

Concrete Deformations under Simultaneous Impact of Loading and Alternate Freezing and Thawing

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Abstract. To the best knowledge available today, the creep of concrete is understood as slow plastic deformation caused by continuous external factors. Changes occurring in the structure of concrete are however not discussed. Creep as a phenomenon is typically perceived “in purity”, in an invariable and favorable environment. Evolution of creep deformations thus has a fading character and usually goes along with consolidation of concrete. It is only under loads near the threshold of concrete’s long-term strength that micro-destructions tend to grow during the first phase following application of the load. Creep phenomenon is researched «in pure form», i.e. in constant favorable external conditions. Developing of creep deformations has fading character and accompanied by seal of concrete. In real exploitation conditions of constructions appears changes in temperature and humidity, influencing on development of creep deformation. Alternate freezing and thawing of concrete, which most affects durability, causes in unloaded concrete significant extension deformations. Deformation development under the joint action of loads and alternate freezing and thawing almost was not researched. In the article presented results of concrete deformation research, differing by frost resistance, under loads in the range from 0,2 to 0,7 of prismatic strength.

1. Introduction

The most detailed research of concrete creep was performed in the period from 1960 to 1975 and led by V.M. Moskvin, A.A. Gvozdev, O.Ya. Berg. Recently, significant attention has been paid to structural changes of concrete under load. Rheological models have been offered to predict and calculate creep deformations [1,2,3] in a sufficiently reliable manner and reflect them in design standards [4].

The most detailed knowledge was obtained for concrete creep in the ambient air environment under normal positive temperatures [5;6;7;8]. Humidity impact on creep deformation evolution was reflected in papers [9;10] to allow these factors to be accounted for in design standards. The impact of positive temperature variations was investigated in papers [11,12]. Creep deformation slowdown under negative temperatures was noted in papers [13;14; 15] which is caused by improved strength of frozen concrete [15]. However, in paper [14] investigating the concrete sample creep within the temperature range from

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+20°C to -20°C it was noted that the deformation increased as ice was formed in concrete. The creep stops if the temperature continues decreasing. The creep increase of frozen concrete samples with high water saturation was also noted in paper [16]. This type of creep deformations indicates that they are associated with changes taking place in concrete during freezing.

Destruction of unloaded concrete under alternate freezing and thawing is accompanied by significant expansion deformations [17]. Sufficiently detailed data on deformation evolution caused by the simultaneous impact of tensile stresses and alternate freezing of concrete can be found in paper [18]. These data allow deflection design values of bending reinforced concrete structures to be adjusted.

Deformation development caused by the simultaneous impact of compressive stresses and alternate freezing and thawing of water-saturated concrete has been insufficiently investigated. According to paper [19], expansion deformations along the load axis are not observed under simultaneous compressive stresses (40% of concrete prism strength) and alternate freezing and thawing. Instead, fading compressive deformations 6 times higher than creep deformations under the same load and normal conditions take place. The paper also notes that the difference in deformations flattens under lower load values.

The above data indicate that deformations of reinforced concrete structures subjected to multiple freezing and thawing cycles may develop which are not taken into account in present-day creep calculations. Such deformations in pre-stressed structures may result in the loss of pre-stress exceeding design values.

Loaded concrete deformation under alternate freezing and thawing may be considered as creep deformations. However, this creep has a specific nature as it is related to water-saturated concrete destruction under negative temperatures. Build-up of deformations is accompanied by concrete softening and strength degradation.

2. Basic Part

In the light of foregoing, a research was carried out to study deformation data and take them into account when designing structures operating under alternate freezing and thawing. Techniques. 10 x 10x 40 cm concrete samples mounted in a levered disk spring loading device and 2.5 x 2.5 x 25 cm samples loaded with high-strength rods running through the sample center were subjected to freezing and subsequent thawing in sea water.

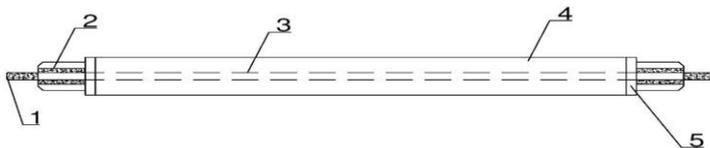


Fig. 1. Loading diagram for sample sized 2.5 x 2.5 x 25 cm:

- 1- taper socket for mounting on the deformation gage;
- 2 – screw nut; 3- 6 mm rod; 4 - concrete sample; 5 - 6 mm washer.

Before concreting, the rods had been treated with a special substance to prevent their bonding with concrete. The sample was evenly loaded across the complete cross section using 6 mm thick steel butt plates. The load value was determined using three techniques: by reading the gauge indication of the torque wrench used to strain the rod; checking the rod and concrete sample deformations. Prior to this, the torque wrench had been calibrated

using a special device equipped with a reference load indicator. The rod elasticity modulus was checked at the same time.

10x10x40 prism deformation was measured using a portable dial gauge strainmeter mounted between prism buttresses (30 cm base). Measurements were performed every 10-15 alternate freezing and thawing cycles. Before commencing the measurement, the strainmeter and reference steel sample were kept exposed to build up the ambient temperature at which the measurements were conducted. Temperature correction for the device deformation was determined using the following formula:

$$\Delta L = aL(t_1 - t_1) + (A_0 - A_1), \text{ where:}$$

a – steel line expansion coefficient;

L – reference standard length;

t - ambient temperature of deformation measurements;

t - constant temperature the measurements were reduced to;

A - reading for steel reference standard at $t = t$;

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2.5 x 2.5 x 25 cm prism deformation was also measured every 10-15 alternate freezing and thawing cycles. A desktop dial gage strainmeter was used. Sample contraction deformations over the period between the measurements did not exceed $2 \cdot 10^{-4}$. At the same time concrete stress decreased by $\Delta\sigma < E_a \cdot \varepsilon \cdot F_a / F_\sigma = 1,8 \cdot 10^6 \cdot 2 \cdot 10^{-4} \cdot 0.196/6 = 11.7 \text{ kg/cm}^2$, which amounts to no more than 10% of the original value. After each deformation measurement, the original concrete stress level of the sample was restored followed by the dynamic elasticity modulus measurement.

Results. The deformation measurement results for the 10 x 10 x 40 cm prisms are shown in Fig. 2. The broken line indicates creep deformation of concrete of the given mix which is not subjected to alternate freezing and thawing. As it is seen, there is a significant difference in the development nature of the regular creep and that caused by alternate freezing and thawing.

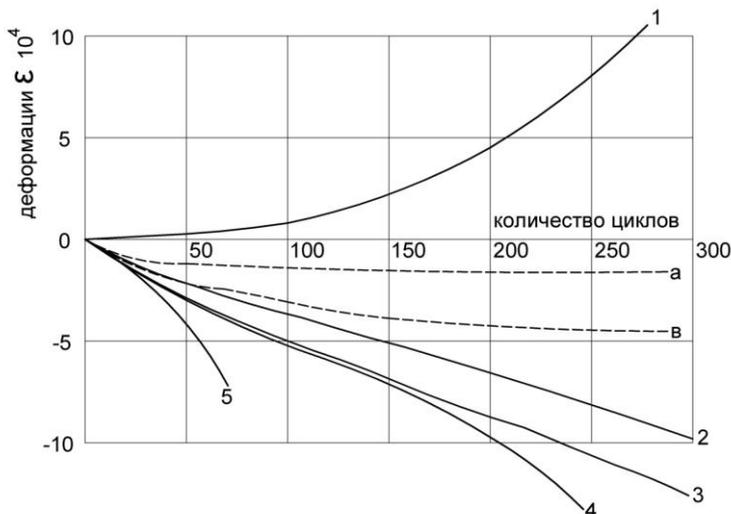


Fig. 2 - Deformation growth in prisms sized 10 x 10 x 40 cm

1 – $\sigma=0$; 2- $\sigma=0.2 R_{np}$; 3- $\sigma=0.4 R_{np}$; 4- $\sigma=0.6 R_{np}$; 5- $\sigma=0.7-0.8 R_{np}$;

a – $\sigma=0.2 R_{np}$; b- $\sigma=0.6 R_{np}$ (under normal conditions)

At $\sigma = 0.2$ and $0.4 R_{np}$, the deformation increase is proportional to the number of cycles. At $\sigma = 0.6$ and especially at $0.8 R_{np}$, deformation development attains a progressive nature which is caused by the formation of micro-cracks and degradation of concrete strength at the given load values. This is confirmed by ultrasonic velocity measurements in the samples.

$2.5 \times 2.5 \times 25$ cm prism deformation measurement results are shown in Fig. (additive-free mix) and Fig.4 (mix with modified air entraining resin added). The dotted curves in Fig. 3 reflect the creep development in samples of the identical mix (at $\sigma = 0.5$ и $0.7 R_{np}$), not subjected to alternate freezing and thawing cycles.

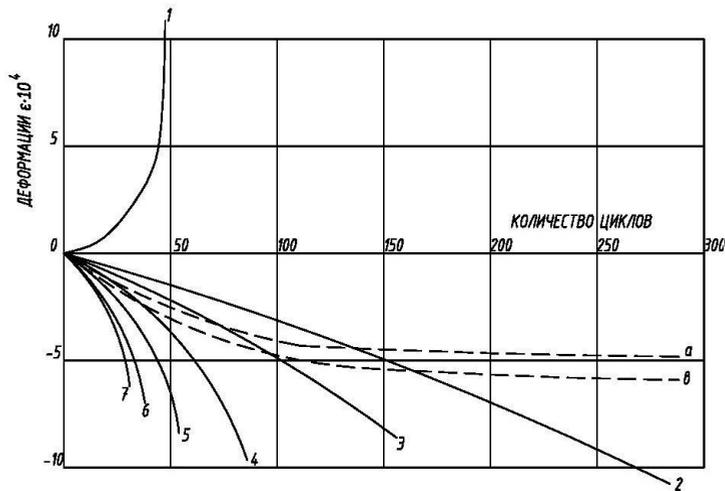


Fig. 3 – Deformation growth in prisms $2.5 \times 2.5 \times 25$ cm (no additives, $R_{np} = 39$ MPa)

1 – $\sigma = 0$; 2 – $\sigma = 0.2 R_{np}$; 3 – $\sigma = 0.3 R_{np}$; 4 – $\sigma = 0.4 R_{np}$; 5 – $\sigma = 0.5 R_{np}$;

6 – $\sigma = 0.6 R_{np}$; 7 – $\sigma = 0.7 R_{np}$; a – $\sigma = 0.5 R_{np}$; b – $\sigma = 0.7 R_{np}$ (under normal conditions)

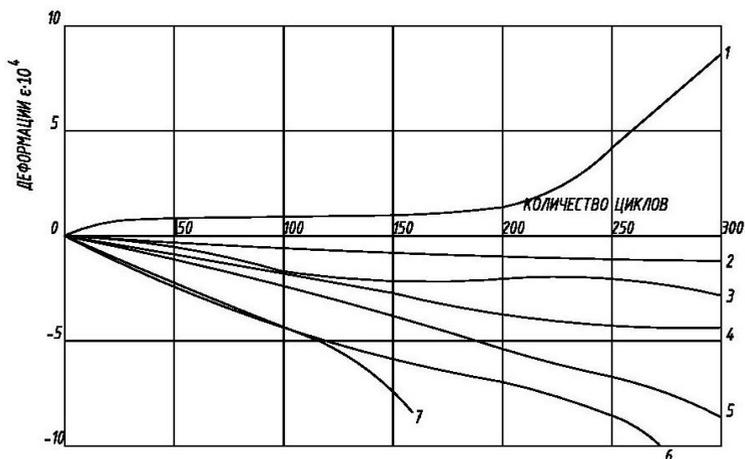


Fig. 4 Deformation growth in prisms $2.5 \times 2.5 \times 25$ cm (mix with modified air entraining resin added, $R_{np} = 37$ MPa)

1 – $\sigma = 0$; 2 – $\sigma = 0.2 R_{np}$; 3 – $\sigma = 0.3 R_{np}$; 4 – $\sigma = 0.4 R_{np}$; 5 – $\sigma = 0.5 R_{np}$;

6 – $\sigma = 0.6 R_{np}$; 7 – $\sigma = 0.7 R_{np}$

As seen from the diagrams, in all the cases the additive-free samples display residual deformations significantly higher than regular creep deformations at the same load value. Deformations develop in a progressive manner at stresses exceeding 0.3-0.5 R_{np} for all additive-free sample batches. At the same time, the highest deformations by the moment of destruction were displayed by the samples with the lowest loads which had survived the biggest number of cycles before destruction.

Test results confirm the data found in paper [19]. In the diagram (Fig. 2), one can see, that at 0.4 R_{np} the contraction deformations are 5 times higher than creep deformations occurring at the same force level under normal conditions. However, such a variance is typical for the concrete with the strength below 30 MPa. At a higher strength, the difference decreases. At 45-50 MPa, deformations (at $\sigma=0.4 R$) vary by 3-4 times. In concrete types with added modified air entraining resin the difference in deformations flattens. (Fig. 4).

Concrete structure modification by adding modified air entraining resin resulted in a significantly improved freeze-thaw resistance and changes in the nature of deformation development due the fact that the additive created reserve "relatively closed" porosity not filled with water under alternate freezing and thawing (Fig. 4). Absolute deformation values in samples with added modified air entraining resin are 3-5 times lower than in additive-free samples (at the same strength). At $\sigma = 0.2-0.4 R_{np}$, not exceeding the R boundary, the nature of sample deformation development differs insignificantly from the creep under regular conditions. However, as the strain increases, the deformations also grow. Ultrasonic measurements in 10 x 10 x 40 cm samples and elasticity modulus measurements in all tested samples indicate that the creep deformation rate and concrete destruction rate under alternate freezing and thawing are correlated. Creep deformations are the highest in the samples where strength degradation and concrete structure softening occur faster, while expansion deformations in unloaded twin samples are the highest too.

3. Conclusion

Based on performed tests, the following key factors affecting the creep nature under compression and alternate freezing and thawing can be identified:

1. During ice formation, moisture migration in the direction of growing ice crystals in the largest pores takes place [20; 21]. At the same time, dehydration of smaller "gel" pores occur which facilitates creep deformations. Therefore, increased creep may take place during concrete freezing without structural damage.

2. It is known that at stresses exceeding the micro-crack formation boundary R, creep rate increase is related to the growth of micro destructions in time. At the same time, if the stresses do not exceed durability limits, micro destructions fade in time and the creep becomes linear. If water-saturated concrete freezes under load, ice formation is accompanied by the development of micro-cracks and new micro-defects which result in persistent nature of creep deformations.

3. Concrete structure softening and concrete strength degradation take place under multiple freezing and thawing. Therefore, the level of relative stress increases from cycle to cycle and results in increased creep.

4. Moisture migration under alternate freezing and thawing is restricted in freeze-thaw resistant concrete (with added modified air entraining resin) and micro-defect either develop slowly or do not develop at all. In this case, under stresses below the R boundary, deformations do not differ significantly from creep under normal conditions.

5. The presented data allow a well-informed selection of concrete specifications during the design process to be performed and potential increase in operational structure

deformations resulting in increased bending and decreased reinforcement pre-stress value to be taken into account.

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