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Moisture Effect on the Ultrasonic Pulse Velocity in Concrete Cured under Normal Conditions and at Elevated Temperature

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Abstract. **The ultrasonic pulse velocity (UPV) in water-saturated concrete is higher than in dry concrete. However, moisture influence on the UPV is defined within a wide range: — from negligible to quite significant (16 per cent). The nature of "UPV − concrete moisture" correlation is also interpreted in different ways — both as linear and as exponential. This paper reviews how various degrees of moisture saturation influence the UPV in concrete when sounding is carried out by the frequently used ultrasonic testing method — the indirect transmission by using longitudinal wave pulse. Research was conducted on specimens hardened both under standard conditions and at elevated temperatures. The results show a sudden UPV increase at the degree when the maximum water absorption in concrete is achieved.**

Keywords: **concrete, nondestructive testing, ultrasonic pulse velocity, effect of moisture**

I. INTRODUCTION

By carrying out tests with the help of ultrasonic equipment, it was established that the moisture factor exerted the most significant influence on the measurement results Specifically, changes in moisture content in concrete mainly define the degree of impact of other physical and mechanical characteristics (for example, temperature and elastic properties) on the UPV in concrete. Besides, recent studies mainly based on concrete direct transmission results have shown that the moisture factor has even a more important influence on the UPV in concrete in comparison with the earlier given inferences. However, course of this research has not been described in detail. The most essential drawbacks were the lack of sufficient detail in describing the method of achieving the minimum/maximum degree of moisture saturation in concrete structure, as well as methods of determining the moisture content in the concrete of construction sites. It should be noted that specifically the above-mentioned conditions are the major ones to allow for qualitative assessment of possible UPV differences in concrete structures with various degrees of moisture saturation.

Many studies were performed in respect of the changes in the UPV in concrete depending on the degree of moisture saturation of the material. Research papers indicate that UPV in moisture-saturated concrete is higher than in dry material. Speaking about the effect of moisture saturation degree it should be admitted that it is defined within a very wide range: from negligible to quite significant [1, 2, 3, 4, 5, 6]. In particular, the change in the UPV can be up to 16%. The nature of the correlation "UPV − concrete moisture" has also received varying assessment. In some research papers, the correlation between these two physical quantities is defined as linear [7]; however, a majority of studies support the exponential model [3, 4, 6, 8].

Quite controversial data is found on the differences in the UPV for one and the same moisture content in concrete with various strength parameters. Referring to the various porosities of the hydrated cement paste, for concrete with higher strength the influence of moisture on the UPV is defined as comparatively minor compared to that of the lower strength concrete [1]. In its turn, some other research shows no evidence of any significant differences in UPV percentage changes that would depend on moisture; these conclusions have been made on the basis of the tests involving concrete with a wide strength range — B12.5...B40 [6].

Previous studies also indicated the following aspects: concrete with a higher water/cement ratio showed a higher water absorption rate, while the duration of the mix vibration did not produce any noticeable effect on water absorption and UPV [7]. The variability of UPV results and effect of the moisture in concrete hardened in the laboratory environment is wider compared to the results fixed on the building site [9].

Analysis of the requirements in various state standards (among others, repealed standards were also analysed because the data on moisture influence on the UPV contained in the currently applied standards is quite scarce) gave no clear concept of the effect that moisture produces on the UPV in concrete. As regards the standards currently applicable in the Republic of Latvia and the European Union [10], it is most likely that they are based on the once existing UK standard [11]. The mentioned standard specifies that for the same concrete the UPV may differ significantly depending on the degree of moisture present. However, this feature is explained primarily by the influence of varying hardening conditions and their impact on cement hydration without providing any explanation of whether changes of the degree of moisture are the key to changing the UPV, for example, in the time of concrete exploitation, etc. In the standard currently applicable in the USA it is stated that the UPV in moisture-saturated concrete may exceed 5% [12]. At the same time, the once existing German standard referred to the moisture producing minor effect on the propagation of the UPV in concrete [13].

The currently existing standard of the Russian Federation indicates that sounding of the building structures with the help of ultrasonic equipment may be carried out only if the relative air humidity of the surrounding environment does not exceed 70% [14]. It should be mentioned that the guidelines that were published to supplement this standard contain no other provisions that would refer to the moisture factor effect [15]. Conversely, for determination of concrete frost resistance with ultrasonic method the standard sets the following procedure: UPV in concrete should be measured at one specific level of moisture — in water saturated condition [16]. Therefore, it can be concluded that the standards currently applicable in the Russian Federation unequivocally admit the possibility of UPV variations and, accordingly, the probability of error in interpretation of the measurement results if the degree of moisture present in the tested concrete objects is not taken into account.

It should be concluded that the degree to which moisture affects the UPV in concrete raises quite a few questions. Furthermore, a practising building engineer quite frequently uses only the information contained in the manuals because scientific papers dedicated to this particular theme are not easily available. At the same time, other widely available publications [1, 5] contain references to the research results that were obtained as far away as in the middle of the last century. Therefore, this paper provides a review on how various degrees of moisture saturation influence the UPV in concrete when the most common method of ultrasonic testing is used.

For the purpose of testing concrete both on the building site and in the laboratory, the indirect transmission method is mainly used to determine the ultrasonic longitudinal wave pulse velocity. Considering that use of the results obtained on the building sites for such research appears quite complicated (at the moment of determining the UPV it is actually impossible to fix the degree of moisture for the whole volume of concrete), a decision was made to study concrete specimens that were specially manufactured for such a purpose. To obtain as much extensive information as possible, various concrete specimens were used in this research — the ones that hardened under standard conditions or at elevated temperatures. These specimens have also different compressive strength parameters.

II. Measuring Device, Specimens for Research

For this research, ultrasonic tester "UK-1401" (made in Russia) was applied, which is a frequently used device for such kind of testing both in the laboratory and in the building objects. This device has two built-in dry point contact (DPC) transducers to achieve the efficient emitting and reception of the longitudional pulses. The main technical parameters of "UK-1401" device are as follows: the path length (constant distance between the contact elements) — 15 cm, the working frequency of the ultrasonic vibrations — 70 kHz, the measuring error of the ultrasonic time and velocity — not more than ±1 % [17].

Object of the research — 9 concrete specimens (with the dimensions 15×15×15 cm) that initially were employed for research of elevated temperature impact on the UPV in concrete during concrete hardening.

After concrete specimens were manufactured they were kept in metal formwork at room temperature for two days, their surface was covered with the polyethylene film. Formwork was removed from the six specimens at the age of 2 days, while three of the specimens were left in the formwork. Three dismantled concrete specimens were placed in the standard moist room, while 6 specimens were put in the climatic chamber (3 dismantled and 3 non-dismantled specimens). The concrete hardening conditions simulated in the climatic chamber for the non-dismantled specimens corresponded to the conditions on the building sites in summer season. Namely, all faces of the specimens were partially protected from moisture evaporation during the hardening of concrete (upper surface of the specimens was covered with the polyethylene film). In the standard moist room, the constant temperature of +18 °C with the relative humidity of 95...100% was maintained, while in the climatic chamber with the constant ventilation and humidity control during 24 hours the following cycle was realized: +10 °C for 17 hours and +30 °C for 7 hours. All specimens were kept in the chambers for 28 days. Approximately a 1-cm-thick layer was cut off from the upper face of 84-day-old specimens in order to determine the possible impact of the shrinkage process on the UPV in concrete below the layer that was cut off. Comparison of the results before and after the upper layer was cut off proved how the upper layers of concrete influence the correlation between water absorption and the UPV.

To distinguish among the groups of concrete specimens that hardened in various environments, the following symbols are used: *N* — cured in standard moist room, *K* — cured in the climatic chamber (dismantled), K_V — cured in the climatic chamber (non-dismantled). Each group consists of three specimens. Study of water absorption was performed when concrete specimens were 3 years old. It should be noted that at the age of 3½ years for all groups of concrete specimens the ultimate compressive strength was determined by subjecting specimens to the destructive test. Concrete specimens that were held in the corresponding chambers for 14 days showed the following compressive strength results: *N* — 63.6 MPa; *K* — 55.4 MPa; K_V — 62.1 MPa.

III. Testing Results

In relation to the degree of saturation of concrete with water, the minimum and maximum levels of moisture were determined on the basis of stabilisation of mass and UPV values of the specimens over a relatively long period of time. Various standards [18, 19, 20, 21] state that saturation with water or drying should be terminated if the change in the specimen mass within 24 hours is less than 0.1%. However, it does not seem correct to follow the above-mentioned mass change criterion. The point is that during the experiment it was determined that the most significant change in the UPV was registered immediately after the moisture minimum or maximum levels were achieved, at the same time the concrete mass showed relatively small change.

For each specimen the sounding was carried out in three faces that were marked according to concrete compacting direction: *U* — top; *S* — side; *L* — bottom. Before sounding the mass of the specimens was determined by weighing, as well as the surface moisture was established (with the help of the measuring device "Tramex Concrete Moisture Encounter"). Each face of the specimen was tested in diagonal directions by carrying out 9 measurements.

The data provided in Table 1 show that different strength concrete (see the above information on the results of control specimens loading) failed to show any noticeable UPV variation nature that would be related to the degree of concrete saturation with water. The maximum water absorption for all groups of specimens fit within the range 5.2...5.6%, while changes in the UPV fixed for the specimens in the totally dry and maximum water-saturated condition were an average of 19%.

TABLE I

RELATIONSHIP BETWEEN WATER ABSORPTION BY WEIGHT AND ULTRASONIC PULSE VELOCITY FOR CONCRETE CURED IN VARIOUS ENVIRONMENTS

Stage[1]	1st	2nd	3rd	4th	Comparison by stages		
Concrete age, days	1008	1023	1031	1075	2/4	1/4	2/1
Environment[2]	↕	↑	↙	↓			
Designation of specimen	W_m (%) / UPV (m/s)				ΔUPV (%) / ΔUPV (m/s)		
N-1.[28]	2.3	5.6	3.3	0	19	14	4
	4614	4804	4430	4032	771	582	190
N-2.[28]	2.5	5.4	3.3	0	18	13	4
	4653	4835	4456	4111	724	542	183
N-7.[28]	2.2	5.3	3.3	0	16	12	4
	4647	4812	4546	4137	676	511	165
On average:					18	13	4
					724	545	179
K-9.[28]	1.9	5.2	3.1	0	15	9	6
	4441	4692	4403	4075	617	366	250
K-11.[28]	1.6	5.3	3.1	0	18	11	6
	4515	4786	4396	4051	735	464	271
K-12.[28]	1.6	5.4	3.1	0	20	14	5
	4493	4699	4416	3931	767	562	205
On average:					18	12	5
					706	464	242
K_V-19.[28]	2.6	5.6	3.4	0	16	11	4
	4555	4753	4385	4095	657	460	198
K_V-21.[28]	1.6	5.5	3.4	0	19	13	6
	4526	4786	4451	4020	766	506	260
K_V-24.[28]	2.2	5.3	3.3	0	21	15	5
	4511	4753	4416	3918	835	593	242
On average:					19	13	5
					753	520	233

Note:
1. [1] — the stage of water absorption process;
2. [2] — the environment before determination of the UPV:
↕ — air-dry condition ($W_m^{air\text{-}dry}$); ↑ — maximum of water absorption (W_m^{max}); ↙ — drying; ↓ — dry condition (W_m^{min}).

All dismantled specimens were kept in the climatic chamber over the period of curing; at least three specimen groups stored in the air-dry environment for a long term attracted hygroscopic moisture. This is proved by the water absorption relationships determined for 1008-day-old concrete specimens in air-dry condition, see positions $W_m^{air\text{-}dry}$ and $W_s^{air\text{-}dry}$:

curing environment (spec. group)	absorption in air-dry condition by weight ($W_m^{air\text{-}dry}$)	absorption in air-dry condition for surface ($W_s^{air\text{-}dry}$)	maximum water absorption by weight (W_m^{max})
N	2.32 %	3.70 %	5.44 %
K	1.67 %	3.20 %	5.32 %
K_V	2.13 %	3.50 %	5.45 %.

The maximum water absorption W_m^{max} for the dismantled concrete specimens that were kept in the climatic chamber (*K*) proved to be by 0.1 per cent points (pp) less than for the specimens of the two other groups. The obtained data, however, differ from the relationships stated in the research [7] — in the mentioned study it is established that in the oven-chamber hardened concrete water absorption is by 1.1 pp higher than in concrete hardened in the water environment.

Analysis of the results obtained for faces of each specimen showed that the change in the UPV was almost identical to the degree of specimen saturation with moisture. It was concluded that for upper faces of concrete specimens approx. 1-cm-thick layer had no significant effect on the relationship between water absorption and UPV because the cutting off of the mentioned layer did not influence the overall results.

It should be emphasized that as a result of application of indirect transmission by measuring the velocity of longitudinal wave propagation in concrete specimens after maximal saturation with water a very specific property was discovered. Additional experiments showed that most cardinal UPV changes in concrete happened at the time when the mass increase rate was less than 0.1% in 24 hours. Namely, water-saturated concrete specimens showed the following results:

curing environment (spec. group)	changes in specimen masses at a maximum absorption level	changes in UPV at a maximum absorption level
N	0.2 %	386 m/s
K	0.1 %	472 m/s
K_V	0.1 %	322 m/s.

The obtained relationships in graphical form are given in Fig. 1.

The adversative nature of UPV changes is observed when the specimens are taken out from water: at a relatively small loss of mass the decrease in the UPV is most significant (see Fig. 2). The most constitutive decrease in the UPV has been fixed during the first 2 hours; besides, it has been identical for all three specimen groups — the velocity has decreased by 270 m/s.

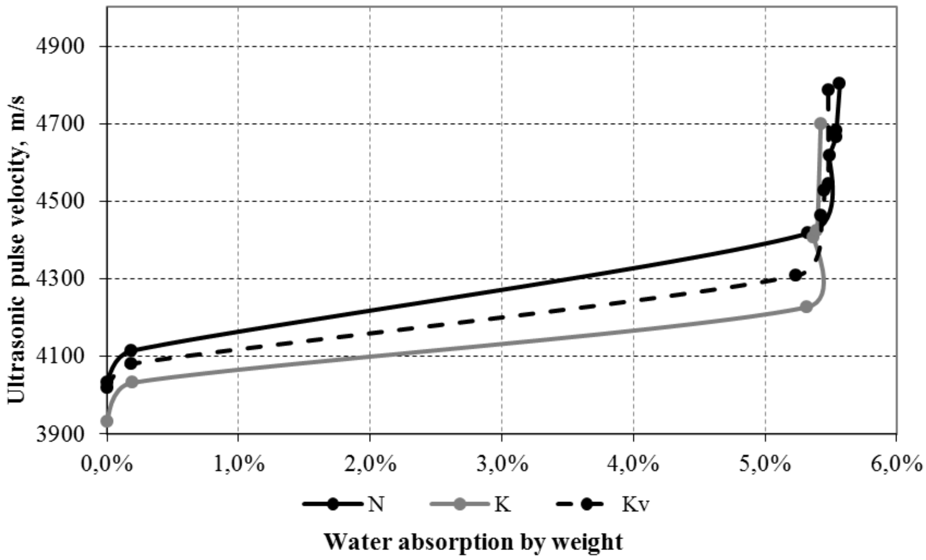

Fig. 1. Relationships between ultrasonic pulse velocity and water absorption by weight for concrete cured in various environments.

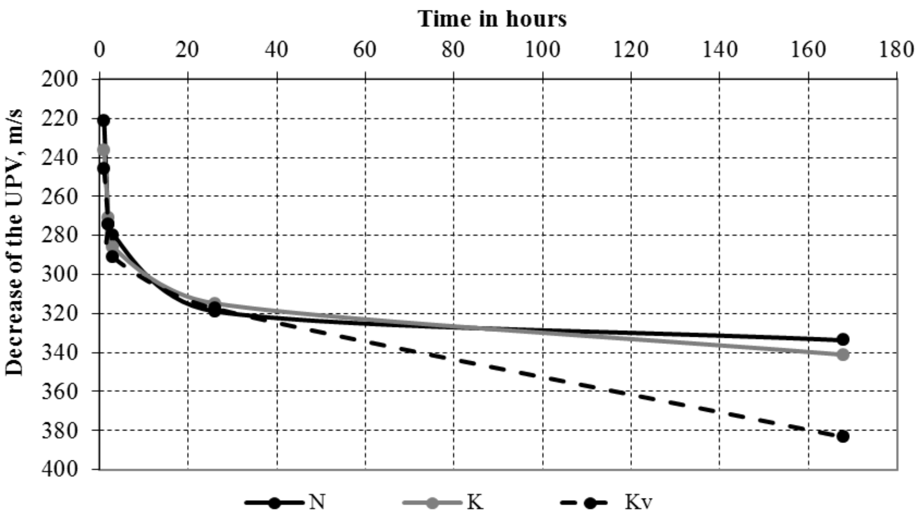

Fig. 2. Decrease in the UPV in concrete after the specimens are taken out from water.

In relation to the earlier described sudden increase in the UPV in the cases when concrete is maximally saturated with water, it would be useful to remind the results of one previously conducted research. Namely, the elastic properties of the fresh concrete mix as a multi-component material were described with the help of various mathematical models [8]. The concrete mix was modelled as a three-component environment, which included: a) hard component (*1*) — cement particles, as well as fine and coarse aggregates; b) liquid component (*2*) — water; c) gaseous component (*3*) — air. The volume of each component in the mix was emphasised as a significant parameter. It was established that in the unloaded three-component environment in all cases irrespective of the degree of porosity, with the amount of air in relation to the overall volume exceeding 0.5…1% a sudden decrease in the ultrasonic longitudinal wave pulse velocity was observed [8]. Besides, the relationship between moisture and material elastic properties was based on the two different ways of achieving the maximum saturation degree: 1) the external pore surface was gradually covered with a layer of liquid, thickness of which corresponded to the degree of pore saturation; 2) the number of pores fully filled with water increased. In the first case, no changes were observed in the concrete elasticity modulus, whereas at the maximum water saturation a sudden increase in this parameter was registered. In the second case, the material elasticity modulus showed a regular increase depending on the number of pores that were fully filled with water [8].

It is known that there is a strong correlation between the material elastic properties and the velocity of ultrasonic propagation in such material [22, 23]. At the same time, the data obtained in this research imply that in case of the hardened concrete both ways of achieving the maximum saturation degree mentioned earlier in the research [8] may be interrelated. And namely, during the process of concrete saturation with water, a regular increase in ultrasonic longitudinal wave pulse velocity is followed by a sudden leap of the UPV at the moment when maximum saturation is achieved.

However, in order to make such assertion one should be convinced that such a tendency is observed also during direct transmission. There is a possibility that only the physical processes evolving in the upper layers of material generate the sudden changes in the UPV, while during the direct transmission in concrete this feature will not be observed. Similarly, it is necessary to determine how elastic properties of concrete change during the water absorption process.

Obtained results unequivocally show the non-linear character of relationship between the UPV and the degree of moisture present in concrete. In another study, where mathematical and physical models were developed, it was established that the above-mentioned correlation was in the best way characterised by an exponential model, and the most significant changes in the UPV emerged at the early saturation stage [3].

After the concrete specimens were dried till the constant mass during a repeated (second) water saturation cycle in compliance with the existing Latvian standards to achieve the constant mass of the specimens, concrete failed to achieve maximum saturation with water. Specimen saturation with water should be performed for a longer period of time. Experiments showed that the UPV increased at a particularly high rate only when concrete specimen mass increased at a much slower rate — by less than 0.1% in 24 hours. If this fact is ignored, egregious errors in respect of compiling the correlation relationships of concrete properties can be made. For instance, if concrete mass differs by just 0.3% on the average, the UPV results will show a more relevant difference — 6% or 250 m/s on the average. Besides, the most significant differences are established for concrete cured in standard moist conditions, and therefore it contains much water. Experimental data unequivocally show the correlation existing among various curing conditions (and accordingly — different amount of water in concrete) and the influence of the amount of water on propagation of the UPV in concrete.

Keeping on the saturation of the above-mentioned concrete specimens with water, the maximum mass of the specimens was achieved during the first cycle; however, concrete did not show the maximum UPV level at a corresponding specimen weight. Moreover, the UPV in concrete cured at the elevated temperature after secondary saturation with water appeared to be much lower in comparison with the results shown by concrete specimens hardened in the standard moist room (see Table II).

TABLE II

ULTRASONIC PULSE VELOCITY IN CONCRETE AT VARIOUS DEGREES OF WATER ABSORPTION, COMPARISON OF THE RESULTS ACHIEVED IN THE FIRST AND SECOND WATER ABSORPTION CYCLES

Curing environment / designation of specimen	UPV in concrete at various degrees of water absorption, m/s: $W_m^{air\text{-}dry}$*	the first cycle: W_m^{max}	the first cycle: $W_m^{max} - W_m^{air\text{-}dry}$	the first cycle: W_m^{min}	the first cycle: $W_m^{min} - W_m^{air\text{-}dry}$	the second cycle: $W_m^{max.II}$	the second cycle: $W_m^{max.II} - W_m^{max}$
N-1.^{28}	4614	4804	190	4032	-582	4758	**-46**
K-12.^{28}	4493	4699	205	3931	-562	4510	**-189**
K_V-21.^{28}	4526	4786	260	4020	-506	4623	**-163**

Note: * — the moisture content of concrete specimens in the so-called air-dry condition was determined at the age of 1008 days (from the age of 84 days specimens were held in the room with the temperature range of +18...25 °C and the relative air humidity of 40...50 %).

Since it was experimentally proven that in case of indirect transmission the most significant UPV changes in concrete were determined at the moment when the maximum degree of water saturation was achieved, it was important to accurately define the maximum degree of absorption.

According to the data obtained in this research and fulfilling the requirements set by the standards regarding attenuation of mass changes that should not exceed 0.1% in 24 hours, it is actually quite problematic to achieve both the maximum concrete saturation with water and drying the specimens to constant mass. This especially refers to the once dried specimens that are quite slow in absorbing water for the second time.

It is established beyond controversy that moisture has a significant influence on the UPV values in concrete, especially if these values are determined by indirect transmission. Moreover, these parameters for the concrete specimens hardened in various environments differ a lot. It should be emphasized that the only difference among the three specimen groups was the environment of the concrete hardening; however, as the experiment was carried out on the water absorption, the degree of moisture influence on them appeared to be the same. Significantly different UPV in the specimens of various hardening groups was observed upon completion of the active phase of cement paste hydration process, while in the further hardening differences in the UPV were levelled out. It should be noted that in case of specimen maximal and minimal water absorption the UPV variations for different specimen groups can be considered absolutely insignificant (see Fig. 3).

The data presented in Fig. 3 show the tendency that should be taken into account: when parameters describing concrete of various ages are compared, we obtain quite different results. However, at the maximum degree of water absorption the differences cease to exist and this fact must be taken into account when concrete structures of hydrotechnical buildings are investigated. However, in order to verify the assertion above additional experiments are required, where along with the UPV measurements in concrete specimens of various ages their compression strength needs to be tested.

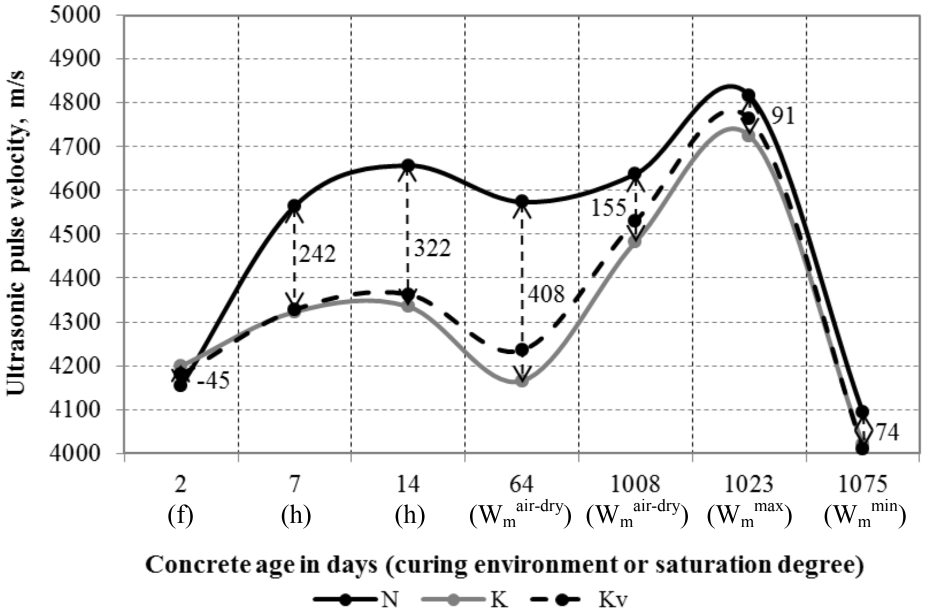

Fig. 3. Ultrasonic longitudinal wave propagation velocity for concrete hardened in various environments depending on moisture saturation over a longer period of time. (Below the concrete age, the degree of moisture saturation or the environment, where the specimens were cured prior to the sounding, is shown in the parenthesis: f — just dismantled specimens; h — hardening environment in the corresponding chamber. The chart provides comparison of the UPV values of *N* type specimen group with the UPV values of *K* group specimens.).

For specimens cured under standard conditions and at the elevated temperatures the measurements were carried out at the age of 64 and 1008 days and quite significant differences of UPV values were determined (Fig. 3); however, for the whole of the mentioned period of time, that is, for 944 days they were kept in identical conditions — in the air-dry environment. And namely, during the time period in question the concrete specimens hardened at elevated temperatures showed a very significant increase in the UPV. Similar tendency of increased UPV is described in another study. Namely, changes in the absolute values of concrete dynamic deformation during hardening to a great extent depend on the specimen curing conditions [8]. It has been established that concrete hardened in water possesses a higher elasticity modulus than concrete of the same composition hardened in the air. However, if concrete hardened in the air-dry conditions is submerged in water, the strength parameters will decrease significantly and the velocity of acoustic waves and the elasticity modulus will slightly increase in the majority of cases [8].

It should be concluded that in the process of cement binder hardening, the changes in the velocity of ultrasonic longitudinal waves measured with indirect transmission fail to fit in with the conventional theory. In effect, it is assumed that during this process the UPV is affected by: a) changes in relations among the bulk amounts of components within a three-component system (m_1, m_2, m_3) (the proportion of the hard component increases) and a decrease in the degree of moisture saturation; b) an increase in the elasticity modulus (L_k) of the particle interaction bonds of the hard component with the development of physical and chemical hydration processes [8]. Most probably, in addition to the above-mentioned factors during concrete hardening the UPV is also significantly influenced by the interaction effect of moisture and temperature (*W-T*). Therefore, the resulting UPV value (V_l) may be defined as the function:

$$V_l(m_1 : m_2 : m_3; L_k; W; T) .$$

It is known that concrete hardening in the favourable environment is a long-term process. Nevertheless, for concrete hardened in various environments the interaction effect of the V_l function factors may differ significantly and can be difficult to predict during both the active and passive phase of the hydration process. Furthermore, it should be emphasized that this function refers to a specific type of concrete. It is worth adding that influence of the raw materials of the mix on elastic properties is not taken into consideration. At present, research is carried out to clarify the interrelation of the V_l function forming arguments and to explore the linkage between the mentioned arguments and the elastic properties of concrete.

To summarize the above-mentioned information, is has been concluded that in case of indirect transmission the unequivocal relationship between the UPV in concrete and the amount of moisture no longer exists in the following cases: a) primary hardening or, during the so-called active phase of hydration processes (for example, after proper curing of concrete over the period of 28 days — if later it is kept in the air-dry conditions, on the average up to the age of 2 months); b) if concrete (especially, at the early age) is subject to high or low temperature impact, including, when it is hardened in the heat or frost conditions; c) in case of fire or when concrete is subject to the impact of temperature above +100 ^oC. (Upon the influence of thermal processes concrete structure obviously changes. Still, concrete hardened in the standard environment has higher resistance to destructive processes). Different moisture values of the concrete specimens measured in air-dry conditions indirectly prove the statement above: *N* and K_V — 2.32 and 2.13% compared to *K*, which is only 1.67%. Another evidence of the equivocal nature of "UPV – concrete moisture" correlation is, for example, the UPV values for the specimen N-1.[28], which for air-dry concrete are 4614 m/s, at 2.3%

moisture by mass and upon reaching the maximum water saturation degree in oven-dried concrete – 4430 m/s at 3.3 %, respectively. It can be seen that in this case the UPV in the air-dried specimen is higher; however, the degree of moisture in concrete by mass and the surface moisture are less than 1% (see Table 1) and 0.9 %, respectively.

IV. Conclusions

1. The concrete specimens — both those hardened in the standard conditions and those kept at the elevated temperature (in the climatic chamber) were subject to ultrasonic longitudinal wave impulse sounding by using indirect transmission. It was established that the nature of fixed UPV changes was similar to the changes in the degree of concrete saturation with moisture. The maximal water absorption of the examined concrete specimens was within the 5.2...5.6% range, while differences in the UPV obtained for the specimens in the absolutely dry and maximally saturated condition were much more impressive and reached 19% on the average. At the same time, the average compression strength values for the concrete specimens fell within the range 55.4...63.6 MPa.
2. By testing concrete with the indirect transmission method, it was determined that ultrasonic longitudinal wave pulse velocity increased significantly at the time when during water absorption process the specimen mass increased by less than 0.1% in 24 hours (namely, when almost maximum concrete saturation with water was achieved). The most significant changes were fixed for concrete hardened at elevated temperature, which showed the UPV increase of 472 m/s at the 0.1% increase of moisture by mass. UPV change results of the contrary nature were obtained for concrete specimens taken out from water: given a relatively small loss of mass within the first 2 hours the UPV decrease was 270 m/s.
3. During the process of hardened concrete saturation with water, indirect transmission shows a steady increase in the ultrasonic longitudinal wave pulse velocity. When the maximum degree of concrete saturation with water is reached, a sudden increase in the UPV is determined. It is possible to find some interrelationship of this phenomenon with the theory earlier suggested by other researchers concerning the influence that moisture produces on elastic properties of porous material, if fresh concrete mix is treated as a multi-component material (an appropriately simulated environment). Namely, when concrete as a material gets gradually saturated with water to the maximal degree, two kinds of processes are observed — the structure elastic modulus either shows a steady and constant increase or remains unchanged at the initial stage, but, upon achieving maximum water absorption shows a sudden increase. These processes are affected by the way how pores are filled with water. Analysis of moisture influence on the acoustic properties of the fresh concrete material implies that in achieving the maximum degree of saturation both cases may be interdependent. However, to prove this theory in practice it is necessary to ascertain whether such a tendency can be observed during concrete direct transmission testing. Besides, at the same time it is necessary to control changes in elastic properties of concrete.
4. For the concrete specimens hardened at normal and elevated temperatures and kept for 2½ years in the air-dry conditions, the changes in the UPV are not interconnected. Besides, substantially different UPV values for concrete hardened in various environments are observed already upon the end of the active phase of the hydration process. In fact, when hardening continues for a prolonged period of time, the UPV differences are levelled out and at the minimum and maximum degrees of concrete water absorption these changes are described as negligible.
5. Application of indirect transmission method has proven that there is no unequivocal interdependence between the UPV and concrete moisture in the following cases: a) at the initial stage of concrete hardening, when curing conditions are changed; b) if concrete hardens at elevated temperatures and is not sufficiently humidified; c) if concrete hardens in cold environment and is not sufficiently heat-insulated; d) after the fire or when concrete is subject to the impact of temperature above +100 °C.
6. The obtained results indicate that during hardening of cement binders the changes in the UPV depend not only on the changes in proportion within a three-component system and the increase in the elasticity modulus of the particle interaction bonds of the hard component, but also on the interaction effect of moisture and temperature. Therefore, the resulting value of UPV should be defined as the function $V_l(m_1 : m_2 : m_3; L_k; W; T)$.

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