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ULTRASOUND PROPAGATION IN CONCRETE

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Abstract

This paper presents some experimental results concerning the ultrasound waves' propagation in concrete. In the field of non-destructive evaluation of concrete, the ultrasonic wave velocity is usually measured and utilized to predict or correlate the strength of concrete. The impact-echo method is a technique for flaw detection in concrete based on stress wave propagation. A transient stress pulse is introduced into a test object by a mechanical impact generator on the concrete element surface. By this test method we can determine ultrasonic pulse velocity, propagated in concrete specimen. It meets the testing standard BS1881: Part 203; ASTMC597. The equipment has a pulse generator, an ultrasonic emitting transducer and a sensitive receiver piezoceramic transducer. The piezoceramic emitting transducer is excited by electrical pulses of high voltage amplitude, and converts the electrical signal in mechanical vibrations, which propagate in concrete specimen. The piezoceramic sensor output signal is displayed on the memory digital oscilloscope, type TDS 3023, Tektronix, USA. Also, by signal graphic representation analysis in time and frequency can be determined the attenuation coefficient of the pulse in concrete.

INTRODUCTION

Ultrasonic methods for the establishment of physical-mechanical properties of non-metallic materials are: pulse method, examination methods, and direct measurement of the propagation velocity and impact-echo method. Utilizing these non-destructive evaluation ultrasonic methods it can be determined the main material parameters and material characteristics (elasticity coefficients, density, propagation velocity, ultrasound attenuation, etc.) of non-metallic materials. These methods are suitable for non-metallic materials because the non-destructive methods for metallic materials cannot be utilized, due to their rugged and non-homogeneous structures and great attenuation coefficients of ultrasound propagation through materials. Also, the impact-echo method is a technique for flaw detection in concrete based on stress wave propagation. Studies have shown that the impact-echo method is effective for locating voids, honeycombing, delaminating, and depth of surface opening cracks, and measuring member thickness.

By the test method we can determine ultrasonic pulse velocity, propagated in concrete specimen. A device generates low frequency pulses and measures the time taken for pulses to pass between the two transducers placed at the end of the specimen being tested. It meets the testing standard BS1881: Part 203; ASTMC597 [1], [2].

The impact-echo method is a technique for flaw detection in concrete based on stress wave propagation [3, 4]. A transient stress pulse is introduced into a test object by mechanical impact on the surface. The stress pulse propagates into the object along spherical wave-fronts as P- and S-waves. In addition, a surface wave (R-wave) travels along the surface away from the impact point. If the receiver is placed close to the impact point, the displacement waveform is dominated by the displacements caused by P-wave arrivals. The displacement waveform can be used to determine the travel time, from the initiation of the pulse to the arrival of the first P-wave reflection. If the P-wave speed, in the test object is known, the distance to the reflecting interface can be determined.

The P-wave generated by the impact propagates back and forth between the top and bottom surfaces of the plate. Each time the P-wave arrives at the top surface it produces a characteristic displacement. Thus the waveform is periodic, and the period, t, is equal to the travel path, 2T, divided by the P-wave speed (Figure 1).

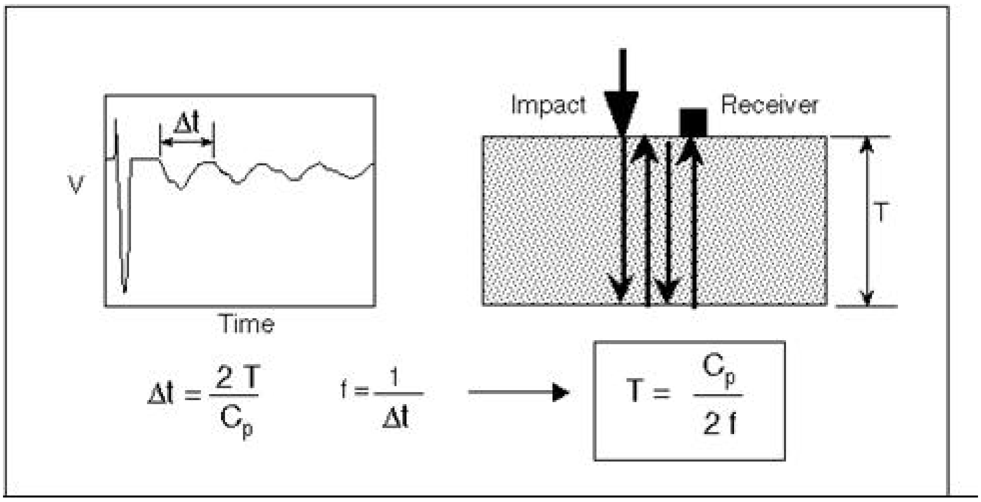

Figure 1 - Frequency analysis based on the principle that the P-wave undergoes multiple reflections between the reflecting surfaces

Since frequency is the inverse of the period, the frequency, f_p, of the characteristic displacement pattern is:

$$f_p = \frac{C_p}{2T} \qquad (1)$$

Thus, if the frequency of an experimental waveform can be determined, the thickness of the plate (or distance to a reflecting interface) can be calculated:

$$T = \frac{C_p}{2 f_p} \tag{2}$$

Note that Eq. (2) is an approximation that is suitable for most applications in plate-like structures.

The calculus relationships to determine the elasticity coefficients (G transversal and E longitudinal), propagation velocities (v_T transversal and v_L longitudinal) are the following:

$$G = \frac{E}{2(1+\nu)} \tag{3}$$

$$\frac{v_L}{v_T} = \sqrt{\frac{2(1-\nu)}{1-2\nu}} \tag{4}$$

$$v_L = \sqrt{\frac{E}{\rho}} \tag{5}$$

$$v_T = \sqrt{\frac{G}{\rho}} \tag{6}$$

$$E = v_L^2 \rho \tag{7}$$

$$G = v_T^2 \rho \tag{8}$$

Weather we consider for **ν = 0.25**, that it is close to reality for most solids, it is resulting the relation **$v_L/v_T = \sqrt{3}$** or **$v_T = 0.58\, v_L \approx 0.6\, v_L$** , and the result is:

:

$$\nu = \frac{\left(\frac{v_L}{v_T}\right)^2 - 2}{2\left(\frac{v_L}{v_T}\right)^2 - 2} \tag{9}$$

As important observation is that ν dynamic is different from **ν static**, where **(v_s) ν static** is the ratio between the transversal and longitudinal strains under static load.

$$v_S = \frac{0,87 + 1,12\nu}{1+\nu}\sqrt{\frac{G}{\rho}} \quad (10)$$

The utilized method of the wave shape propagated into the studied material is described as follow. Piezoelectric sensors offer unique capabilities which are typically not found in other sensing technologies. As discussed, there are certain advantages (such as wide frequency and amplitude range) and disadvantages (no static measuring capability) depending on the particular application. Therefore, when choosing a specific sensor or sensor technology, it is important to pay close attention to the performance specifications.

In the specialty literature we can find tables with experimental material parameter values for different type of concrete. Therefore, we are able to compare our experimental results with known concrete parameters. Table 1 presents mechanical properties of different construction materials.

Table 1 Mechanical, elasticity properties of construction materials

Material	Longitudinal Elasticity Module E, daN/cm^2	Transversal Elasticity Module, G, daN/cm^2	Poisson Coefficient μ	Thermal Dilatation Coefficient α_t
Steel (soft)	$(2.0\text{-}2.15)\cdot10^6$	$(7.8\text{-}8.5)\cdot10^5$	0.24-0.28	$12\cdot10^{-6}$
Steel (hard)	$(2.0\text{-}2.2)\cdot10^6$	$8.5\cdot10^5$	0.25-0.29	$11.7\cdot10^{-6}$
Wrought white iron	$(1.0\text{-}1.6)\cdot10^6$	$4.5\cdot10^5$	0.23-0.27	$10\cdot10^{-6}$
Pig iron	$(0.9\text{-}1.6)\cdot10^6$	-	-	$10.4\cdot10^{-6}$
Cooper	$(1.1\text{-}1.3)\cdot10^6$	$4.9\cdot10^5$	-	$16.5\cdot10^{-6}$
Bronze	$1.1\cdot10^6$	-	-	$17.5\cdot10^{-6}$
Brass	$(0.8\text{-}1.0)\cdot10^6$	$(3.5\text{-}3.7)\cdot10^5$	0.32-0.42	$18.4\cdot10^{-6}$
Hard-aluminium	$(0.7\text{-}0.75)\cdot10^6$	$(2.6\text{-}2.7)\cdot10^5$	-	$23.5\cdot10^{-6}$
Nickel	$2.0\ .10^6$	$7.5\cdot10^5$	0.33	$13\cdot10^{-6}$
Zinc laminat	$0.84\cdot10^6$	$3.2.\ 10^5$	0.27	$16.5\cdot10^{-6}$
Tin	$0.2\cdot10^6$	$0.7\cdot10^5$	0.42	$26.7\cdot10^{-6}$
Limestone	$(0.42\text{-}0.49)\cdot10^6$	-	-	$(7\text{-}9)\cdot10^{-6}$
Brick masonry	$(0.027\text{-}0.03)\cdot10^6$	-	-	-
Limestone masonry	$0.06\cdot10^6$	-	-	-
Concrete, with strength 100-200 daN/cm^2	$(0.15\text{-}0.23)\cdot10^6$	-	0.16-0.18	$(8.8\text{-}10.4)10^{-6}$
Concrete	$(0.18\text{-}0.43)\cdot10^6$	-	-	$10\cdot10^{-6}$
Wood (longitudinal fibers)	$(9\text{-}14)\cdot10^6$	$(4.5\text{-}6.5)\cdot10^3$	-	$(4\text{-}6)\cdot10^{-6}$
Wood (transversal fibers)	$(0.4\text{-}1.0)\cdot10^6$	$(4.5\text{-}6.5)\cdot10^3$	-	-
Glass	$(50\text{-}60)\cdot10^4$	$(21\text{-}23)\cdot10^3$	0.24-0.27	$(0.5\text{-}8)\cdot10^{-6}$
Rubber	$0.008.10^4$	-	0.47	-
Ice	$0.1\cdot10^{-6}$	$(0.28\text{-}0.3)\cdot10^5$	-	-

Table 2 Material parameters for experimental construction materials

Construction material	Sample length (mm)	Delay time (μs)	Velocity (m/s)
Heavy concrete	141	35.2	4006
Light concrete	100	71.8	1393
Brick	128	73.0	1754

EXPERIMENTAL RESULTS

The experimental research was made by an ultrasonic generator of high frequency and intensity, equipped with an ultrasonic emitting transducer of 50 kHz and a sensitive ultrasonic receiving transducer.

The emitting transducer (ET) of ultrasonic generator is excited with electrical impulses and converts the electrical signal in mechanical vibrations as ultrasonic impulses, which are transmitted then through the studied material. Also, the receiver transducer (RT) on the opposite side of construction material element makes the mechanic-electrical conversion. Both emitting and receiving transducers have piezoceramic PZT discs, as active elements.

The emitting transducer works on the basis of the reveres piezoelectric effect, converting an electrical impulse into a mechanical displacement in the range of a few microns. For example, a PZT element of 1 mm thickness, supplied with 1000V, can realize displacements between 0.3 and 0.6 μm. Also, the receiving transducer realizes the conversion of mechanical vibration received throw the material into an electrical signal, which can then be amplified by a sensitive amplifier. There is silicon Vaseline between the transducer surface and the materials, which realizes the optimum eletroacoustical transmission of ultrasonic impulses.

For this study it was utilized as performed apparatus: memory digital oscilloscope type TDS 3023, Tektronix, USA for registration of the electrical diagrams for the received signals, ultrasonic generator N 2703, ICE and piezoceramic transducers made in laboratory (Figure 2). The electrical diagrams show the dependence between the acoustical vibration shape after the propagation through the material and the type and structure of studied material (Figures 3 and 4).

By utilizing non-destructive tests made on construction material elements (concrete and brick) it can be determinate some parameters, such as: times and velocities of sound propagation, elasticity modules, Poisson coefficients, resistance at compression and tensile and some characteristic diagrams.

This method is effective for locating voids, honeycombing, delaminating, depth of surface opening cracks, and measuring element thickness for different construction material (concrete and bricks). Also, the sonic methods are suitable for quality control of fresh cementations materials [5].

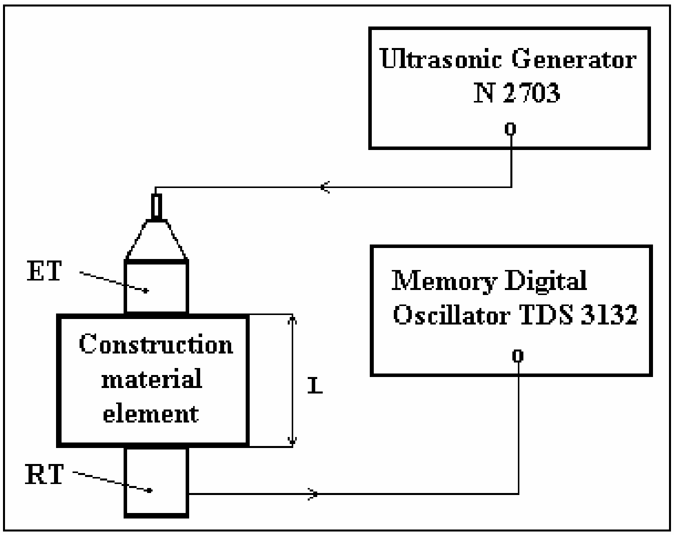

Figure 2 - Test set-up for parameter measurements of construction materials

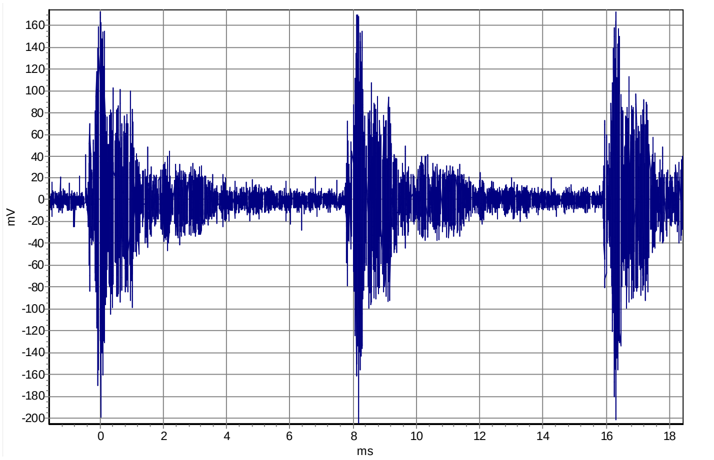

Figure 3 – Brick sample with L = 121 mm length

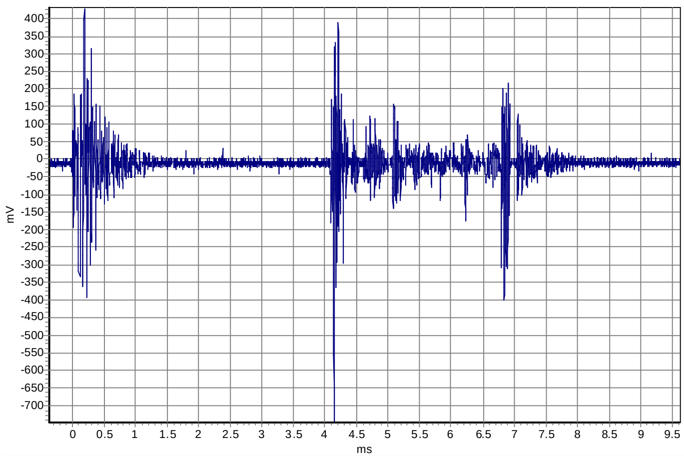

Figure 4 – Concrete sample with L = 141 mm length mm length

The piezoceramic emitting transducer is excited by electrical pulses of high voltage amplitude, and converts the electrical signal in mechanical vibrations, which propagate in concrete specimen. The piezoceramic sensor output signal is displayed on the memory digital oscilloscope, type TDS 3023, Tektronix, USA. Also, by signal graphic representation analysis in time and frequency can be determined the attenuation coefficient of the pulse in concrete.

The electromechanical piezoceramic transducer works on the basis of the reveres piezoelectric effect, converting an electrical power into a mechanical displacement in the range of tens microns.

The experimentation was made with an ultrasonic generator of high frequency and intensity, equipped with an ultrasonic emitting transducer of 50 kHz and a sensitive ultrasonic receiving transducer. Registered electrical diagrams were made with a performed memory digital oscillator type TDS 3036, Tektronix, USA.

Figure 5 shows the set-up for measurements by pulse-method of parameters for concrete material. Special software interfaces the piezoceramic generator transducer and the piezoceramic receiver transducer. The emitting transducer (ET) is powered by a pulse-generator and the receiver transducer (RT) converts the ultrasound vibrations into electrical signal, which is magnified by an amplifier. These piezoceramic transducers work at low resonance frequencies, about 100 kHz. Inside the generator transducer case there is a high power pulse-generator, in order to have higher security. Also, inside the receiver transducer there is a signal pre-amplifier, in order to minimize the noise due to the cable capacitance.

Figure 5 - Set-up for measurements by pulse-method of parameters for concrete material

CONCLUSIONS

Signal graphic representation analysis in time and frequency can determine the attenuation coefficient of the pulse in concrete. In the specialty literature we can find tables with experimental material parameter values for different type of concrete. Therefore, we are able to compare our experimental results with known concrete parameters. The pulse-echo method is suitable for non-metallic materials because the non-destructive methods for metallic materials cannot be utilized, due to their rugged and non-homogeneous structures and great attenuation coefficients of ultrasound propagation through materials.

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