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Reinforcement effect on the ultrasonic pulse velocity in concrete, depending on the sounding method and measuring device

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Abstract

In practice it is often required to determine the technical condition and the load carrying capacity of reinforced concrete. The quality of the constructions is also characterized by the structural properties of the concrete. However, sometimes the obtaining of the full value concrete specimens from such structures is problematic to carry out further researches with the material destructive test methods. It is known that physical and mechanical properties of concrete are best characterized by the density, porosity and strength of the structure. The integrity of such properties can be assessed by using material nondestructive test method — by applying the ultrasonic pulse velocity measuring devices. At the same time, it is also known that there are several factors that influence the ultrasonic pulse propagation velocity in the concrete and the reinforced concrete structures. The earlier performed investigations have established that presence of the reinforcement located close to the surface of the tested concrete increases the ultrasonic pulse velocity. Reinforcement effect is also described in the notes to various standards. In practice the concrete structures of many different building objects have been tested with specific ultrasonic devices, and obtained results leads to the doubts about the relevance of reinforcement effects. To explore this question, 5 model specimens were manufactured with different diameter of reinforcement rebars. Diameters of the rebars used for specimens — 6; 8; 12; 16 and 22 mm. For reinforced concrete structures, which are necessary to test in a larger area, reinforcement diameter normally does not exceed the greater of the above mentioned size. Furthermore, determining of the rebars dislocation in large areas is very time-consuming process, even if for this purpose corresponding device has been used before ultrasonic velocity measurements. In present research performing measurements in the zones direct over the rebars and in the rebar-free zones (in plain concrete), different ultrasonic measuring devices show a comparatively different results. It is concluded that the reinforcement effect on the ultrasonic pulse velocity in concrete depends on both sounding methods and technical parameters of the measuring device.

Introduction

Evaluating the technical condition and the load carrying capacity of reinforced concrete, which is already built in different constructions, unfortunately, quite often it is not possible to drill out the full value specimens from structures for testing the concrete strength or other properties. The ultrasonic pulse velocity (UPV) measuring devices can be applied for the complex investigation of the concrete properties (density, porosity and strength, as well as its integrity). However, in many investigations up to now, there have been frequent references on the effect of reinforcement close to the tested product surface — as it increases the UPV in concrete. In practice, when concrete is tested at a number of different building objects, doubts emerged with regards to essentiality of the effect of reinforcement. To investigate this issue more comprehensively, 5 model specimens were made, where rebars of different diameter were embedded. The chosen largest diameter of the specimen rebars (22 mm) does not exceed the maximal diameter of the rebars embedded in reinforced concrete structures, which are necessary to test in a larger area and simultaneously in this case determination of the rebars dislocation must be realized before ultrasonic velocity measurements. Furthermore, different ultrasonic devices including the several sounding methods and transducers were applied for this research.

When comparing with concrete, the UPV in steel is higher. Hence, it is generally assumed that the essential concentration of reinforcement in the tested concrete surface zone increases the UPV. Similarly, if for ultrasonic tests direct transmission is applied, influence of the reinforcement on the UPV has been also determined. Therefore, it must be acknowledged that correct investigation of the technical condition of the reinforced concrete in structures by using ultrasonic methods is problematic.

Previous experiments, performed by other scientists, affirms the changes of the UPV depending on the substantial reinforcement concentration in the surface zone — the increase of the UPV is determined as large as up to 20 … 30 % [1, 2]. It is known that the UPV in concrete can be determined by applying indirect transmission (so-called surface sounding), and direct transmission — the sounding through the material. Thereto, the surface (Rayleigh), shear (transverse) and longitudinal (compressional) waves can be transmitted in materials [2, 3, 4]. The acoustic contact of the transducers with the concrete surface can also be different — both the point and the so-called flat surface transducers can be used for the tests. Having summarized the aforesaid, it can be assumed that transmission of different nature waves through the material, by applying different methods of sounding, provides different information on the material structure to a greater or lesser extent.

The target of this research is based on the following: — if effect of the increase of the UPV is not observed, the fixed measurements can cause considerable inaccuracies in interpretation of the results, and namely, physical and mechanical properties of concrete could be evaluated higher, than they really are. Therefore, it is necessary to ascertain whether the applying of UPV in determining of concrete strength is quite problematic or not.

Measuring Devices, References to the Researches and Standard

The latest ultrasonic measuring devices, which are often used for testing both in the laboratory and in the building objects, are portable devices: ultrasonic tester "УК-1401" and low-frequency ultrasonic flaw detector "A1220 Monolith". Both of them are made in Moscow by the «АКС» company.

The operational principle of device "УК-1401" is to fix the ultrasonic longitudional pulse by using indirect transmission. A microprocessor installed in the measuring device body determines the UPV and shows the result in digital form on the display. There are two built-in dry point contact (DPC) transducers for this tester to achieve the efficient emitting and reception of the longitudional pulses. The main technical parameters indicated by the manufacturer of the "УК-1401" measuring device are as follows: the sounding base or so called path length (the 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 % [5].

Ultrasonic detector "A1220 Monolith" can be used to determine longitudinal and transverse waves of UPV. For this purpose two DPC transducers T1802 (frequency — 50 kHz) must be connected with electronic unit. Electronic unit contains in itself a screen and a keyboard. The device can display the results in different forms. For determination of UPV an A-scan form was used. Besides, the additional option — zoom mode — has been applied, which increases the quantity of displayed parameters. During this research adhesion between the reinforcement bars and concrete also was determined (as for anchor bolts tests). For this purpose low-frequency (25 kHz) transducer S0202 can be used for longitudinal waves excitation and receiving. This transducer is broadband with liquid type of contact. Also in this case the results of sounding are represented in A-scan form [6].

As a third device for UPV determination has been used stationary oscillograph "УКБ-1М". Device was equipped with two exponential type transducers (frequency — 100 kHz). These transducers have also DPC and with the help of them it is possible to carry out both direct and indirect transmission, for which accordingly longitudinal and surface impulses were used. It must be emphasized that for surface sounding the longitudinal profiling principle has been applied. The results are presented in the form of the oscillogram.

In handbook of concrete nondestructive testing [2] terms of reinforcement influence are also given. For indirect transmission method UPV is affected by concrete cover a, path length L, the pulse velocity in steel V_s and in plain concrete V_c. However, when the relation a / L reaches 0,2 … 0,25, influence of the reinforcement becomes negligible. There is no reinforcement influence if (see [2]):

$$\frac{a}{L} > \frac{1}{2}\sqrt{\frac{V_s - V_c}{V_s + V_c}}. \tag{1}$$

In the case of direct transmission influence of reinforcement bars must be calculated by taking into account the full diameter of each bar during the pulse path L_s (see [2]):

$$\frac{V_c}{V} = 1 - \frac{L_s}{L}\left(1 - \frac{V_c}{V_s}\right). \tag{2}$$

For fair quality concrete the difference of UPV can be in the range of 3 … 20 % [2].

With regards to application of the ultrasonic method for determining the concrete properties, there is the State Standard issued in the former USSR — ГОСТ 17624-87 "Бетоны. Ультразвуковой метод определения прочности" ("Concretes. The Ultrasonic Method for Determining Strength"), which is still efficient in the Russian Federation. In 2004 the methodological instructive regulations for application of this standard were issued [7], which anticipate the conditions, when reinforcement influences the UPV. Primarily, it is indicated that measurements for determining the UPV with regards to the main or the so-called work reinforcements placed in the construction are to be performed transversally. In case measurements are performed along the rebars (as it is actually made in the experimental investigations, which are comprehensively described hereinafter), the distance from the sounded surface till the rebar must not be less than 60% from the sounding base length. Thus, for instance, if the reinforced concrete is sounded this way with the help of the "УК-1401" tester, the concrete cover must be at least 9 cm thick [7]. It must be noted, that in the Operation Manual of this measuring device there also given the indications on the direction for performing the measurements, depending on the reinforcement location in the reinforced concrete construction [5].

To make sure of the effect of reinforcement influence on the UPV, by applying both direct and indirect transmission, previously manufactured specimens were used, which are similar to the ones used in the experiment and described in the work [1].

Specimens for the Research, the Measuring Scheme

The geometric parameters of the manufactured specimens are as follow: height — 15 cm; width — 20 cm; length — 40 cm. The so-called herringbone profile rebars of different diameters (6; 8; 12; 16 and 22 mm) are placed at a certain distances from the specimen surface (15; 30; 45; 60 and 75 mm). In total, five specimens of the reinforced concrete have been manufactured. These specimens differ from each other in diameter of the embedded reinforcement, but thickness of the concrete cover from the so-called experiment guide-mark surface (see further on) is similar for all specimens.

All the specimens were manufactured of the same concrete mixture. The main parameters of the concrete used for the specimens are: the compressive strength class — C16/20; the workability class — S3 (the cone slump — 12 cm); the cement class — CEM II/A-T 42,5 R; the coarse aggregate maximal diameter — 16 mm; the mineral admixture — limestone powder; the chemical admixture — plasticizer. Specimens manufacturing date — 28th February of 2008.

Initially the specimens were tested when the concrete was 4, 7, 14 and 28 days old (for results see [8]). The results of last measurements, which are collected in this paper, were done when concrete age was 2 years and 2 months.

The top and bottom surface of each specimen is divided into 11 zones in the cross direction, and namely: five zones are selected exactly above the rebars, four — symmetrically between the rebars, and two — between the outer rebars and transverse edges of the specimens. The zones located on the bottom surface of the specimens, over the rebars, are designated in the order of the increasing thickness (correspondingly 15, 30, 45, 60 and 75 mm) of the concrete cover of the specimens — from *1* to *5*. Whereas designations for the zones, where there are no rebars, are assigned depending on location of these zones between the so-called specific rebar zones. For instance, the concrete surface areas on both sides of the rebar zone *1* are designated as *0,5* and *1,5*. Designations of the zones corresponding to the so-called top surface of the specimens are assigned symmetrically, they are supplemented by the mark " ' ". See the geometric parameters and the measurement zones of the reinforced concrete specimen at Fig. 1.

Each testing method and device has its own measurement scheme. Performing the indirect transmission, path length of measurements coincides with the rebars direction. With ultrasonic tester "УК-1401" 88 measurements were done for each specimen, the same number of measurements performed with a device "A1220 Monolith". Whereas, performing the longitudinal profiling with oscillograph "УКБ-1М" in total 176 measurements were carried out for one specimen. Hence, when investigating one specimen with the indirect transmission 352 measurements in total have been done. Proximity of transducers to the edge of specimen (in its cross direction) for devices: "УК-1401" — 2,5 cm; "A1220 Monolith" — 5,5 cm; "УКБ-1М" — 2,5 and 5,5 cm.

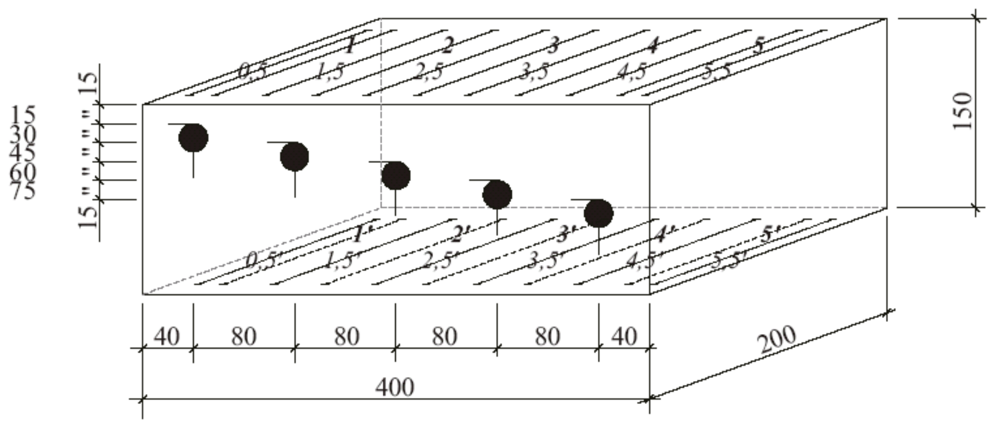

Fig. 1. Parameters of the reinforced concrete specimen with rebars Ø22 mm and the measurement zones for the top and bottom surfaces (the sizes are provided in mm)

Sounding trough the material, path length of measurements was orientated perpendicular to the reinforcement bars. With detector "A1220 Monolith" and oscillograph "УКБ-1М" every zone over the rebars and in plain concrete was sounded accordingly in 3 and 5 different places. The total amount of direct transmission measurements for one specimen is 88.

Testing Results

In this paper the experimentally obtained data is provided in the concentrated form. As the results obtained for all five specimens contains in itself quite extensive information, further in the paper comprehensive data will be given only for specimen, where the rebars of the largest (22 mm) diameter are embedded.

It must be emphasized that during the ultrasonic tests the moisture content of concrete specimen on both measured (upper and bottom) surfaces was equal — 3,5 %.

As the information summarized in Table 1 specifies, the increase of UPV in concrete caused by reinforcement is not obtained. Besides, there are no correlations observed between changes in the UPV and the concrete cover thickness, as well as the diameter of the rebars. When comparing the measurements performed over the rebars and in the plain concrete, the range of changes of the UPV mean value V_m was –9,50 … +5,23 %.

Table 1. Change of the ultrasonic pulse velocity (UPV) for different sounding methods by comparing the average data in the corresponding reinforcement zones with plain concrete

Thickness of the concrete cover, mm	Transmission method / type of waves / device / working frequency / path length // change of UPV (results over the rebars in comparison with plain concrete, %)					
	indirect				direct	
	longitudinal		transverse	surface	longitudinal	
	УК-1401	A1220 Monolith		УКБ-1М		A1220 Monolith
	70 kHz	50 kHz		100 kHz		50 kHz
	15 cm	9 cm		3 … 12 cm	15 cm	
15	-3,37	-4,98	-2,42	-4,35	-9,50	-5,82
30	-2,11	-7,51	-3,49	-1,37	-2,51	-5,73
45	3,26	3,80	2,41	1,56	-0,94	-4,11
60	1,88	1,86	-1,60	0,54	-2,41	-4,68
75	2,11	5,23	2,41	2,84	-5,77	-7,22
15…75 *	0,35	-0,32	-0,54	-0,15	-4,23	-5,51

Note: * — UPV results on average for all five zones selected above the rebars in comparison with results obtained in rebar-free parts, i.e., in plain concrete.

Since data of compressional waves during this research are achieved, our results of indirect and direct transmission testing can be inserted accordingly in formula (1) and (2).

Let's consider the most inconvenient condition for indirect transmission: path length — 15 cm; concrete cover — 1,5 cm. In this case relation a/L leads to condition $V_c / V = 0{,}85$, where V — UPV above the rebars [2]. Consequently, UPV above the reinforcement bar in current measurement zone should be 18 % higher, as the average value of UPV in the plain concrete is 4378 m/s (calculated not including zones 0,5 and 5,5 because of edges effect). However, in reality the UPV above the rebar is 3 % lower than in plain concrete, and the relation is following: $V_c / V = 4378 / 4230 = 1{,}03$. Similarly, inserting the results in formula (1), it is calculated that there must be an influence of reinforcement:

$$\frac{1}{10} \overset{?}{>} \frac{1}{2}\sqrt{\frac{5930-4378}{5930+4378}} \rightarrow 0{,}1 < 0{,}19.$$

As it seen, this formula can not be applicable for all types of reinforced concrete.

By inserting the data in formula (2), can be predicted the influence of the reinforcement on the UPV, if for sounding direct transmission is used:

$$\frac{V_c}{V} = 1 - \frac{22}{150}\left(1 - \frac{4378}{5930}\right) = 0{,}96\,.$$

It means that increase of the UPV in rebars zone for current specimen should have been 4 %. However, the change of the UPV is conversely — the decrease on average is 5 %, see Table 1. It is consider as a significant difference, especially in the case of concrete strength evaluation by using correlation curves "UPV – concrete strength". And namely, 5 % change in the UPV can cause up to 50 % difference in the concrete strength evaluation. Therefore, in the interpretation of reinforcement influence there is need to be cautious, as theoretical calculation of the UPV change in different zones of reinforced concrete is very approximate and in this case even unacceptable.

Fig. 2 demonstrates the tendency of the UPV mean values in the zones over the rebars and in the plain concrete. The results for indirect transmission were obtained by carrying out specimen's bottom (experiment guide-mark) surface testing.

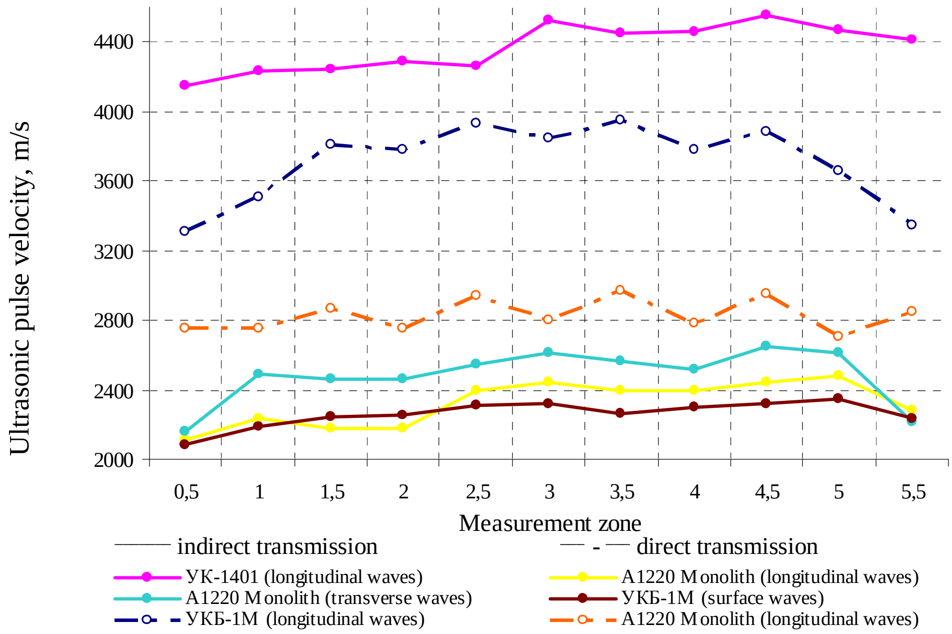

Fig. 2. Mean values of the UPV in the measurement zones for different sounding methods (1; 2; 3; 4; 5 — in the reinforcement zones, 0,5; 1,5; 2,5; 3,5; 4,5; 5,5 — in the plain concrete)

As can be seen, for indirect transmission lower results for the UPV are determined in zones, where rebars located closer to the measuring surface, see Fig. 2. Comparison of results obtained by all devices shows that the mean values of UPV in measurement zones 0,5…2,5 and 3…5,5 are accordingly 2774 and 2928 m/s — difference is 5,54 %. Furthermore, the largest difference in the UPV results for these zones has been fixed for longitudinal waves propagation — 5,75 … 8,38 %, in its turn for transverse and surface waves — accordingly 4,25 % un 3,73 %.

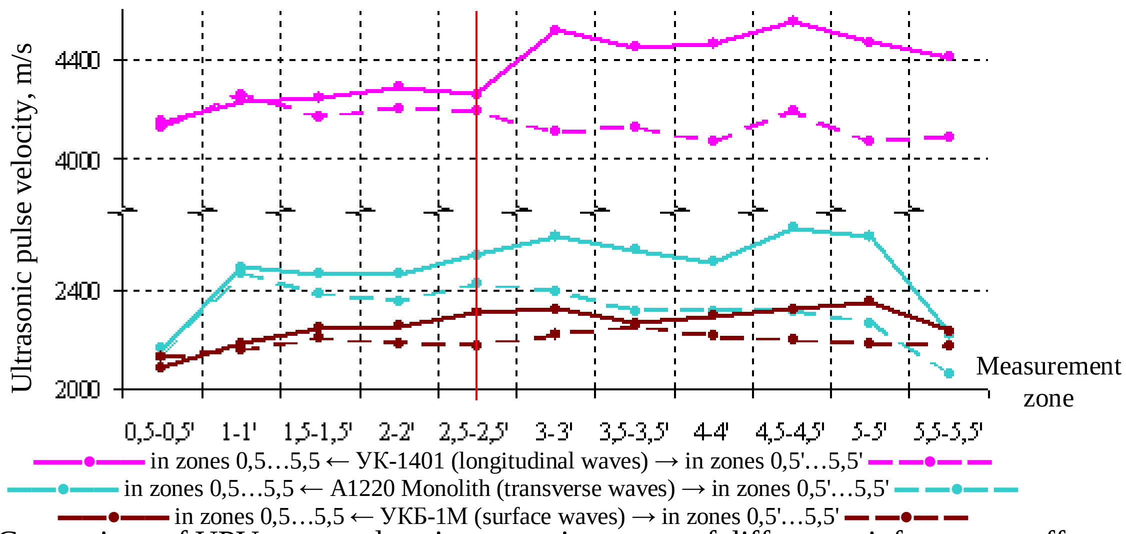

Fig. 3. Comparison of UPV mean values in measuring zones of different reinforcement effect obtained by indirect transmission for bottom and top surfaces of the reinforced concrete specimen

Since the measurements were carried out also for specimen's upper (top) surface, it is possible to ascertain whether the concrete compacting quality has not been lower in volume of zones 0,5…2,5. Comparing the results for this surface, it is established that in measuring zones 0,5'…2,5' propagation of the UPV has been even higher (+1,01 %) than in zones 3'…5,5'. In graphical form the differences between the UPV of indirect transmission for bottom and top surfaces of specimen are shown in Fig. 3, where vertically orientated red line separates the measuring zones of different reinforcement effect.

Summarizing the above mentioned, the assumption can be drawn that, performing the indirect transmission testing, in some conditions the reinforcement located close to the measuring surface of concrete can cause the reduction of UPV propagation. It can be related both with the heterogeneity of concrete in reinforcement zones and with the reflections of ultrasonic pulse.

Previously stated assumption can be indirectly confirmed by data obtained during the direct transmission of concrete. And namely, above the rebars decrease of UPV mean values is 5 %, comparing with UPV in the plain concrete, see last two columns in Table 1. In graphical form this feature is shown in Fig. 2, see the discontinued lines.

The results obtained with all devices in the outer zones indicate the comparatively lower UPV in concrete, see Fig. 2 and 3. It is mainly explained due to the so-called edges effect. To define more accurately the influence of the specimens' edges on the UPV, additional measurements with the "УК-1401" tester were made for the reinforced concrete specimens [8].

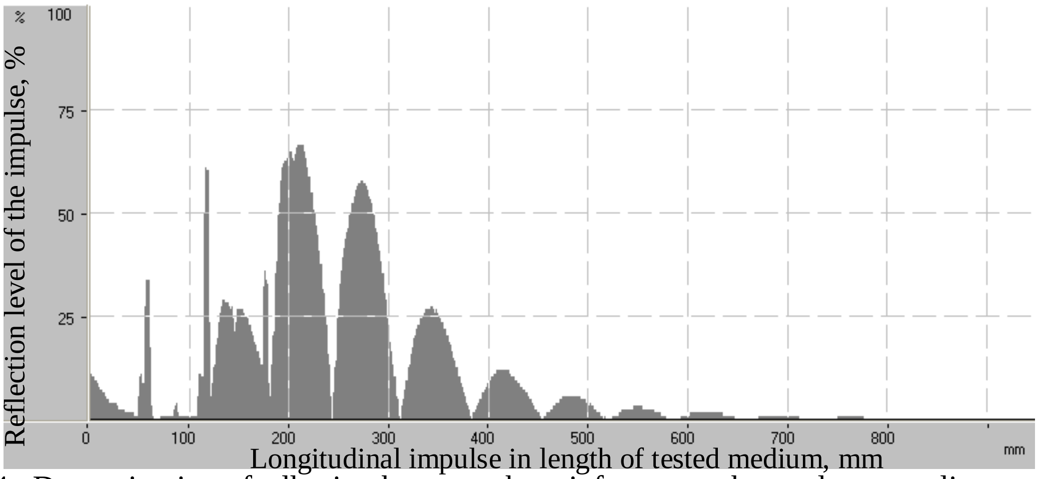

Fig. 4. Determination of adhesion between the reinforcement bar and surrounding concrete

One of the reasons for lower UPV in zones above rebars can be unsatisfactory adhesion between the reinforcement bars and surrounding concrete. To ascertain for the quality of this property ultrasonic detector "A1220 Monolith" was applied. With the help of transducer S0202 longitudinal impulses through the reinforcement bars has been transmitted. All rebars of specimen were tested and the scene of longitudinal impulse through the reinforcement bar and surrounding concrete was determined as the same. And namely, decrease of the ultrasonic impulse after the third reflected signal is evaluated as a nosedive, see Fig. 4. Consequently, the adhesion between the rebars and surrounding concrete is fixed of good quality and this cannot be the reason for the differences in UPV.

Conclusions

1. The experimentally obtained data confirm that when ultrasonic pulse velocity is determined with indirect transmission mehod by using different type of waves, in case of testing reinforced concrete, does not depend on reinforcement diameter (up to 22 mm) and location depth of rebars in the tested surface zone (more than 15 mm). Applying the direct

transmission, decrease of ultrasonic pulse velocity has determined above the rebars in comparing with the plain concrete.

2. For the reinforced concrete elements, where the reinforcement maximal diameter does not exceed 22 mm, sounding in the reinforcement longitudinal direction can be quite successfully performed also when the rebars are rather close (≥ 15 mm) to the sounding surface. Hence, the interpretation of ultrasonic pulse velocity results for determination of physical and mechanical properties of concrete can be carried out with precision of measuring error of specific device.
3. Performing the indirect transmission testing, in some conditions the reinforcement located close to the measuring surface of concrete can cause the reduction of ultrasonic pulse velocity. It can be related both with the heterogeneity of concrete in reinforcement zones and with the reflections of ultrasonic pulse.
4. Theoretical calculation of change of the ultrasonic pulse velocity in different zones caused by reinforcement can not be applicable for all types of reinforced concrete.
5. Analyzing the results of this research, some assumptions can be made about the reduction of the reinforcement effect on the ultrasonic pulse velocity increase. This factor may be affected by development of concrete aggregates and admixtures, which might have changed the medium of reinforced concrete where the ultrasonic pulse propagates. Similarly, these changes may be related with the different surfaces of reinforcement bars — surface of profiled rebars possibly has a different ultrasonic pulse reflection in comparing with smooth ones. However, to ascertain for these assumptions further experiments must be carried out, besides the concrete cover should be less than 15 mm.

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