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Research the influence of acoustical treatment of concrete on its water absorption

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Abstract. The problem of the influence of the technological seam of concreting on the performance of reinforced concrete structures was studied. The requirements of the current regulatory documents on the construction of the working seam of concreting and the existing proposals on increasing the adhesion of "new" and "old" concrete in Russian and foreign sources are considered. The methodology of carrying out and the results of an experimental study of the effect of acoustic treatment of concrete on its moisture absorption in combination with the following technological factors are presented: the type and pH of the medium (penetrating composition), the orientation of the layers of "old" concrete with respect to the plane of moisture absorption. In the course of this study, the frequency of free vibrations of the structural elements of concrete samples was calculated. The conclusions are formulated that will serve as the basis for drawing up technological maps for the organization of the working seam of concrete structures.

1. Introduction

When building and reconstructing buildings and structures from reinforced concrete constructions, an important role is played by ensuring a reliable contact between the cured and newly stacked concrete [1-7]. When erecting monolithic reinforced concrete structures, high demands are placed on the structure of working seams. As is known, their presence leads to a decrease in the load-bearing capacity of the structure, even in the absence of defects in the structure [8-10].

According to normative documents [11], before concreting it is necessary to provide a number of requirements related to cleaning the surface of contact from dirt, oil, snow and cement film; washing with water and air-drying; achievement of concrete strength of at least 1.5 MPa, depending on the method of processing the concrete surface, as well as the perpendicularity of laying the concrete mixture relative to the axis of the concrete columns and beams, the surface of the slabs and walls.

In addition, the factors that also affect the amount of adhesion of previously laid concrete with newly laid are known:

- the greatest increase in the strength of the working seam is observed at its structure temperatures close to 0 °C [12];

- the increased temperature of the concrete mixture with respect to the colder base ("old" concrete), which leads to a mass transfer of moisture in the concrete mix [13,14].

In previous experiments [15], the influence of the following technological parameters on penetration of the new medium into previously laid concrete was determined: type of environment (acidic, neutral, alkaline); concentration and/or pH of the medium; presence of a cement film on the contact surface; nature of the location of layers concrete with respect to the plane of contact with newly laid concrete (parallel or perpendicular).

The works [16,17] devoted to the investigation of the influence of ultrasound, acoustic and electromagnetic fields on the rate of drying and impregnation of modified concrete showed that the efficiency of mass transfer in materials depends not so much on the properties of concrete, the temperature of the impregnating composition as on the frequency of power characteristics-field strength. This observation is explained by the fact that the applied fields destroy the structure of the liquid, as a result of which its viscosity decreases and mass transfer accelerates.

It is logical to assume that with the organization of the technological seam of concreting, the acoustic impact will also affect the structure of the concrete of the newly added formulations and lead to an acceleration of mass transfer, which will qualitatively affect the adhesion of the "new" and "old" concrete.

In addition to the foregoing, it should be noted that high-frequency sound vibrations can cause changes not only in the newly added composition and its rheological properties playing a role in penetrating the structure of "old" concrete, but also directly affect the "old" concrete, leading it to conditions of increased adhesion abilities.

In the conducted experiment, the influence of acoustic treatment of concrete on the first stage of interaction of a liquid medium with concrete samples (during the first three minutes) on the final value of moisture absorption of concrete was investigated.

2. Methods

Based on the results of the studies [15], in this experiment, two series of concrete samples were also prepared, which differed in the way the concrete mix was packed into a cylindrical shape:

- parallel to the plane of the sample cross-section;
- perpendicular to the plane of the sample cross-section.

Depending on the method of laying the concrete mixture in the mold, the samples were characterized by different arrangement of the layers of concrete laying in relation to the plane of moisture absorption: parallel or perpendicular, respectively (Figure 1).

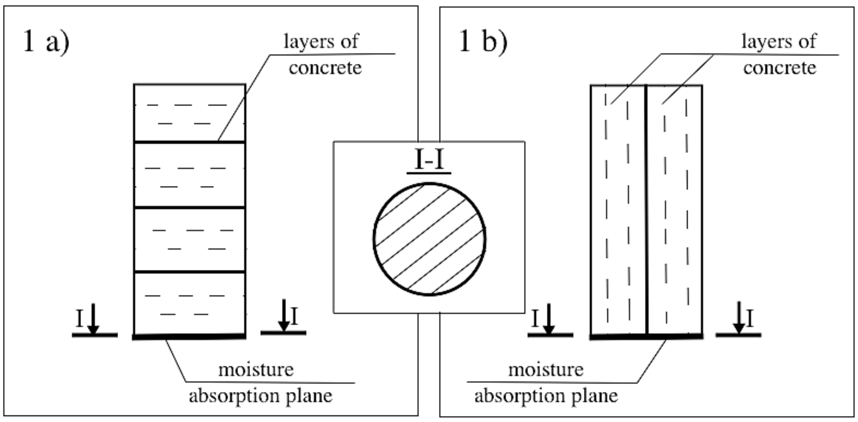

Figure 1. Layout of layers of concrete in the samples: 1a - parallel character of layers of concrete relative to the plane of moisture absorption; 1b - perpendicular character of layers of concrete relative to the plane of moisture absorption.

In the experiment conducted for the moisture absorption of concrete, a mass of concrete absorbed by concrete samples was adopted. Since the concrete mixture has the properties of a heavy liquid [18], aqueous solutions were used as media.

Concrete samples had a cylindrical shape with the following dimensions: diameter - 10.5 cm, length - 20 cm. Molding of the samples occurred using standard polyethylene pipes.

For the experimental samples, concrete of class B30 was used. The choice of the class was determined by its prevalence for the manufacture of prefabricated and erected monolithic reinforced concrete structures. The composition of the concrete, the characteristics of its components and properties are presented in Table 1.

Samples were held for 28 days under normal hardening conditions. After removing the samples from the molds, the entire surface of the samples was waterproofed, with the exception of the lower face, through which the moisture absorption process subsequently took place.

Table 1. Characteristics of concrete.

Materials	Characteristics	Normative document	Consumption per 1m3, kg
Cement	PC400-D20 LAFARGE	GOST 30515-2013. Cements. General specifications	500
Sand	ρ =2,69 g/cm3; ρsatuer. = 1,54 g/cm3;	GOST 8736-2014. Sand for construction works. Technical specifications.	540
Crushed stone	Fraction 5…20 mm	GOST 26633-2012. Concretes heavy and fine-grained	1190
Water	Filtered	GOST 23732-2011 Water for concrete and mortar. Technical specifications.	212
Slump = 4 cm; R28 = 32,7 MPa			

In earlier experiments [15], the effect of stripping of the contact surface from the cement film on the moisture absorption of concrete was revealed. The unconsolidated concrete surface of the contact zone contributes to moisture saturation, however, leads to the appearance of an interlayer with a lower density and, correspondingly, strength (cement film). The presence of a cement film in the zone of the technological seam concreting is not desirable. For this reason, the contact surface of concrete samples with liquid media was cleaned with a metal brush.

Next, some of the samples were placed directly in the container with liquids. The parameters of the liquids used to create different media are given in Table 2. Solutions were selected in such a way that they in their chemical composition had compounds that are part of most concretes [18,19]: CaO; MgO; NaCl; SiO2; Al2O3; Fe2O3; CaCO3.

Table 2. Liquids parameters.

Name of solution	Chemical formula of solution	Concentration (density) of the solution, g/l (g/cm3)	pH	Type of medium
Distilled water	H_2O	– (0,998)	7,0	neutral
Aqueous solution of sodium chloride	NaCl	229,5 (1,148)	7,3	neutral
Aqueous solution of sodium bicarbonate	$NaHCO_3$	10,06 (1,008)	10,5	alkaline
Aqueous solution of sodium bicarbonate	$NaHCO_3$	84,65 (1,055)	11,0	alkaline
Aqueous solution of magnesium sulphate	$MgSO_4$	20,36 (1,018)	5,5	acid
Aqueous solution of magnesium sulphate	$MgSO_4$	160,7 (1,067)	5,0	acid

The other part of the samples was prepared for further experiments under acoustic conditions according to the following scheme:

- the first stage - the interaction of the penetrating composition (liquid medium) with concrete samples during the first three minutes under conditions of acoustic processing;
- the second stage - the aging of concrete samples in a penetrating composition under normal conditions.

The moisture saturation of concrete samples was studied for 210 hours, which was due to the possibility of the presence in the newly laid concrete of a disconnected liquid component.

In order to select the parameters of the experiment, the necessary frequency of sound oscillations was calculated, which corresponds to the frequency of free vibrations of the elements of the structure of concrete samples.

The oscillation frequency is determined by the following formula [20]:

$$f = \frac{1}{T} \tag{1}$$

where T – period of oscillations taken equal, sec:

$$T = 2t \tag{2}$$

here t – time of passage of a sound wave in a medium, sec.

A point located at a distance x from the point of excitation, will perform oscillatory movements, trailing for a time t, necessary for the passage of a wave of distance x [21]:

$$t = \frac{x}{c} \tag{3}$$

where c – speed of sound wave in the medium under consideration, m/s; x - characterized by the particle size h, m.

A significant difference in the moduli of elasticity of coarse aggregate and cement stone [19] is the basis for the assumption of conditional freedom of vibrations of large aggregate particles. We calculate the frequencies of the natural free oscillations of the particles of a large aggregate of concrete and a concrete sample.

According to the reference data [22], the speed of sound in concrete varies in the range 4200 m/s - 5300 m/s.

The particle size is determined by the fraction of the aggregate of the concrete mixture and is 5 ... 20 mm. Accordingly, the frequency of oscillations of particles with extreme values of the dimensions of the aggregate:

- with h_1 = 5mm (0.005 m) – f = 420.2 ÷ 529.1 kHz
- with h_2 = 20mm (0.02 m) – f = 105.0 ÷ 132.5 kHz

The range of frequencies of natural oscillations of particles of a large aggregate of concrete according to the resulted calculations has made 105,0 - 529,1 kHz.

According to the above formulas, we calculate the natural frequency of free vibrations of a concrete sample: the sample height h = 20 cm (0.2 m) – f = 10.5 ÷ 13.25 kHz. The frequency range of the natural oscillations of the experimental sample according to the above calculations was 10 500 - 13 250 Hz.

However, the obtained frequency values cannot be realized in the conditions of the construction site. In addition, the frequencies obtained in the calculations exceed the normalized value of the frequency of sound vibrations that affect human health [23]. Proceeding from this, it was decided to conduct experiments on the effect of acoustic influence on the moisture absorption of concrete at a frequency of 4000 Hz, which is close to the frequency of bending vibrations of a sample of concrete grade B30 with the dimensions and mechanical properties indicated above. Figure 2 shows the lowest form of vibration of a concrete sample (bending, frequency 3900 Hz), obtained by finite element calculation in the ANSYS Workbench environment. Note that the nearest torsional form can appear only at a frequency of 6300 Hz, the second bend is 9074 Hz and is not realized in experiments. It is known that near-resonance modes of oscillation excitation effectively deform the sample and contribute to the closure-opening of microcracks on the surface, which in experiments in the aqueous medium leads to an increase in moisture absorption.

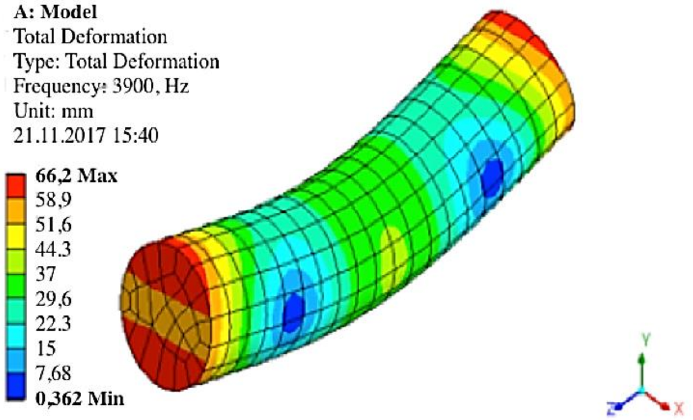

Figure 2. Shape of vibrations of a sample of concrete for bending, frequency 3900 Hz.

In the experiment, a vibrating electrodynamic stand of the VEDS-200 was used [24]. The stand consists of a generator of sinusoidal signals for controlling the frequency and amplitude of the excitation, the intermediate amplifier and the table of the exciter. Parameters of the VEDS-200 installation are presented in Table 3.

Concrete samples were installed one at a time and fastened to the table of the VEDS-200 stand according to the above scheme (Figure 3). Then the samples immersed in the solution were exposed to sound for 3 minutes, after which they were removed from the unit and placed in similar containers with the same solutions for further moisture absorption without additional influences.

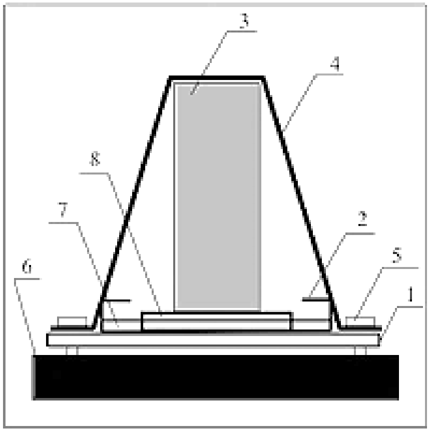

Figure 3. Scheme of mounting the sample to the VEDS-200 installation: 1 - a platform from a plywood sheet; 2 - a plastic tank; 3 - concrete sample; 4 - fixing sheet; 5 - fixing bolt; 6 table of exciter of the stand VEDS-200; 7 - used solution; 8 - gauze pad.

Table 3. Parameters of the VEDS-200 test facility.

Parameter name, unit of measure	Quantification
Maximum excitation force, H	2000
Operating frequency range, Hz:	
- nominal	20 – 2500
- extended	5 – 5000
Maximum acceleration, m/s2	400
Maximum table travel, mm	± 4,5
Maximum load mass, kg	45

3. Results and Discussion

As a result of the experiment, the dependence of the moisture absorption of solidified concrete samples on time was obtained: with the influence of sound vibrations and in their absence, for the media types under study and for two variants of the location of the concrete layers relative to the moisture absorption plane (Figure 4).

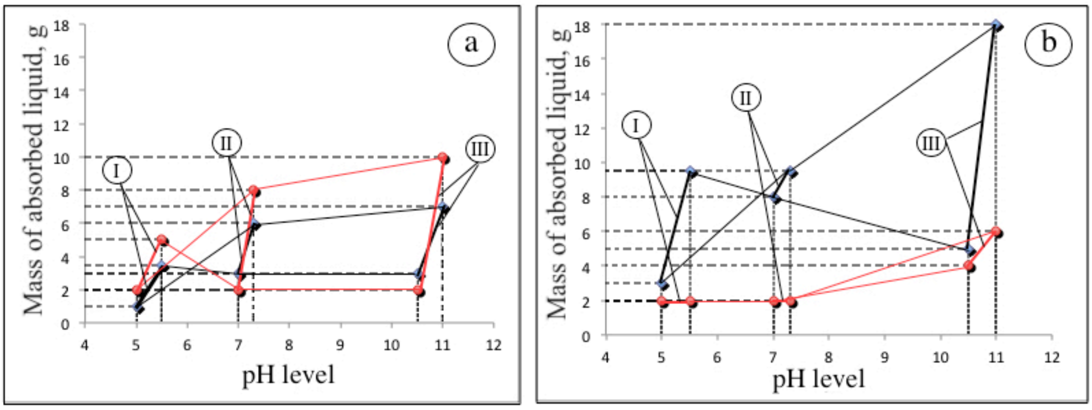

Figure 4. Moisture absorption of concrete with a different character of the location of the concrete layers relative to the plane of moisture absorption: a - parallel to the plane of moisture absorption, b - perpendicular to the plane of moisture absorption; I, II, III - acidic, neutral and alkaline medium, respectively; --- - with acoustic influence, --- - without acoustic influence.

As can be seen from the graphs, with the parallel arrangement of the laying layers of the concrete mixture in the samples relative to the moisture absorption plane (according to Figure 1), the effect of sound oscillations leads to an increase in the moisture absorption of the samples for most of the media under consideration. The increase in moisture absorption in the presence of acoustic impact is 33 - 43% of W_{210}. The positive effect of sound processing on the moisture absorption of samples is especially observed with an increase in the density of the compositions. The only exception is the medium with pH = 7 and pH = 10.5.

At a perpendicular character of the arrangement of the layers of concrete relative to the plane of moisture absorption, the reverse effect is observed. The acoustic action reduces the moisture absorption of the samples by 20 to 80% with respect to the control samples without acoustic treatment.

These regularities can be explained by the fact that in the perpendicular nature of the arrangement of the layers relative to the plane of moisture absorption, a sound wave passing through the vertically-stacked layer causes large aggregate particles to oscillate predominantly in the vertical direction, and with a parallel arrangement of the layers, the horizontally disposed layer enables particles large aggregate to oscillate and in a horizontal direction, these oscillations cause the effect of the pump, due to which walks "absorption" of solution into the space between the cement stone and gravel particles leads to increased hygroscopicity samples.

Fluctuations in the particles of coarse aggregate caused by the passage of a sound wave in vertically arranged layers, on the contrary, lead to the ejection of a new medium from the concrete structure - this is confirmed by experimental data on the decrease in the moisture absorption of samples during acoustic treatment in comparison with its absence in the perpendicular character of the arrangement of the layers with respect to plane of moisture absorption.

4. Conclusions

Analyzing the obtained data, it should be noted that the expediency of using acoustic processing of the concreting seam should be assessed in combination with other technological factors of the working seam structure:

The favorable effect of acoustic processing is achieved with a parallel arrangement of the concrete layers relative to the contact plane. The highest value of moisture absorption during acoustic treatment was shown by a sample with a parallel arrangement of layers of concrete relative to the absorption surface, kept in an alkaline solution with pH 11 (in the experiment, only the smoothed surface was considered) - W_{210} = 10 g (43% increase from W_{210} in the absence of acoustic processing).

When comparing the absolute moisture absorption of concrete samples aged in different process conditions, the maximum result was shown by a sample in contact with an alkaline medium with a pH level of 11.

Based on the results of the experiment and the data presented in [15], the main factor affecting the moisture absorption of concrete is the nature of the location of the concrete layers relative to the contact plane. Of secondary importance is the type and pH of the medium in contact with the "old" concrete. Acoustic treatment affects the process of moisture absorption of concrete, however, does not lead to a significant improvement in the moisture absorption of the sample with the maximum result of the absolute value of W_{210}, achieved by a combination of the most significant technological factors.

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