland cement concrete and slag Portland cement concrete without surface-active additives (PEAHENS), such concretes are used extremely seldom now. In order to obtain new tables long labour-consuming experiences which imply using basic methods are needed [15].

The objectives of the project is expansion of methods of rapid determining the freeze-thaw resistance of concrete, decreasing labour input and increasing operability.

III OFFERED METHOD OF DETERMINING THE FREEZE-THAW RESISTANCE OF CONCRETE

Suppositive solution belongs to test methods of porous water-saturated bodies and is intended for definition of a concrete brand in terms of freeze-thaw resistance. The main purpose has been reached both in the prototype by production of specimens' series from concrete mix, specimens sated with water , measure specimens, and freezing up to the standard temperature. However, the offered method includes the following important steps:

- Measurement of the relative tension set of a specimen Θ_{ten} after the one cycle of freezing defrosting by dilatometer (here the DOD-100-K dilatometer has been used).
- Measurement of the greatest nondestructive loading L_0 of a specimen in the conditions of stretching by acoustic methods for the nondestructive testing of concrete [16] (here AF-15 AE-complex by Kishenevskiy has been used) to determinate specimen's long-time strength Rlt in the conditions of stretching.
- Measurement of the short-term strength R.

At present the concept of greatest non-destructive loading L_0 is usefully employed for express-monitoring of different kinds of long resistance, such as durability (mechanical [17] and exegetical [18], remaining life of the product [19], longevity [20, 21], freeze-thaw resistance [22,23] and cracking resistance [24]. Moreover, there are a vide scope of modern concrete mixtures, such as light-weighted concrete [25], vibropressed structures [26], hight- performance concrete [27], concretes with additives [28, 29]. These are also porous materials and, therefore, should be tested for frost-resistance.

In time of freezing, development of concrete's damages is explained by subcritical cracks growth. In brittle solids cracks begin taking off by a shearing action [30], also the speed of their development is no more than 10-4m/s [31]. Therefore in 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 stretching tension in a material equal to long-time strength of a specimen in the conditions of stretching [32]. If the body's temperature changes from 78 K to 1493 K and the loading is as described earlier, the L0 value shifts inside of deviation determination of it, i.e. 1÷3%. This fact permits using the L0 value received at low temperature when the energy per unit of the specimen's volume which is disseminated in the course of freezing-defrosting is established.

If L_0 is determined, it is possible to calculate a specimen's long-time strength R_{lt} in conditions of stretching:

$$R_{lt} = 2L_0/\pi S \tag{1}$$

where: S – area of a specimen's section perpendicular to compression planes;L0 – the greatest non-destructive loading of a specimen in the conditions of stretching;

Definition of a relative tension set and long-time strength of a specimen allows estimating the energy disseminated on processes destructions in the course of freezing-defrosting W_{tc} as per formula:

$$W_{tc} = \theta_{ten} R_{lt} \tag{2}$$

where: θ_{ten} - relative tension set of a specimen; R_{lt} - specimen's long-time strength in the conditions of stretching.

Specimen's loading in the conditions of monoaxial compression to extreme loads, registration of these values of axial loads and axial strain is corresponding to loads, which allows calculating energy per unit of the specimen's volume which is disseminated in the course of its compression to extreme loads by numerical integration of dependence of axial loading from axial strain. Value of the energy disseminated in the unit of volume of a specimen in the course of its compression to extreme loads is in proportion to a square value of short-term strength [28]:

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

where: R – short-term strength; α – proportionality coefficient.

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

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

where: [ΔR/R] - standard relative decreasing in terms of strength ([ΔR/R] = 0,05 … 0,15 [4]);

Concrete's freeze-thaw resistance is found as an average of freeze-thaw resistance values for specimens.

IV REALIZATION OF THE OFFERED METHOD

Suppositive This method is realized as follows. First of all specimens in the form of cylinders or cubes with an edge of 10 cm from concrete mix of demanded structure are made. After that curing specimens are sated with water, and measured. Further greatest non-destructive loading of L0 is defined for each specimen by a non-destructive testing, for example, an acoustic emission method [29]. Without outreaching L0, a specimen's crack doesn't develop yet in the conditions of stretching. R_{lt} is calculated as per formula (1). After specimen's freezing-defrosting up to the standard temperatures and definition Θten it is possible to calculate W_{tc} as per formula (2).

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

In particular, this way has been realized across 10 specimens cubes, an edge of 10 cm at the age of 88 days made of a concrete mix of such 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 established in two different ways for this concrete at the age of 88 days that after 105 freezing-defrosting corresponding to this concrete brand in terms of freeze-thaw resistance, average relative decreasing in strength makes 0,142 on an offered way and 0,16 on the basic way [12], that is both values lie within an error of the used ways. On the average relative decreasing in strength amounts to 15%.

Specimens have been sated with water according to the item's state standard specification, measured and registered volume. For each cube sated with water, splitting according to the item value of the greatest nondestructive load (without which excess of a crack in a specimen which doesn't develop yet is irreversible) have been defined. After each test the plane of compression of a specimen has been changed for the perpendicular plane to previous compression. Definition of the greatest nondestructive loading carried out by means of an acoustic emission way [30,31], using the AF-15 AE-complex by Kishenevskiy. Acoustic sensors with a frequency of 20-200 kHz have been established on the verge of a specimen, parallel to plane of compression. For creation of axial loading a hydraulic press has been used. Value of a specimen's long-time strength in the conditions of stretching has been counted by the received value of the greatest nondestructive loading, corresponding to it. Then average value of a long-time strength has been counted too. Results of calculating are given in the table.

The water-saturated specimens have been placed in the measuring camera of the DOD-100-K differential volume dilatometer and have been tested according to the standard [14]. According to the dependency diagrams of differences, relative volume tension set of a concrete and aluminum specimen have been calculated. Energy per unit of specimen's volume disseminated in the course of its freezing-defrosting as per formula (2) for each specimen.

Further average value of the specimen's long-time strength in the conditions of stretching has been defined as arithmetic average R_{lt} long-time strength values in the conditions of stretching.

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

Then for each brand of a concrete specimen freeze-thaw resistance values have been counted, (table 1) as number of freezing defrosting necessary for decrease in its strength by 15% is achieved by formula (4).

Further, an average $\overline{F}_{15}$ for values of the F_{15i}, and an average square deviation of results of experience have been calculated:

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

where: S – an average square deviation of experience results; F_{15i}- i-specimen concrete value in terms of freeze-thaw resistance at decreasing specimen's short-term strength in the conditions of compression by 15% have been received by the offered way; where i is changed since 1 to 10; $\overline{F}_{15}$ – concrete's freeze-thaw resistance equal to an arithmetic mean value of freeze-thaw resistance for series of concrete specimens at decreasing their short-term strength in the conditions of compression by 15%.

The average square deviation of F_{15i} values was equal 16. Taking this into account, a divergence of the average value of freeze-thaw resistance of concrete is considered to be 99,7 and the earlier experimentally found number of cycles is 105 (F15 brand) which is necessary for decreasing R for 15%. It is possible to consider these data casual, and the offered way is correct.

TABLE I

DEFINITION OF THE CONCRETE'S TYPE IN TERMS OF THE FREEZE-THAW RESISTANCE AS PER OFFERED METHOD

№	$\overline{R}_{lt}$ [MPA]	$\Theta_{TEN} \cdot 10^4$	$W_{TC} \cdot 10^4$ [MPA]	$W_{COM} \cdot 10^4$ [MPA]	$[\Delta W] \cdot 10^2$ [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

V CONCLUSIONS

The offered way expands a list of technical means for the rapid method of determining the freeze-thaw resistace 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 [11]). At present this method was pattented [33]. Detailed researches and pilot experimental studies are necessary to get more data and create new method of determining the freeze-thaw resistance of concrete in the future.

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