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Decrease of the Ultrasonic Pulse Velocity in Concrete Caused by Reinforcement

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Abstract: In many countries, the standards issued in the 70s and 80s of the 20th century contain references to reinforcing bars as having impact on the ultrasonic pulse velocity (UPV) propagation in reinforced concrete. The criteria specified in the standards mostly provide for UPV increase in the rebar zones. The presently applied standards, in their turn, contain only recommendations on how UPV measurements should be performed for reinforced concrete, moreover, these recommendations are quite different. Since the times when scientists were focused on the researches in this scope, concrete fillers technology has experienced significant development, improving concrete properties and at the same time changing its structure. The purpose of this research is to evaluate the impact of reinforcing bars on UPV in concrete. Various ultrasonic devices were applied for research to determine longitudinal, transverse and surface wave propagation in concrete by direct and indirect transmission. Measuring in rebar zones and in plain concrete it was established that the obtained results are influenced by specific conditions, which was proved by significant UPV variations and changes given in comparison of the measurement data obtained at various points. The results of present research differ from previously formulated assumptions of UPV increasing in concrete rebar zones.

Key words: Concrete, nondestructive testing, ultrasonic pulse velocity, effect of reinforcement.

1. Introduction

In many countries, the standards issued in the 70s and 80s of the 20th century contain references to reinforcing bars as having impact on the UPV propagation in reinforced concrete. The criteria specified in the standards mostly provide for UPV increase in the rebar zones. When comparing with concrete, the ultrasonic pulse propagation velocity in steel is higher. Hence, it is generally assumed that the essential concentration of reinforcement in the tested concrete surface zone increases the ultrasonic pulse velocity. Similarly, if for ultrasonic tests direct transmission is applied, influence of the reinforcement on the ultrasonic pulse velocity 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.

The presently applied standards contain only recommendations on how UPV measurements should be performed for reinforced concrete, moreover, these recommendations are quite different. It should be noted that the valid applicable standards mostly refer to UPV measurements determined by longitudinal wave impulse method. The overwhelming majority of scientific data archives reviewed with the aim to find recent year publications on UPV in concrete environment unfortunately do not contain any newly obtained data in the mentioned area. Various recently published handbooks on concrete nondestructive testing only contain references to the researches carried out at the end of the last century, which are the basis of the theory of correction factors application in determining UPV in concrete rebar zones. Previous research quite frequently fails to specify the research

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method, namely, it does not mention what type of waves have been used for measurements and what is the possible difference between the obtained results. However, they differ from each other. It is known that the ultrasonic pulse velocity 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 [1-3]. 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.

Since the times when scientists were focused on the researches in this scope, concrete fillers technology has experienced significant development, improving concrete properties and at the same time changing its structure. Therefore there is likelihood that a different approach to evaluate the influence of concrete reinforcing bars on UPV should be realized. As the results of present research demonstrate, previously formulated assumptions of the UPV increasing in concrete rebar zones should be defined more accurately or even adjusted.

For the purpose of researching the impact of reinforcing bars on UPV in concrete, five concrete specimens reinforced with the rebars of different diameter were used in the tests. 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 location must be realized before ultrasonic velocity measurements. Various ultrasonic devices were applied for research to determine longitudinal, transverse and surface wave propagation in concrete by direct and indirect transmission. Measuring in rebar zones and in plain concrete it was established that the obtained results are influenced by specific conditions, which was proved by significant UPV variations and changes given in comparison of the measurement data obtained at various points.

2. Measuring Devices, References to the Researches and Standards

The ultrasonic measuring portable devices mainly used for testing both in the laboratory and in the building objects are ultrasonic tester “UK-1401” and low-frequency ultrasonic flaw detector “A1220 Monolith”. Both of them are made in Moscow by the «AKC» company.

This device “UK-1401” fixes the ultrasonic longitudinal pulse by using indirect transmission. In this case the results are shown in digital form. There are two built-in dry point contact (DPC) transducers to achieve the efficient emitting and reception of the longitudinal pulses. DPC transducers ensure a good contact between the ultrasonic source and the testing surface without both contact liquid and necessity to prepare the surface for testing. Such high-quality contact cannot be achieved by using flat surface transducers, as the concrete surface is almost always more or less uneven, having microscopic elevations. 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% [4].

Ultrasonic detector “A1220 Monolith” can be used to determine longitudinal and transverse waves of the UPV by applying both direct and indirect transmission. For this purpose two DPC transducers T1802 (frequency, 50 kHz) must be connected with electronic unit. The results of the UPV were achieved in A-scan form. Besides, between the reinforcement bars and concrete adhesion has been determined. The measuring error for device “A1220 Monolith” is equal to tester “UK-1401” [5].

As a third device for UPV determination has been used stationary oscillograph “UKB-1M”. Device was equipped with two exponential type transducers (frequency, 100 kHz). These transducers have also DPC. Direct and indirect transmission methods were applied for accordingly longitudinal and surface impulses determination. The results are presented in the form of the oscillogram and the measuring error for this device is the same as for equipments mentioned before.

The theory and the previous researches have been studied so far claims that propagation of the UPV in reinforced concrete can be increased by certain parameters of the embedded rebars. The main assumption for this theory is that the first ultrasonic pulse travels partly in concrete and partly in steel, consequently the measured UPV will be higher because the compressional pulse velocity in steel is 1.4 to 1.7 times higher than in plain concrete [1, 6, 7].

In scientific work [6] it is defined the changes of the UPV, there is stated that at indirect transmission the maximum increase of the UPV in the concrete is 20% when the diameter of embedded rebars is 22 mm and concrete cover, 15 mm.

The theory described in handbook of concrete nondestructive testing [1] specifies that for indirect transmission method the UPV is affected by concrete cover a, path length L, the pulse velocity in steel V_s and in plain concrete V_c. According to the given data for the concrete of fair quality, the increase of UPV in rebars zone in comparing with plain concrete can be up to 30%. However, when the relation a/L reaches 0.2-0.25, influence of the reinforcement becomes negligible. There is no reinforcement influence if [1]:

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

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:

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

For fair quality concrete the increase of UPV can be in the range of 3%-20% [1].

Quite similarly to the theory mentioned before, influences of the reinforcement on the UPV in concrete are described in paper [7]. The application of the correction factor k shows that reinforcing steel increases the UPV in concrete when specific zones with embedded rebars are measured. This factor depends on both ultrasonic pulse velocity in plain concrete and measured apparent velocity in rebar zone V_r:

$$V_c = k\, V_r \tag{3}$$

In this paper it is stated that bars below 20 mm diameter have no practical influence on the UPV when V_c is above 4,000 m/s, and the correction factor k for the UPV measured over the rebars prescribes only the decrease of results [7].

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 currently in force in the Russian Federation. In 2004 the methodological instructive regulations for application of this standard were issued [8], 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. Performing the measurements in rebars direction the distance from the sounded surface till the rebar must be not less than 60% of the sounding base. Thus, if the reinforced concreteis sounded this way, for instance, with the help of the “UK-1401” tester, the concrete cover must be at least 9 cm thick [8].

Active standard of American Society for Testing and Materials (ASTM) C597-09 "Standard Test Method for Pulse Velocity through Concrete" includes an explanation that the UPV measured in the vicinity of the reinforcing steel will be higher than in plain concrete of the same composition. There is given a recommendation to avoid the measurements close to steel parallel to the direction of longitudinal stress wave pulse propagation [9]. Similarly, currently existing standard in Latvia LVS EN 12504-4:2004 A, which is identical to the European Standard EN 12504-4:2004 "Testing concrete, part 4: Determination of ultrasonic pulse velocity" suggests the same avoidance of measurements close to rebars, however, there isn't given any explanation [10].

The information collected in this chapter indicates that for the UPV measurements in reinforced concrete different recommendations are to be found on how to avoid the rebars effect, and it is still doubtful whether such an effect exists in general. Besides, the changes of measured UPV followed by incorrect application of the theory given correction factors, as well as by ignoring them when it should not do, can lead to the misinterpretation of results.

To verify the effect of reinforcement influence on the UPV, by applying both direct and indirect transmission, previously manufactured specimens were used.

3. 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 bottom or the experiment guide-mark surface (see further on) is similar for all specimens.

All the specimens were manufactured from 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. Similar curing for all specimens was ensured during 28 days, by keeping them in a standard moist room.

Initially the specimens were tested in the zones above the reinforcement and in the plain concrete at the time when the concrete was 4, 7, 14 and 28 days old (for results see Ref. [11]). Only the indirect transmission has been realized for those tests. Combined testing of direct and indirect transmission was started out when concrete age was 2 years and 2 months. For previous results see Ref. [12]. The results of further researches, which were carried out six months later in more detailed way, have been collected in this paper.

Considering that the UPV depends on the specific moisture content of the tested medium (material), this parameter has been determined for measured concrete surfaces by using moisture meter.

The upper part 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. Thus, the measurements were performed both above the rebars (in 5 zones) and in the plain concrete (in 6 zones). The zones located on the bottom surface of the specimens, above the rebars, are designated in the order of the increasing of the concrete cover (correspondingly 15, 30, 45, 60 and 75 mm), from 1 to 5. Whereas designations for the plain concrete zones, 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 upper part surface of the specimens are assigned symmetrically, they are supplemented by the mark " ‘ ". Geometric parameters and the measurement zones of the specific reinforced concrete specimen can be seen in Fig. 1.

Each testing method and device has its own measurement scheme, however, all specimens were tested in all measurement zones.

Sounding trough the material, path length (~ 15 cm) of measurements was orientated perpendicularly to the reinforcement bars. In this case with detector "A1220 Monolith" and oscillograph "UKB-1M" propagation of longitudinal waves has been determined. Each zone through the rebars and in plain concrete was sounded in 5 different places. The total amount of direct transmission measurements for one specimen is 110. Proximity of transducers to the edge of specimen was, 2.5-10 cm.

Performing the indirect transmission, path length of measurements is parallel to the reinforce-ment bars. With ultrasonic tester "UK-1401" for each specimen 330 measurements were done (path length l_p, 15 cm, number of measured paths in each zone n_p, 5, step of measuring in each zone s_m, 0.4 cm). 660 meas-urements performed with a de-vice "A1220 Monolith" for lon-gi-tudinal and transverse waves sounding (l_p, 9 cm, n_p, 5, s_m, 1.5 cm). Whereas, performing the longitudinal pro-fi-ling with oscillograph "UKB-1M" in total 198 measurements were carried out for one speci-men (l_p, 3-12 cm, n_p, 9, s_m, 3, number of profiling base points, 2). Hence, when investigating one specimen with the indirect transmission 1,188 measurements have been done in total. Proximity of transducers to the edge of specimen (in its cross direction) for devices: "UK-1401", 1.7-3.3 cm; "A1220 Monolith" and "UKB-1M", 2.5-5.5 cm.

4. Testing Results

In this paper the experimentally obtained data is provided in the concentrated form. Results achieved for the concrete at the age of early hardening and after 2 years and 2 months of manufacturing are given in the previous researches [11, 12].

It must be emphasized that since the moisture content of concrete has a significant effect on the UPV, it was determined every time before the measurements were carried out. The results shown in this paper have calculated by taking into account the effect of moisture.

Prior to the analysis of the obtained data, the classification and comparison methodology of different measuring zones should be explained. Table 1 contains the UPV results of testing methods applied for specimen with rebars of largest diameter. In further explanations the references are giving to this table's row called position. First, the essential features of the UPV were obtained in measuring zones of specimens located closer to (zones 1-2.5) and farther from (zones 3-5) the rebars embedded in concrete to the surface to be tested. The comparisons of the UPV in these measuring zones are shown in positions 1-3, (Table 1). Position 1 and 2 indicates comparison of the UPV for indirect transmission measured accordingly in the bottom and upper part of concrete specimen, while the position 3 demonstrates the correlation between these two classified zones when direct transmission is applied. Second, at direct transmission quite significant difference of the UPV has been fixed between rebar

Table 1 Comparison of the UPV longitudinal wave propagation measured with device «A1220 Monolith» at direct and indirect transmission by comparing classified measuring zones of concrete specimen reinforced with 22 mm diameter rebars.

Transmission method	Indirect		Direct		Indirect	
Position	1	2	3	4	5	6
Zones compared	1...2.5 / 3...5	1'...2.5' / 3'...5'	1-1'...2.5-2.5' / 3-3'...3-5'	1-1';...;5-5' / 1.5-1.5';...;4.5-4.5'	1;...;5 / 1.5;...;4.5	1';...;5' / 1,5';...;4.5'
Δ, %	-9.73	1.43	-0.03	-6.81	0.38	0.25

zones (zones *1-1′*; …; *5-5′*) and plain concrete (*1.5-1.5′*; …; *4.5-4.5′*), see position *4*. Similarly, rebar and plain concrete zones have compared also for indirect transmission testing, for bottom and upper part of specimen see accordingly position *5* and *6*.

The before-mentioned relations between different measuring zones of reinforced concrete specimen in graphical form are given in Fig. 1. It should be noted some features discovered in this research differ from the experimentally validated assumptions so far. First of all, not in all cases the bottom massive of the reinforced concrete specimen will produce the higher UPV than in upper part. Furthermore, depending on the embedded reinforcement diameter and its proximity to the surface to be tested, this relation may be variable even within the same specimen. Also the attention must be paid to the following. When for tests direct transmission is applied, the UPV shall be reduced in zones where the emitted pulse crosses the reinforcement bar.

4.1 Comparison of Rebar Zones and Plain Concrete

Measuring scheme for direct and indirect transmission has been described in previous chapter. However, it should be emphasized that in order to elaborate the comparison of the UPV propagation in rebar zones and in plain concrete, at indirect transmission were tested both the bottom and the upper part surfaces of specimens. Comparison of the UPV in classified zones for all specimens and sounding methods are given in graphical form (Fig. 2). Results for indirect transmission are calculated as average values of measurements in bottom and upper part surfaces of specimens.

As shown in Fig. 2, the reinforcement effect is observed only for direct transmission method. According to results of this research, decrease of the UPV has been determined in rebar zones. And namely, propagation of the UPV longitudinal waves in plain concrete is higher. Besides, by increase of rebars' diameter in specimens, a relatively higher rate of reduction of the UPV in rebar zones has been obtained (Fig. 2). For reinforced concrete specimen with rebars of largest diameter (22 mm), depending on the ultrasonic device, decrease of the UPV in rebar zones is even up to 7%. For other specimens (see rebars diameter Ø) decreases of the UPV are as follows: Ø16 mm, 4.7%; Ø12 mm, 3.7%, Ø8 mm, 2.7%; Ø6 mm, 2.4%. It is concluded that the smaller diameter of rebars in concrete leads to the smaller difference between the UPV in rebars zone and in plain concrete. In its turn, for indirect transmission method this relationship wasn't established.

Impact of the reinforcement on the UPV can be expressed in the form of correction factor *k* as it is done in previous researches [7], see formula (3). The values

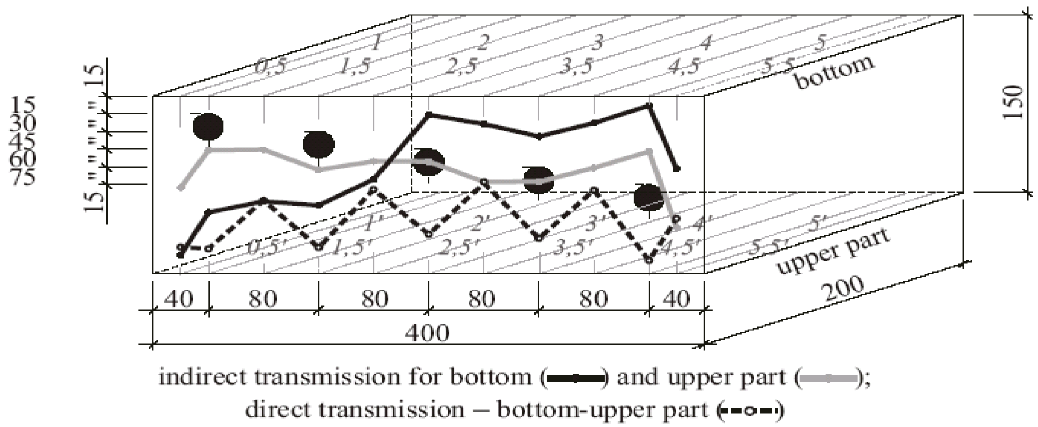


Fig. 1 Parameters of the concrete specimen with embedded rebars (Ø22 mm), the sizes in mm; measurement zones for upper part and bottom surfaces; curves of the UPV longitudinal wave propagation in concrete for transmission methods measured with device «A1220 Monolith».

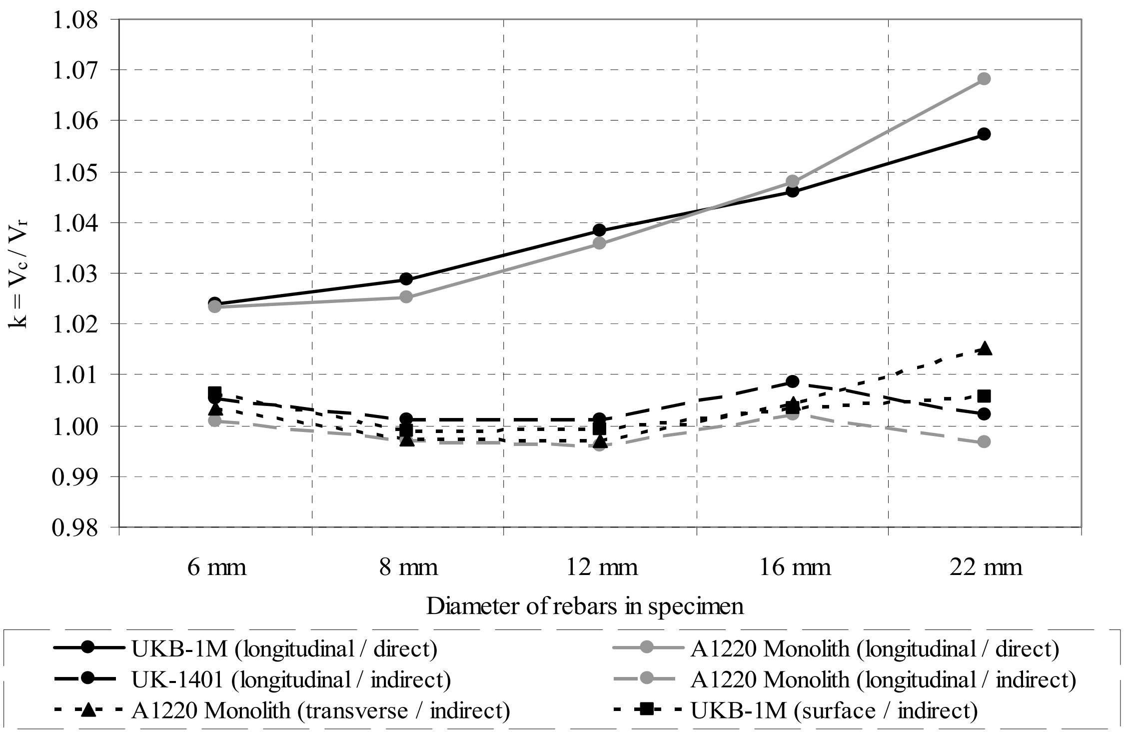


Fig. 2 Impact of reinforcement diameter on the UPV using different transmission methods by comparing results in plain concrete V_c and in rebar zones V_r.

of correction factor, which are determined in present research, depending on the diameter of rebars in reinforced concrete specimens for direct and indirect transmission methods in graphical form are shown in Fig. 2.

The value of correction factor, which is determined by inserting data in formula (3), for specimen with 22 mm diameter rebars is in the range from 1.06 to 1.07. Let's compare results of present research with suggestions of other researches in accordance to determine the correction factor [1, 7].

Since data of compressional waves during this research are achieved, results of direct transmission testing can be inserted in formula (2). Lets consider the most inconvenient condition for direct transmission: full diameter of each bar during the pulse path, 22 mm; path length, 15 cm. The UPV of longitudinal waves for all specimens used in this research is in range from 4,300 to 4,500 m/s, but for particular specimen of 22 mm diameter rebars, 4,327 m/s on average. In this case can be predicted the influence of the reinforcement on the UPV:

$$\frac{V_c}{V_r} = 1 - \frac{22}{150}\left(1 - \frac{4327}{5200}\right) = 0.98$$

It means that increase of the UPV in rebars zone for current specimen should be 2%. However, the change of the UPV is conversely, the decrease is 6%-7% (Fig. 2). As can be seen, between the results has been obtained a significant difference. In particular, it is related to the case of concrete strength evaluation by using correlation curves "UPV-concrete strength". In previous experiments it is found that 5% change of 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.

Results of research described in paper [7] indicate that for 22 mm diameter rebars correction factor k is very close to 1. Similarly, for the smaller diameter rebars in above-mentioned research has not found changes of the UPV in rebar zones. It should be noted the following, relation of parameters L_s and L in research is equal to 0.25, but for specimens with rebars of largest diameter (22 mm) used in experiment of this work, 0.15. However, this discrepancy does not affect the nature of the relationships established in present research, because supposedly by minimizing the sounding base or increasing the thickness of the rebars in path length of the ultrasonic pulse, the value of correction factor can be increased even more.

There are no references that correction factor in some conditions would be greater than 1, i.e., that reinforcement can reduce the propagation of the UPV in concrete [1, 7].

Graphical illustration in Fig. 3 shows the relationship between correction factor and rebar diameter for direct transmission method. There is given the comparison of results obtained in this research and collected by J. H. Bungey. According to this research data the value of correction factor increases from 1.02 to 1.07 with the increase of rebars diameter in specimens. However, the results given in paper [7] are contrary to present findings, furthermore, the correction factor value k in previous researches has never exceeded 1.

Summarizing the results, it is concluded the following. The direct transmission method shows the significant decrease (7%) of the UPV in zones of 22 mm diameter rebars in comparing with the UPV in the plain concrete. At the same time for indirect transmission suchlike changes of the UPV in concrete caused by reinforcement is not obtained (Fig. 2). More detailed information on indirect transmission test results is collected in papers of previous researches [11, 12]. Results of previous measurements have also been inserted in formula (1) and it arrived at a conclusion that this formula can't be applicable for any reinforced concrete [12]. Moreover, 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, see below.

4.2 Impact of Rebars Proximity to the Surface to be Tested

Following the scheme described in the previous

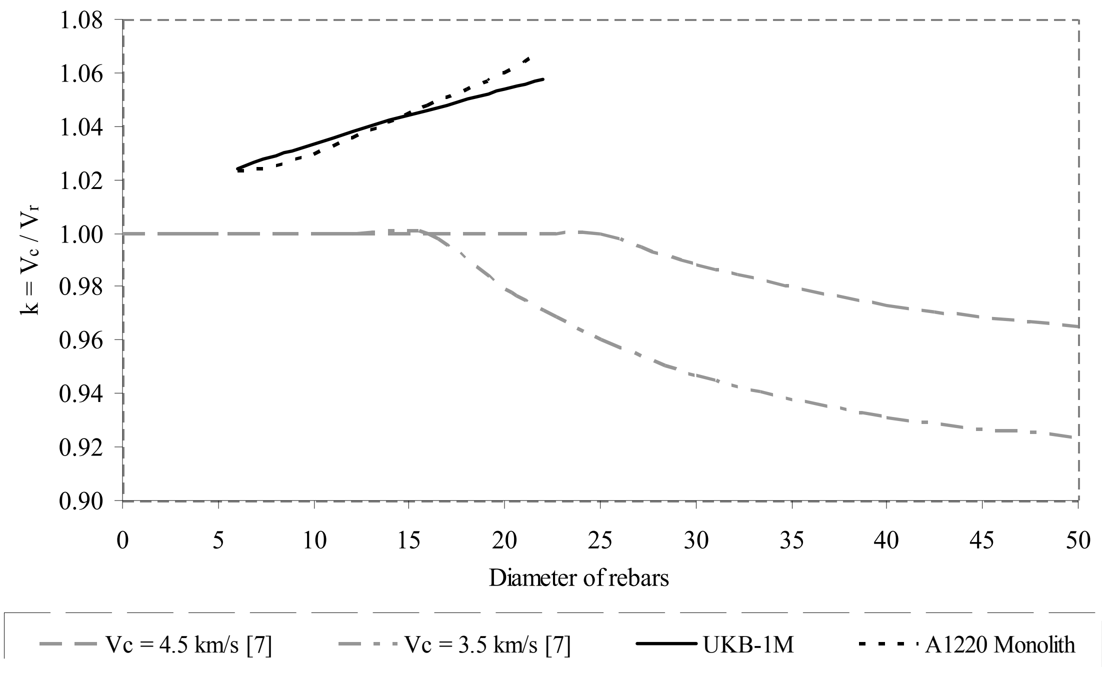


Fig. 3 Comparison of the correction factor *k* values obtained in present research (black curves) and given in paper [7] (gray curves) depending on the diameter of transversally orientated rebars to the path between transducers.

chapter, the ultrasonic measurements were performed with both the direct and indirect transmission testing methods. It should be noted that the changes of the UPV caused by the proximity of the reinforcement bars to the surface only appears in the case of indirect transmission, this regularity was not observed during direct transmission. In any case, the UPV measurements obtained at direct transmission demonstrates the information on the degree of compacting of any tested specimen through the bulk of it. Such a control option allows to exclude the possible impact of the irregular compacting of concrete to the further described relations.

According to the results achieved during this research, for specimen with 22 mm diameter rebars at indirect transmission obtained propagation of the UPV in measuring zones shows a rather peculiar nature, see Fig. 1. And namely, the UPV obtained at bottom surface sounding in the specimen's area, where the rebars is embedded at 1.5 and 3 cm distance from the tested surface in measuring zones *1 ... 2.5*, is significantly lower in comparison with the UPV in the measuring zones *3 ... 5*, where the concrete cover is more than 4.5 cm. The Table 2 collected results show that before mentioned difference for the longitudinal waves is in average 5.4%-9.7%, for transverse waves, 4.6% and for surface waves, 3.8%. It is possible that these differences are related also to the working frequencies of ultrasonic devices.

Besides, for this specimen the UPV at the concrete bottom massive is even comparatively lower than at the upper part (Fig. 1). Usually this relation is reversed (see the last column of the Table 3), because at the moment of concrete's placing the upper part of the specimen does not, in comparison, get compacted as well, and during the hardening process in formworks its environment is not as favourable as for the concrete of the bottom part, where the moisture evaporation is prevented by the formwork (for detail see further).

For the upper part concrete, in its turn, in the measuring zones *1′ ... 2.5′* and *3′ ... 5′*, before mentioned relation of the UPV changes is not observed, given that the reinforcement here is located further away from the tested surface. From the acquired results it can be concluded that the 22 mm diameter rebars embedded in the depth of 4.5 cm do not affect the UPV.

The influence of the rebars diameter on the UPV, that is obtained in the measuring zones *1 ... 2.5* and *3 ... 5*, is graphically given in the Fig. 4. In this figure, the results for all methods of indirect transmission testing are summarised and the data is provided for all specimens used in research. The relation $V_{1...2,5}$ and $V_{3...5}$ describes how reinforcement affects UPV change depending on the rebar diameter and the proximity of their placement to the tested surface. It is

Table 2 The results of the UPV in specific measuring zones by comparing bottom and upper part massive of the specimens.

Transmission method	Type of waves	Ultrasonic device	Zones compared	Diameter of rebars in specimen				
				Comparison of the UPV in different zones, %				
				22 mm	16 mm	12 mm	8 mm	6 mm
Indirect	Longitudinal	UK-1401	1...2,5 / 3...5 1'...2,5' / 3'...5'	-5.44 2.05	-2.26 -0.21	-1.59 -0.28	-1.33 -0.26	-1.10 -0.10
	Longitudinal	A1220 Monolith		-9.73 1.43	-1.91 -0.22	-1.36 0.74	-1.10 0.30	-0.48 0.50
	Transverse	A1220 Monolith		-4.60 3.09	-1.57 0.26	-1.08 0.46	-0.91 -0.31	-0.35 -0.72
	Surface	UKB-1M		-3.81 -1.41	-1.39 -0.43	-1.16 0.37	-0.67 -0.14	-0.42 -0.32
Direct	Longitudinal	UKB-1M	1-1'...2,5-2,5' / 3-3'...5-5'	-1.54	-1.36	-1.17	-1.40	-0.49
		A1220 Monolith		-0.03	0.66	-0.31	0.06	-0.29

Table 3 Differences of the UPV measured with indirect transmission method in bottom and in upper part of reinforced concrete specimens in classified measuring zones.

Ultrasonic device	UK-1401			A1220 Monolith						UKB-1M			Average in total
Type of waves	Longitudinal						Transverse			Surface			
Zones compared / Diameter of rebars in specimen	1...2.5 / 1'...2.5', %	3...5 / 3'...5', %	Δ_{3-2}, pp	1...2.5 / 1'...2.5', %	3...5 / 3'...5', %	Δ_{6-5}, pp	1...2.5 / 1'...2.5', %	3...5 / 3'...5', %	Δ_{9-8}, pp	1...2.5 / 1'...2.5', %	3...5 / 3'...5', %	Δ_{12-11}, pp	1...5 / 1'...5', %
1	2	3	4	5	6	7	8	9	10	11	12	13	14
22 mm	0.28	7.94	7.66	-4.38	6.45	10.8	1.68	9.76	8.07	2.63	5.05	2.43	4.05
16 mm	4.53	6.67	2.14	3.45	5.20	1.75	4.44	6.35	1.91	3.40	4.39	0.98	4.91
12 mm	4.89	6.26	1.37	2.85	5.02	2.17	4.43	6.05	1.62	2.78	4.36	1.58	4.67
8 mm	4.79	5.91	1.12	2.96	4.40	1.44	3.07	3.69	0.62	0.47	1.00	0.53	3.32
6 mm	8.30	9.38	1.08	5.66	6.69	1.03	6.96	6.58	-0.38	4.32	4.43	0.10	6.59

fixed a considerable UPV reduction for specimen with 22 mm diameter rebars, depending on the devices used for the testing and the type of waves, the correction factor is in the range of 0.91 to 0.96. With the decrease of the rebar diameter, the changes of UPV decrease as well. For all other specimens these changes are insignificant.

To understand the impact of the rebar diameter on the UPV propagation in concrete, let's consider two comparative charts, where the results of UPV measurements are shown in the above defined measuring zones *1 ... 2,5* and *3 ... 5* relation principle. These charts show the results obtained with all of the indirect transmission measurement devices in the measuring zones *1 ... 5*. The UPV results for each testing method are determined by the relation V_i/V_m, where V_i is the average of each individual measuring zone, V_m, an average of all measuring zones. One of the charts presents the results for specimen with 22 mm diameter rebars, the other one, for the specimen with 16 mm diameter rebars (Fig. 5).

As shown, the curve nature is different for both charts in the measuring zones *1 ... 2,5*. Namely, the propagation of the UPV in specimen with the 22 mm

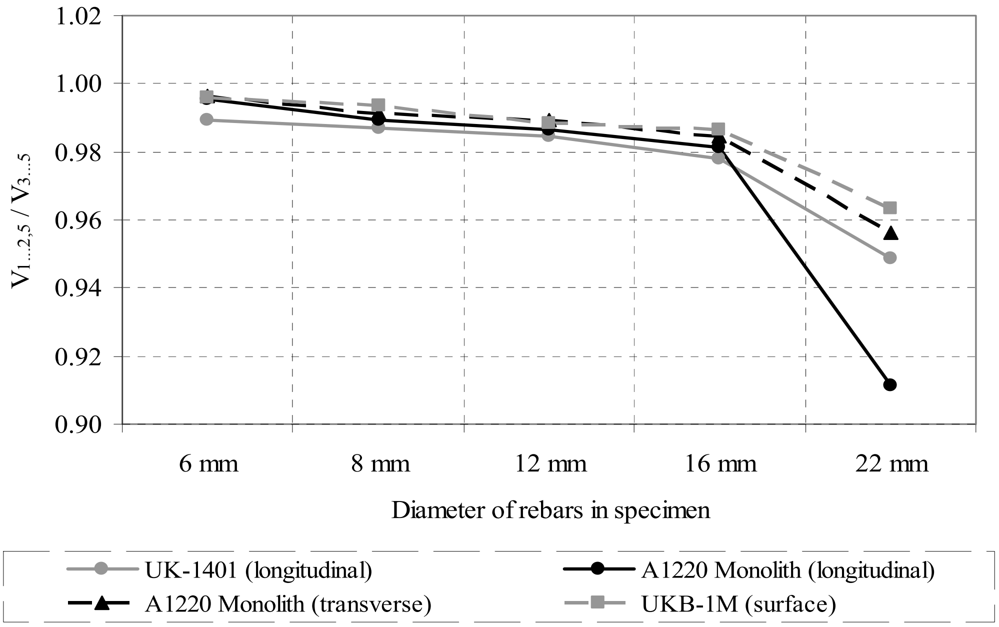
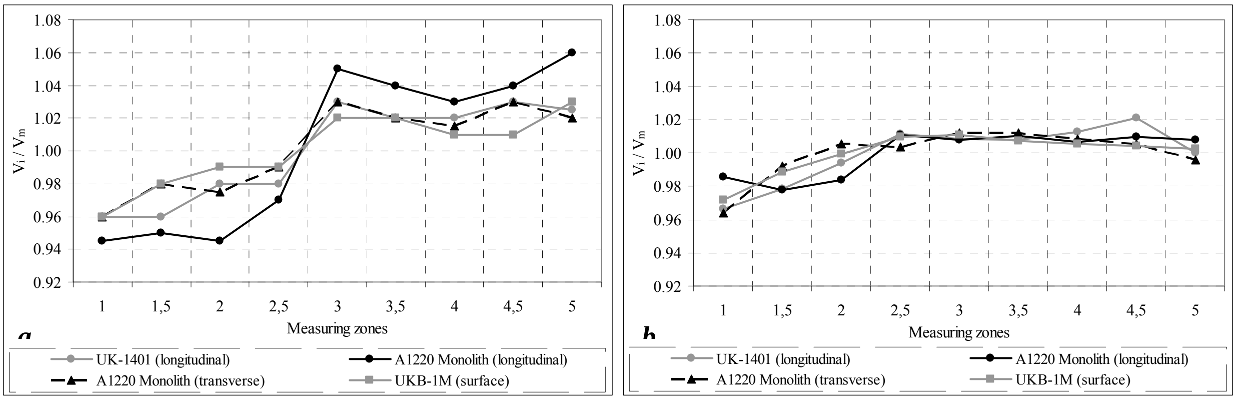


Fig. 4 Influence of reinforcement diameter on UPV at indirect transmission by comparing measuring zones *1...2,5* and *3...5*, where rebars located accordingly closer to and farther from the surface to be tested.



(a) (b)

Fig. 5 Impact of the concrete cover on the UPV above the rebars of 22 mm (a) and 16 mm (b) diameter at indirect transmission when different types of waves were applied for sounding.

diameter rebars is considerably lower than in specimen with 16 mm diameter rebars, if the results of the measuring zones *1 ... 2,5* are compared with the UPV in corresponding specimens measuring zones *3 ... 5*. For the specimens with a smaller rebar diameter the curves V_i/V_m of all measuring zones are practically identical, parallel to the *x* axis.

To ensure that the above defined relations are not influenced by irregular degree of concrete compacting within the tested specimen, the data for direct transmission in these measuring zones was collected. As shown by measurements carried out with both direct transmission devices, the compacting of specimen along its height has carried out regularly (Fig. 1 and Table 3).

Thus it could be concluded that the decrease of the UPV in the zones where the rebars are embedded close to the measured surface was caused most likely either by the heterogeneity of the tested medium (as evidenced by observations, in transition zone “hydrated cement paste (HCP) —reinforcement bars” the concrete is characterised by heightened porosity in (HCP), or by the different concentration of the coarse aggregates around the rebars caused by centrifugal forces, which are promoted during the compacting of concrete by vibration.

The data achieved can also be classified by the following principle. Namely, for each specimen and for each indirect transmission method, the UPV, obtained by measuring the bottom and the upper part massive in the corresponding measuring zones *1 ... 2,5* and *3 ... 5,* as well as *1′ ... 2,5′* and *3′ ... 5′*, will be compared. As it mentioned before, the bottom part concrete of the specimens usually shows a higher UPV, which is related both to the more favourable environment during the hardening in formworks and the compacting performed at the moment of placing (it is believed that during the vibration the coarse aggregates moves downward due to gravity, thereby contributing to the propagation of the UPV at the bottom part of a specimen). The comparison of the above-mentioned zones is summarised in the Table 4.

According to the calculation model shown in the Table 4, the high degree of homogeneity of the reinforced concrete specimens is demonstrated by the identical percentage difference between the measuring zones relations *1 ... 2,5* to *1′ ... 2,5′* and *3 ... 5* to *3′ ... 5′* that describe the UPV results in the upper and bottom parts. And namely, ideally, the percentage points (pp) difference *Δ* should be equal with zero. Evidently, the UPV obtained for concrete specimen with 22 mm rebars in these measuring zones shows a significant difference: for longitudinal waves 7.66 ... 10.8, for transverse waves, 8.1 and surface waves, 2.43 pp. For specimens with smaller rebar diameters the established *Δ* values indicates relatively high homogeneity of concrete. Hence, a correlation is confirmed, the smaller the diameter of rebars located close to the surface to be tested, the higher the homogeneity of specimen's concrete in this zone.

One another reason for lower UPV in rebar zones can be unsatisfactory adhesion between reinforcement bars and surrounding concrete. To ensure the quality of this adhesion property ultrasonic detector "A1220 Monolith" was used. The results of this test confirmed that adhesion between rebars and concrete is fixed of good quality and this cannot be the reason for the differences in UPV mentioned before [12].

To summarise what is described in this section, it could be concluded that the reinforcement, which is located close to the surface to be tested, is able to decrease the UPV significantly, if indirect transmission method is applied for measurements. Besides, depending on the rebar diameter and its proximity to the tested surface, significantly different UPV results can be observed even within the same specimen. As demonstrated by the results of this research, for a concrete specimen with 22 mm diameter rebars, when sounding with longitudinal waves until the area, where the concrete cover is 3 cm, the UPV decrease amounts to 10%.

5. Conclusions

The experimentally obtained data show that the reinforcement has the opposite effect on the ultrasonic pulse velocity (UPV) in concrete as it specifies other scientific studies and various standards so far. In rebar zones propagation of the UPV shows the decrease of values. Furthermore, this is related to the longitudinal waves, as well as to the transverse and surface waves. Thus, application of the previously published correction factors for the UPV determination in rebar zones is not recommended because it can cause misinterpretation of the measurements. Mistake of 5% in the determination of the UPV can cause up to 50% difference in the concrete strength evaluation.

Impact of rebars proximity to the tested concrete surface has been found only for the indirect transmission. In zone of 22 mm diameter rebars, even if the concrete cover is up to 3 cm, it is determined a significant decrease of the UPV in comparison with the results of the rest surface area of specimen. The maximum decrease of UPV in average is 10%. For specimens reinforced with smaller diameter of rebars than 22 mm these changes are insignificant. Measurements that have performed perpendicularly to the rebars direction showed the results of similar nature.

Comparing the results between the rebar zones and plain concrete, the direct transmission shows the decrease of UPV in zones where the emitted pulse crosses the reinforcement bars. The maximum value of the UPV decrease is 7%. It is concluded that the smaller diameter of rebars in concrete leads to the smaller difference between the UPV in rebars zone and in plain concrete. For indirect transmission there is no reinforcement influence on the UPV.

By ignoring the decrease of the UPV in concrete caused by reinforcement, determined properties for tested structure will be lower than they actually are. Hence, following should be considered. Direct transmission applied for columns, beams a.o. similar structures will give correct results only if in the path of the ultrasonic pulse the load-bearing reinforcement is not located. Performing the indirect transmission tests for floor, slab and wall structures, ignorance of reinforcement effect in most cases would be acceptable only when the concrete cover is equal to 4 cm or more.

Reducing factor of the UPV in rebar zones mainly can be related both with the different properties (incl. heterogeneity) of concrete in transition zone "hydrated cement paste (HCP)—reinforcement bars" because of heightened porosity in HCP and with the difference in concentration of coarse aggregates around the rebars caused by centrifugal forces, which are promoted during the compacting of concrete by vibration. It is not excluded that the UPV may be affected also by development of concrete aggregates and admixtures, which might have changed the medium where the ultrasonic pulse propagates.

Obviously, variations in concrete moisture content will also introduce corrections in assessment of reinforcement impact factor on the UPV. There are indications that with increasing of the concrete moisture content, the influence of this factor should be reduced. The relationship between concrete moisture content and impact of reinforcement on the UPV is being studied at present.

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