Atypical Applications of Ultrasonic Method in Testing of Concrete Structures

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Abstract. This paper presents atypical applications of the ultrasonic method in the *in situ* testing of concrete in structures by means of exponential heads. In typical applications of the ultrasonic method, the large contact surface area of flat measuring heads (20-50 mm in diameter) sometimes makes it difficult to carry out such measurements on the investigated element. If detailed information about the tested material along its thickness is to be obtained, e.g. in order to determine the depth of an improperly made floor surface concrete layer, then exponential heads should be used, which is described in this paper.

1. Introduction

In the building industry the ultrasonic method is used mainly to assess the strength and homogeneity of concrete in existing structures thanks to the correlation between the velocity of an ultrasonic wave in concrete and the properties of this material [4-7]. Such tests can be carried out on both concrete samples and concrete in structures. In typical ultrasound tests the ultrasound heads are in contact with concrete via a flat surface with an average diameter of 20-50 mm. As a result, the number of measuring points on the tested structural element, particularly along its thickness, is rather limited. But it is often necessary to obtain information about the concrete in a structural element by testing the latter along its thickness in order to determine, for example, the depth of a frozen zone or an improperly made floor surface layer or to detect defects (voids and caverns not filled with concrete) in a structural component with a high percentage of reinforcement. Then a different approach must be employed. Exponential heads coming into contact with concrete pointwise (the contact being 1 mm in diameter) are suitable for this purpose. In this case, the number of measuring points on the tested component can be very large.

This paper presents a few atypical applications of the ultrasonic method, i.e. to determine the depth of a frozen zone in the concrete of a structural floor and that of an improperly made surface layer of an industrial floor, using core drillings. The method is also applied to detect hidden defects in the form of air voids not filled with concrete in a reinforced concrete with a high percentage of reinforcement.

2. *In situ* testing of concrete in structures by means of atypical exponential ultrasound heads

Exponential heads with a point contact with concrete are suitable for testing concrete along the thickness of a structural element. Detailed specifications of the heads can be found in [1, 2]. It should be mentioned that their frequency must be in a range of 40 ÷ 100 kHz and their diameter at the tip is 1 mm. The test consists in drilling cores 80 or 100 mm in diameter from a structural floor or an industrial floor. Then the cores are investigated by exponential ultrasound heads with a point contact with concrete [2, 3]. Thanks to this shape of the heads the distance between neighbouring measuring points can be small. The longitudinal velocity of the ultrasonic wave is measured in two mutually perpendicular directions in planes spaced at every 10 mm, as shown in fig. 1. Then one or two cylindrical specimens (with the height and the diameter approximately equal) are cut out from a core and crushed in a testing machine. In this way the correlation between longitudinal ultrasonic wave velocity C_L and tested concrete strength f_c is determined. Finally, the compression strength of the concrete in the core along the latter's thickness is determined.

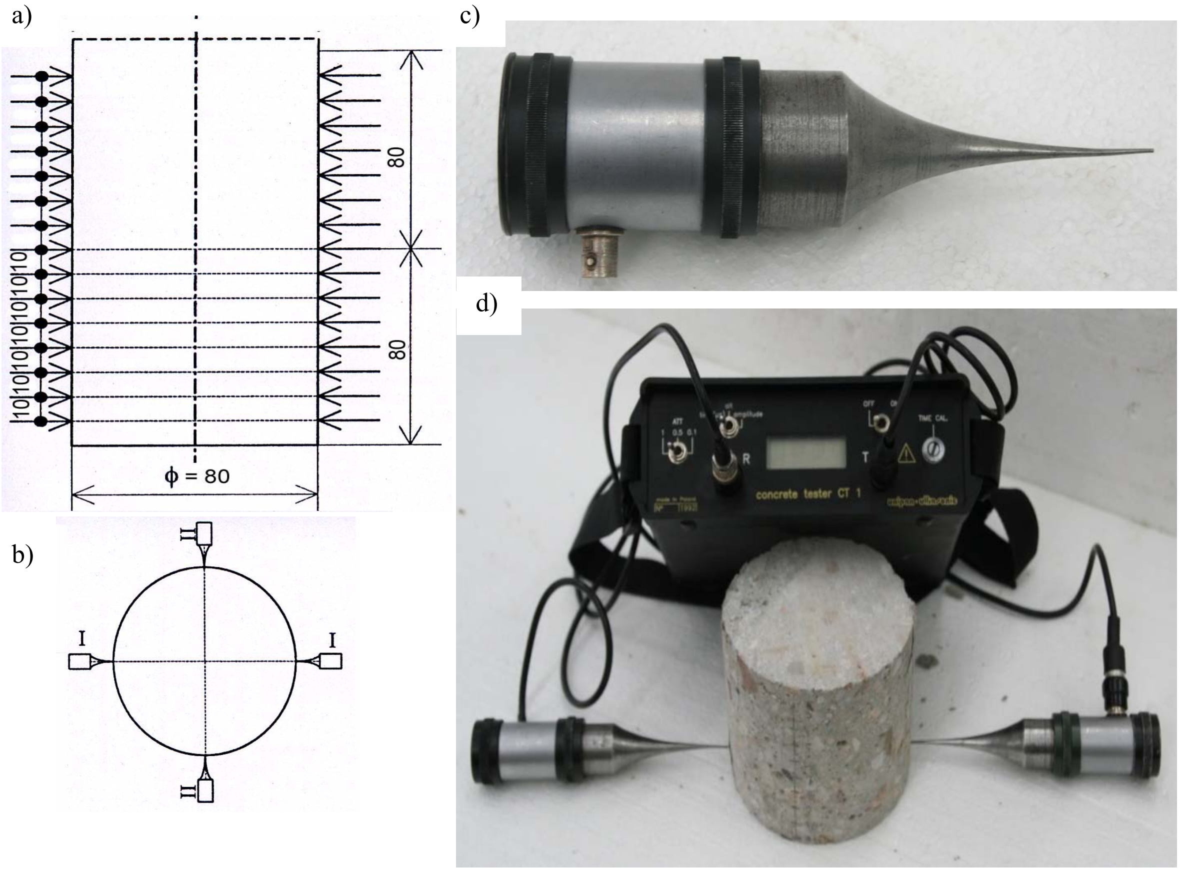


Fig. 1. Measurement of longitudinal ultrasonic wave velocity by means of exponential heads: a) spacing of measuring points, b) investigation direction I and II, c) exponential head, d) view of measuring stand

3. Examples of atypical applications

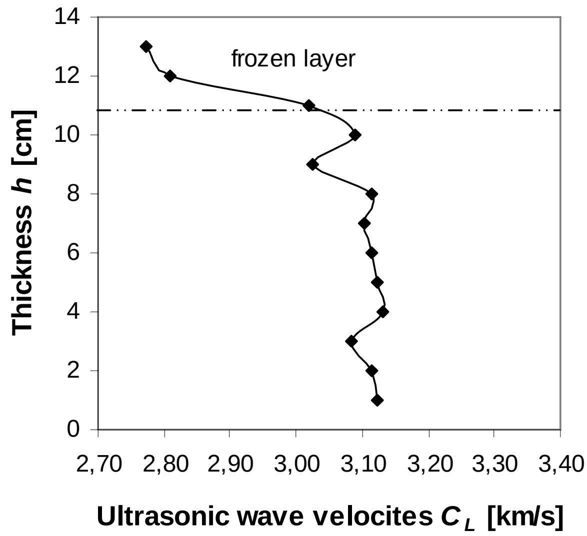
3.1. Determination of thickness of frozen concrete layer in structural floor

The structural floors of buildings are often made as composite concrete structures. An example here are *Filigran* floors consisting of prefabricated reinforced concrete units which make up the foundation for a 140÷180 mm thick upper monolithic layer made of ordinary concrete.

During the laying of a monolithic layer on such a floor in a building the air temperature dropped to below -10°C. As a result, the concrete in a part of the floor (which was not protected against frost) froze at an early stage of curing. Thus it became necessary to determine to what degree the strength of concrete along the thickness of the monolithic layer was affected by the sub-zero temperature.

For this purpose 3 cores 80 mm in diameter were drilled from the floor's part where the concrete was frozen and 3 such cores were drilled from the part undamaged by frost. The cores were investigated along their thickness by the ultrasonic method using exponential heads, as shown in fig. 1. The obtained longitudinal ultrasonic wave velocity distribution along the thickness of the monolithic layer is shown in fig. 2.

a)



b)

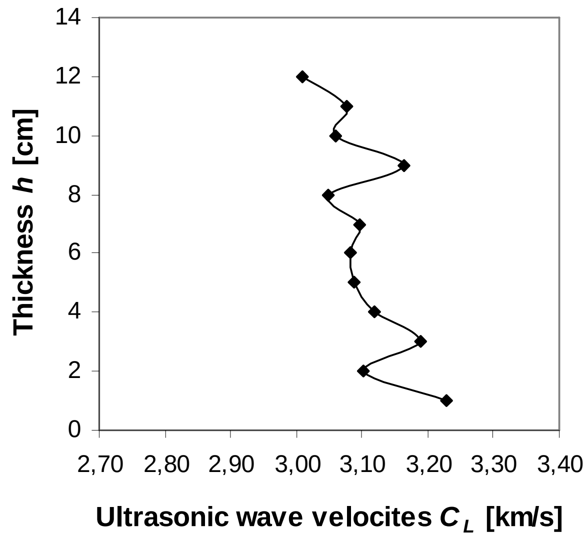


Fig. 2. Longitudinal ultrasonic wave velocity distribution along monolithic layer thickness for: a) part of floor where concrete was frozen at an early stage of curing, b) part of floor with concrete undamaged by frost

Both the frost-damaged concrete and the undamaged concrete are characterized by a similar ultrasonic wave velocity graph shape, but the frozen concrete (fig. 2a) shows a much lower ultrasonic wave velocity (considerably below 3.0 km/s) in the top layer. For comparison, the ultrasonic wave velocity in the top layer of the concrete not damaged by frost is 3.05-3.10 km/s. According to fig. 2, the layer of concrete damaged by frost is about 30 mm thick, which is marked in fig. 2a.

In order to find out how the ultrasonic wave velocity distribution along the thickness of the same floor made from similar ordinary concrete a few weeks earlier in a neighbouring building looks like, a few cores were drilled from the floor and they were tested in the same way as described above. Matched hypothetical relation f_c–C_L was expressed by this equation

$$f_c = 23.7\, C_L - 56.03 \tag{1}$$

The distribution of longitudinal ultrasonic wave velocity along the floor's thickness is shown in fig. 3a while the distribution of concrete strength in this floor, determined from the hypothetical relation, is shown in fig. 3b. It becomes apparent that the longitudinal ultrasonic wave velocity distribution in fig. 2b is similar to that in fig. 3a. This confirms that the top monolithic layer of concrete is damaged to a depth of about 30 mm, as shown in fig. 2a.

a)

b)

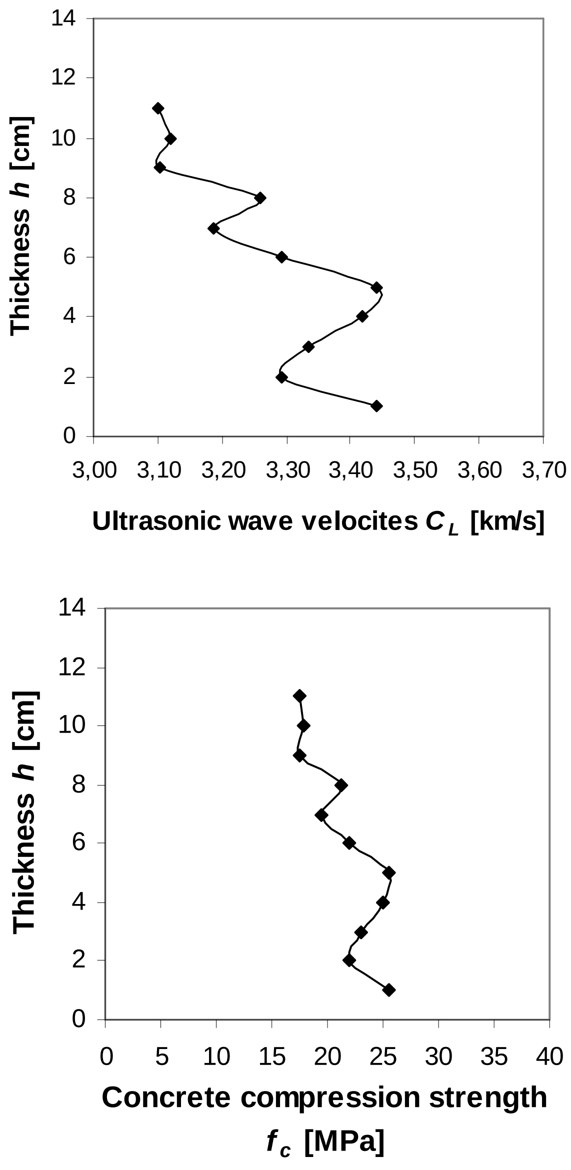


Fig. 3. Distribution of: a) longitudinal ultrasonic wave velocity and b) concrete compression strength along thickness of floor made a few weeks earlier

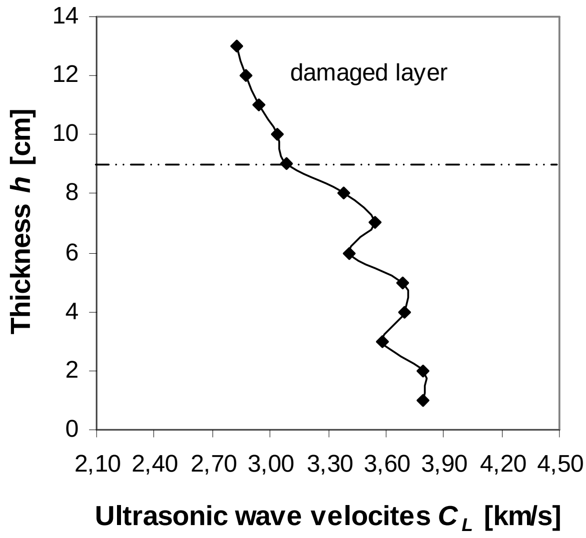
3.2. Test of workmanship of industrial floor's surface layer

Industrial floors are mostly exposed to heavy mechanical loads (abrasion, impacts, local pressures, etc.). This means that their top layer should not be weaker than the bottom one.

In order to check this, similar ultrasonic tests as in the case of the structural floors (see pt. 3.1) were carried out.

The floor in one production hall showed numerous cracks while in the other production hall situated nearby, the floor, made of the same material, was undamaged. In order to determine the causes of the damage, three cores (80 mm in diameter) were drilled from each of the floors. The cores were investigated using the ultrasonic method according to the procedure described in pt. 2. Sample diagrams showing the longitudinal ultrasonic wave velocity distribution along floor thickness are presented in fig. 4.

a)



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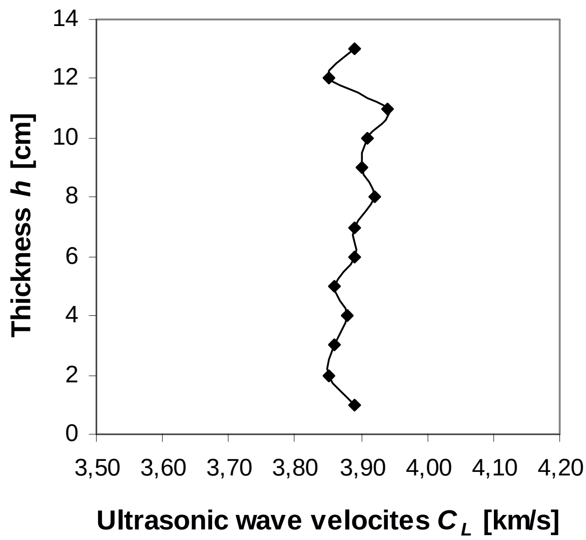

Fig. 4. Longitudinal ultrasonic wave velocity distribution along floor thickness for: a) floor in first hall, b) floor in second hall

The two graphs shown in fig. 4 have similar shapes, but the damaged concrete (fig. 4a) is characterized by a much lower ultrasonic wave velocity in the top layer – considerably below 3.0 km/s. This indicates that the top layer may have lower strength than the bottom one, which means that it was not made properly. For comparison, the longitudinal ultrasonic wave velocity in concrete in the undamaged floor's top layer (fig. 4b) is 3.80-3.90 km/s. According to fig. 4, the damaged layer is about 40 mm thick, as marked in fig. 4a.

3.3. Detection of material defects in reinforced concrete girders

It became necessary to check if there were any air voids not filled with concrete in the reinforced concrete roof girders of one of the production halls. Such material flaws were suspected since some of the girders in the hall had failed due to workmanship defects.

The investigations were carried out as follows. Measuring points, spaced at every 50 mm in four planes: A, B, C and D, were marked on the girders, as shown in fig. 5. Then a Fe-meter was used to nondestructively localize the reinforcement bars in the girders. Exponential heads were used for ultrasonic testing. The tests were conducted across the girders. The determined longitudinal ultrasonic wave velocities are shown in fig. 6 where the X-axis runs along the beam's length.

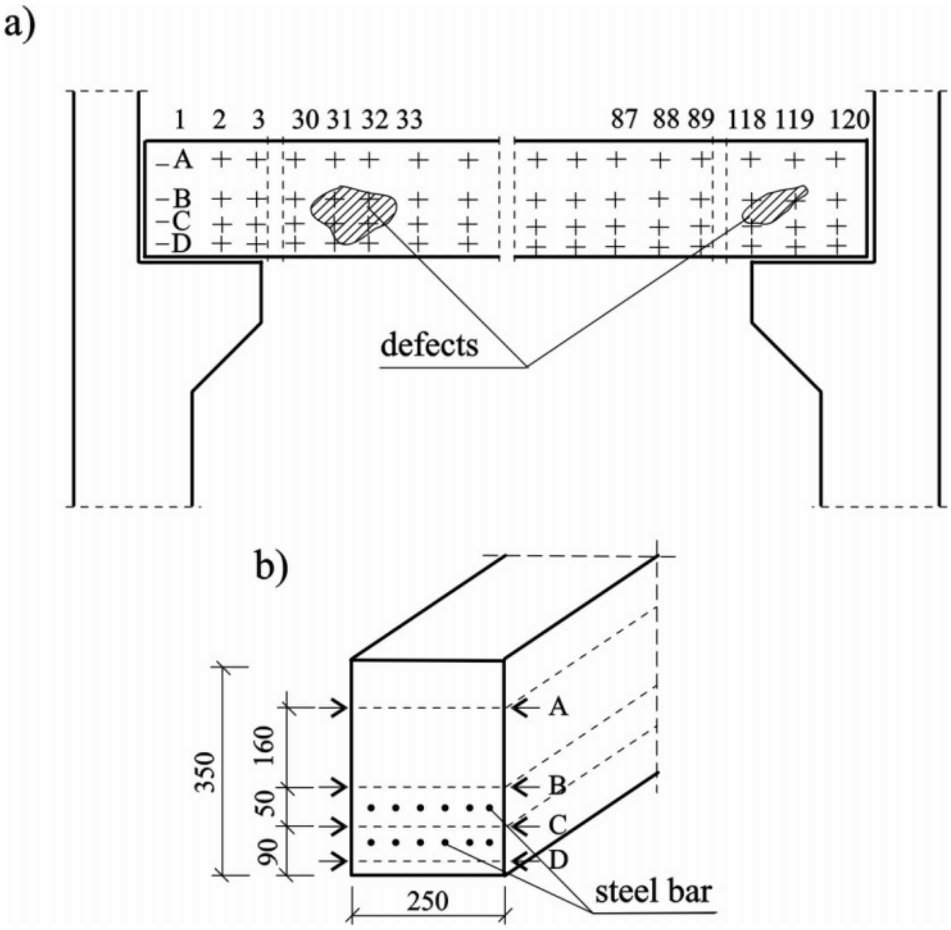

Fig. 5. Procedure for ultrasonic investigation of reinforce concrete girders aimed at detecting large air voids and caverns: a) girder with marked measuring points and places where defects were detected, b) cross section of girder

Areas in which the recorded velocity would be significantly lower than the average determined for flawless concrete were sought. In planes B and C, among others in the regions of measuring points 30 to 33 and 118 to 119, material defects in the form of large air voids were detected, as shown in fig. 5a.

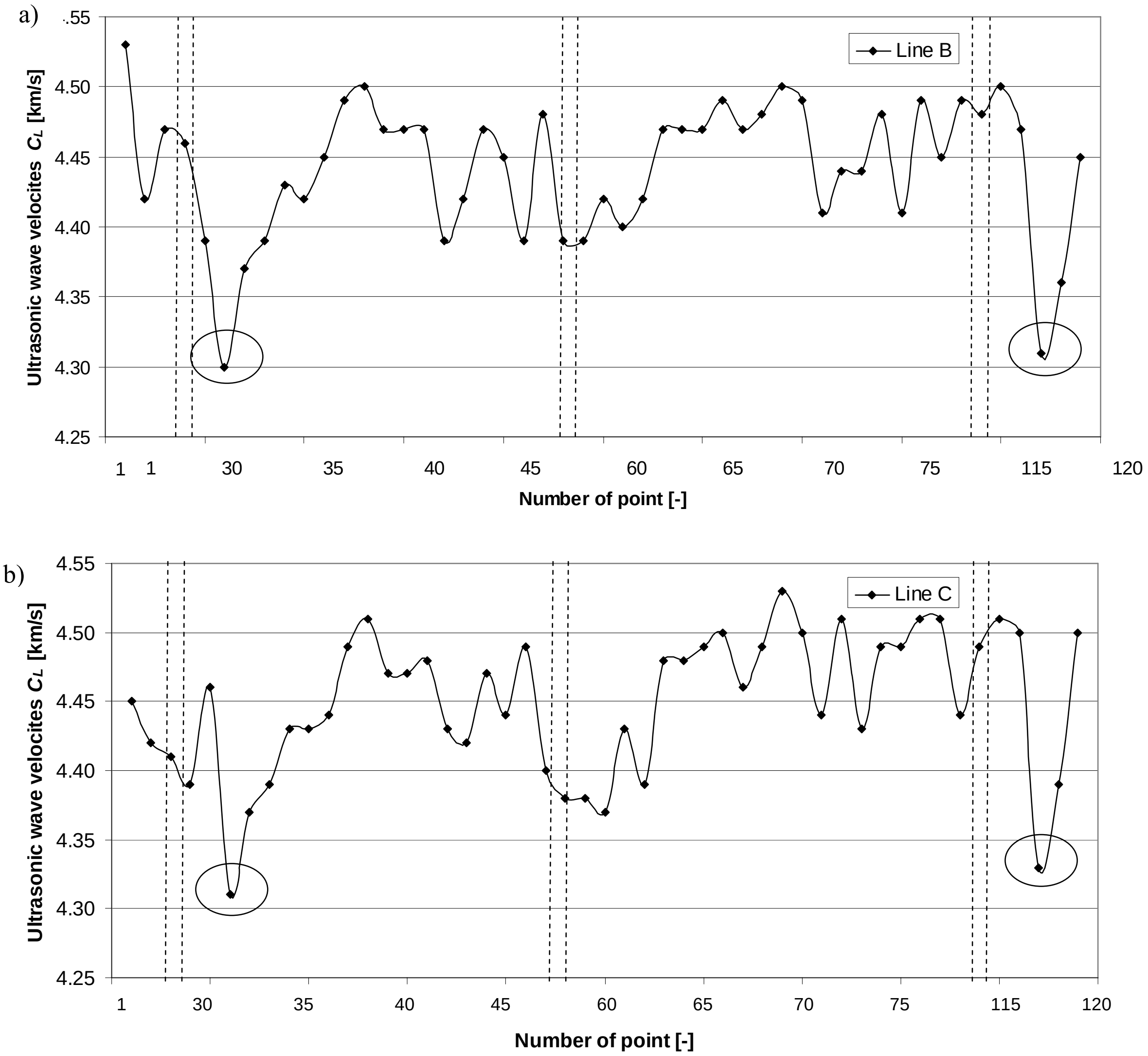

Fig. 6. Diagrams of longitudinal ultrasonic wave velocity in tested section of reinforced concrete girder: a) plane B, b) plane C

4. Conclusion

Several atypical applications of the ultrasonic method with exponential heads in the testing of concrete structures have been presented. The investigations of cores drilled from structural floors with a frozen top concrete layer and from improperly made concrete industrial floors conclusively showed that the differences in the longitudinal ultrasonic wave velocity between the bottom layer and the top one in the damaged components are significant. This means that the ultrasonic method is suitable for qualitative assessment in such situations, i.e. for the determination of the depth of a frozen concrete zone and that of an improperly made floor surface layer. The method can also be used to detect hidden defects, in the form of air voids not filled with concrete, in structural reinforced concrete components by analysing ultrasonic wave velocities in several cross sections of the tested structural component.

References

[1] Dzenis V., "Application of the ultrasonic transducers with point contact for the nondestructive testing" (in Russian), Zinatne Publishing House, Riga 1987.

[2] Gudra T., Stawiski B., " Non-destructive strength characterization of concrete using surface waves", NDT&E international, 2000, vol. 33, no. 1 pp. 1-6.

[3] Hoła J., Stawiski B., "Tests on the usefulness of the ultrasonic method for quick assessment of concrete constructions" (in Polish). 32nd KKBN, Miedzyzdroje, 2003.

[4] Hoła, J., and Schabowicz, K. (2005). "Beurteilung der Betonfestigkeit unter Nutzung der kunstlichen Neuronalen Netze aufgrund zerstorungsfreier Untersuchungen" (in German). Beton-Stahlbetonbau, 5, 416-421.

[5] Kaszyński J., 'Ultrasonic Testing of Concrete, Taking into Account Reinforcement and Cracking Zone' (in Polish), Szczecin Polytechnic, Szczecin, 2003.

[6] Runkiewicz L., 'Tests of Reinforced Concrete Structures' (in Polish), Biuro Gamma, Warsaw, 2002.

[7] Runkiewicz L., '*In Situ* Tests of Concrete Structures in Building Expertise' (in Polish), Proceedings of Building Expertise Conference, Kielce, 1995.