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Development of Special Steel Holder for Concrete Ultrasonic Testing in the Hot Cells

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Introduction

Failure of internal structure of concrete can be investigated using destructive or non-destructive testing methods. One of the most promising of the non-destructives in ultrasonic pulse method which shows the pulse velocity (Hlaváč, 2015).
Dynamic characteristics of the material can be determined on the base of ultrasonic pulse velocity. Concrete can be tested during freezing and thawing (Cikrle, 2007), with higher temperature damage (Zavalis, 2009), or in case of irradiation damage (Žďárek, 2013).
The influence of cavities in reactor shielding concrete was published in (Svoboda 2007; Svoboda et alt., 2007). Comparison of these results taken in situ and in vitro as well as comparison between static and dynamic testing of concrete was published in (Hlaváč, 2007; Hlaváč, 2011).
By high dose irradiated samples shall be tested in special conditions. This article deals with a tool for ultrasonic testing in the hot cells.

1. Non-destructive methods

Non-destructive testing (NDT) methods were chosen to check the quality of concrete cylinders exposed to the radiation. Ultrasonic (US) pulse method will be introduced briefly in following paragraphs.

1.1 Ultrasonic method

Structural damage of concrete is detectable by several destructive or non-destructive methods. One of the non-destructive is ultrasonic pulse method. It deals with elastic waves in the material and time of their transmission through the sample.

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1.1.1 Principle of ultrasonic pulse method

US pulse method is non-destructive testing method using existence of elastic waves. Stress wave excited as electro-acoustic impulse in piezoelectric transducer (transmitter) spreads in all directions spherically through the material. Front of the wave is detected by piezo-electric transducer (receiver) on the opposite side of tested object. The time of transmission is recorded afterwards.
Pulse velocity *v* is calculated as distance of two piezoelectric transducers *L* divided by transmission time *t*.

$$v = \frac{L}{t} \tag{1}$$

here $t = t' - t_0$
t' - transmission time measured on the concrete cylinder of the length *L*,
t_0 – so called dead time, used for correction of the measurement,

$$t_0 = t_{Em} - t_e \tag{2}$$

where t_{Em} – time measured on the calibration etalon,
t_e – nominal time of the etalon.

Dead time is caused by the differences is cables, transducers and especially in acoustic coupling agent. In order to measure correctly the transducers must be bonded to concrete by so called coupling agent, which is usually wax or vaseline. In our case, plasticine is used as the coupling agent.

1.1.2 Measuring procedure

Firstly calibration etalon is measured three times to determine the dead time. Secondly, the concrete sample is measured several times. Average dead time determined using formula (2) is taken off average time measured in the concrete sample. This procedure can be done twice for each sample to prove the repeatability.

1.1.3 Defected concrete testing

The time *t* of the transmission varies due to the quality of the concrete. Fresh concrete appears by higher pulse velocity (shorter transmission time). Concrete with damaged structure seems to be worse because of longer time *t*. The tests results of concrete with various quality are shown in Figure 1. There one transducer fits on each side of the tested concrete. The record of acoustic pressure amplitude changing in time is shown on the right hand side of the Figure 1.

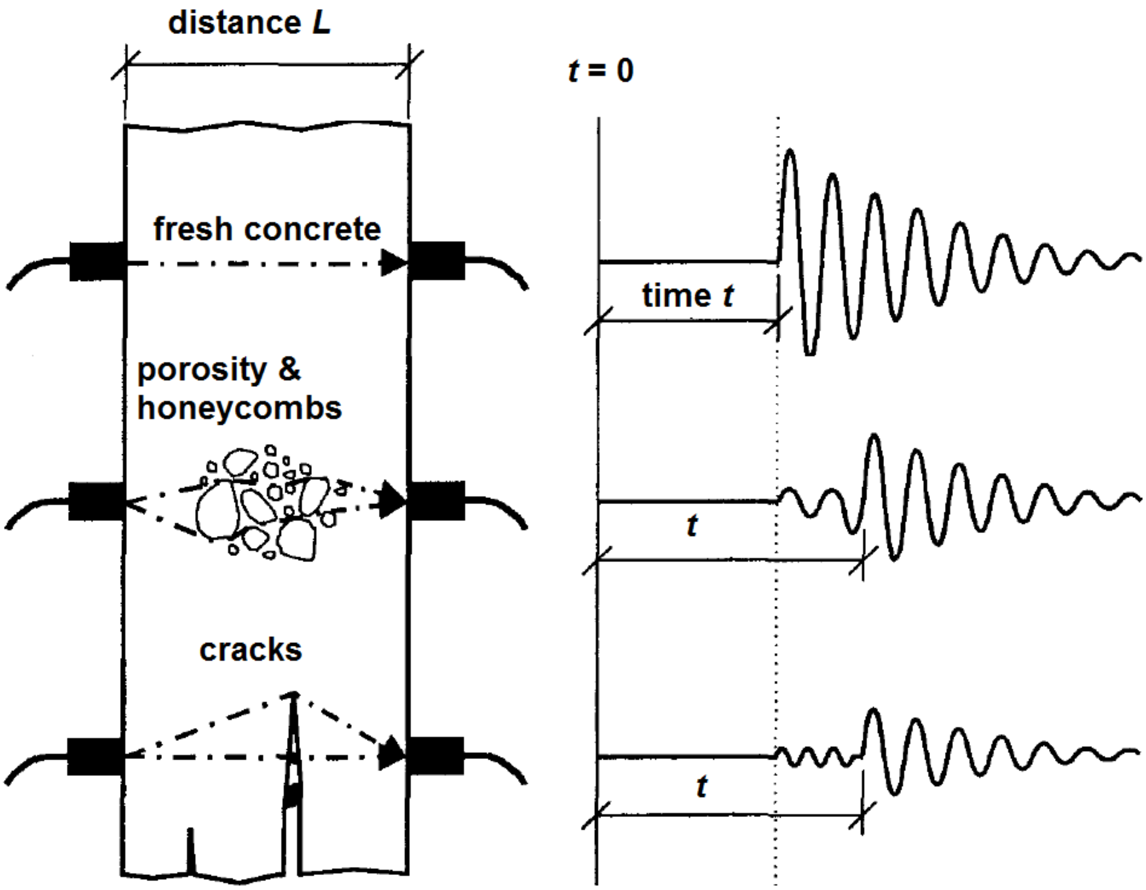

Figure 1. Concrete of various quality testing (Anton, 2002)

1.1.4 Irradiated concrete measurement

The problem of irradiated concrete testing is more complex. Firstly, all the conditions must be filled in the same as by any other concrete testing. It is necessary to take the tested sample, fix it and enable to squeeze it between two transducers covered by coupling agent.

There are problems in case of irradiated concrete testing, because one cannot touch the sample nor the transducers. Nevertheless, there must be respected the conditions of one-axial compression from the both sides with the transducers. Moreover, the repeatability must be allowed as well. Due to this condition, a special shaped frame was developed.

1.2 E-modulus

Special approach of ultrasonic pulse method was found for irradiated concrete testing. There are many methods which can be used for irradiated concrete testing.

Ultrasonic pulse method provides quite consistent repeatable results which are a good estimation of future destructive testing.

1.2.1 Conditions

E-modulus shall be measured by ultrasonic transducers of appropriate exciting frequency. Dimensionality of the environment is determined taking into account transversal dimensions of tested object. This problem is connected with transmission of transversal waves (shear waves) within the cross-section of the sample.
There must be fulfilled condition (3) to let the sample behave as an 3D object,

$$d > \lambda, \tag{3}$$

where d - diameter of the cylindrical sample,
λ - length of the wave,

$$\lambda = \frac{v}{f}$$

Velocity v can be either estimated or measured by equation (1). Each piezoelectric transducer has its nominal frequency f. Taking into account condition (3) transducers 150 kHz may be used for testing of small cylinders of diameter 30 ÷ 50 mm,

$$\lambda = \frac{4000 \text{ m/s}}{150\,000 \text{ Hz}} = 0{,}027 \text{ m} < 0{,}030 \text{ m} = d$$

Transducers 82 kHz or 54 kHz won't be sufficient for this problem. On the other hand, the dimension of the particles may be smaller than the wave length λ.

1.2.2 E-modulus by ultrasonic pulse method

Dynamic E-modulus can be determined by knowledge of specific gravity, pulse velocity and Poisson ratio of concrete.
Specific gravity of regular shaped object can be calculated as mass m divided by sample's volume V,

$$\rho = \frac{m}{V} \qquad (4)$$

where $V = \frac{\pi d^2}{4} L$.

Poisson ratio μ is either estimated, for ordinary concrete μ = 0,20, or measured.
When condition (3) is met, Ldynamic E-modulus is evaluated according to formula (5),

$$E = \rho v_L^2 \frac{(1+\mu)(1-2\mu)}{(1-\mu)}. \qquad (5)$$

Here v_L is the velocity of longitudinal waves (Hlaváč, 2015).

$E \cong 0{,}9\rho v_L^2$ for Poisson ratio μ = 0,20.

1.2.3 Dynamic Poisson ratio

Dynamic Poisson ratio can be calculated comparing the properties of shear and stress waves (S-waves and P-waves, or transversal and longitudinal waves, respectively), by ultrasonic or resonance methods.
The way of μ determination by ultrasonic method is described in Czech normative ČSN 731371. It is quite complicated to differ the two types of waves P and S when having no transversal (shear) waves transducer. Some new types of ultrasonic instruments du have special software, where the waves can be differed. Unfortunately it is still not enough reliable and must be corrected manually.
Resonance, as well as ultrasonic method, uses condition (6) for determination of Poisson coefficient,

$$\mu = \frac{E}{2G} - 1. \qquad (6)$$

Here E and G are dynamic modulus of elasticity and shear modulus, respectively.
E-modulus can be determined by formula (5) in case of US method or (7) in case of resonance method,

$$E = \rho L^2 f_L^2 , \qquad (7)$$

G-modulus can by determined by expressions analogous to (5) and (7) as:

$G = \rho L^2 f_t^2$ in cylinder by resonance method, (8)

$G = \rho v_t^2$ in any shaped sample by ultrasonic method.

Here f_L and f_t are fundamental frequencies of longitudinal and torsion oscillation, respectively. Both are determined by resonance method (Zapletal, 1982).
Transversal S-waves velocity v_t can be determined using ČSN 731371, Príloha informatívna.

1.2.4 Relative dynamic E-modulus

Relative dynamic modulus (RDM) is used for evaluation of structural damage of one or more specimens. In current case, RDM is calculated by relationship (9),

$$\mathrm{RDM}=\frac{E_1}{E_0}\cdot 100\%, \quad (9)$$

here E_1 - dynamic E-modulus of damaged (irradiated) sample,

E_0 - dynamic E-modulus of fresh (non-irradiated) sample.
E_0 can be understood as a reference value of E-modulus.
Both moduli can be calculated according to equations (5) and (7), i.e. either by ultrasonic or resonance methods.
Only ultrasonic method will be mentioned in this paper. For this particular case Poisson ratio is taken as a constant value μ = 0,20. Thus equation (9) can be expressed as:

$$\mathrm{RDM} = v_1^2 / v_0^2 \cdot 100\%. \quad (10)$$

Here v_1 and v_0 are longitudinal pulse velocities of damaged and reference or fresh samples, respectively (Cikrle, 2007).
If the tested samples are of the same length or one the same sample is being compared,

$$\mathrm{RDM} = t_0^2 / t_1^2 \cdot 100\%. \quad (11)$$

Here t_1 and t_0 are longitudinal P-waves transmission times of damaged and fresh samples, respectively (Pospíchal, 2009).

If RDM equals 100 %, it means the sample is not damaged. If the value is about 80 %, there is serious reason why the sample behaves like that and may be proved by other inspection procedures.

2. Special steel holder

To be able to work with the active concrete samples after irradiation, special holder had to be developed. It may consist of a spring, stick and some cantilever.
The pilot development study in shown in Figure 2.

2.1 Steel holder development

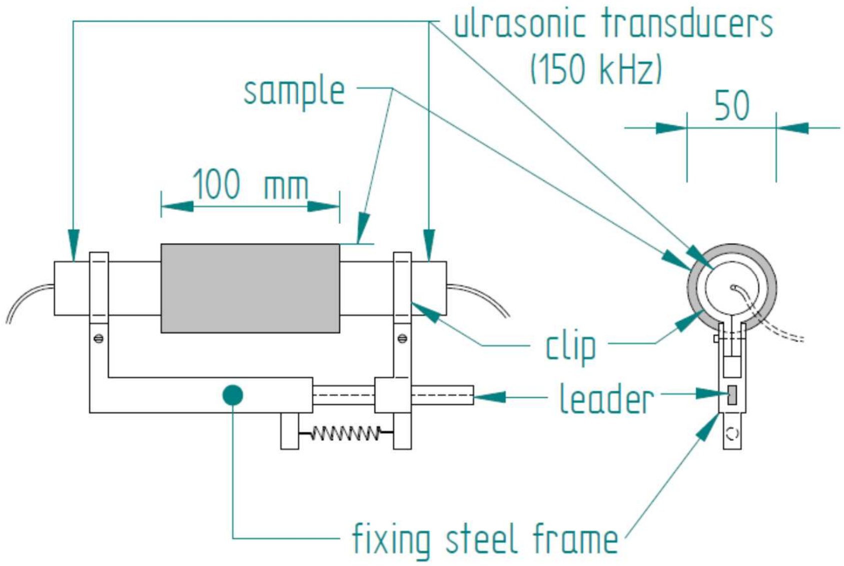

Figure 2. Scheme of fixing steel frame with a spring and 2 clips for holding of the both transducers tight at a front of the concrete cylinder

The first proposal was remade many times and finally designed as two-sides supported steel holder with a plates for transduces with a holes in it for cables and their connectors.
The initial work was done in Řež in the beginning of the year 2014. The planning, determining of the aims and general purposes of the “tool”, the holder – the frame.
Realization of the design was executed in Vilnius during the first internship of the postdoc. The initial proposal was changed and prepared for fabrication.
One of the demands was small light holder of the transducers. The result was a simple frame mountable for various sizes of the element. See Figures 3 and 4.

2.2 Steel holder fabrication

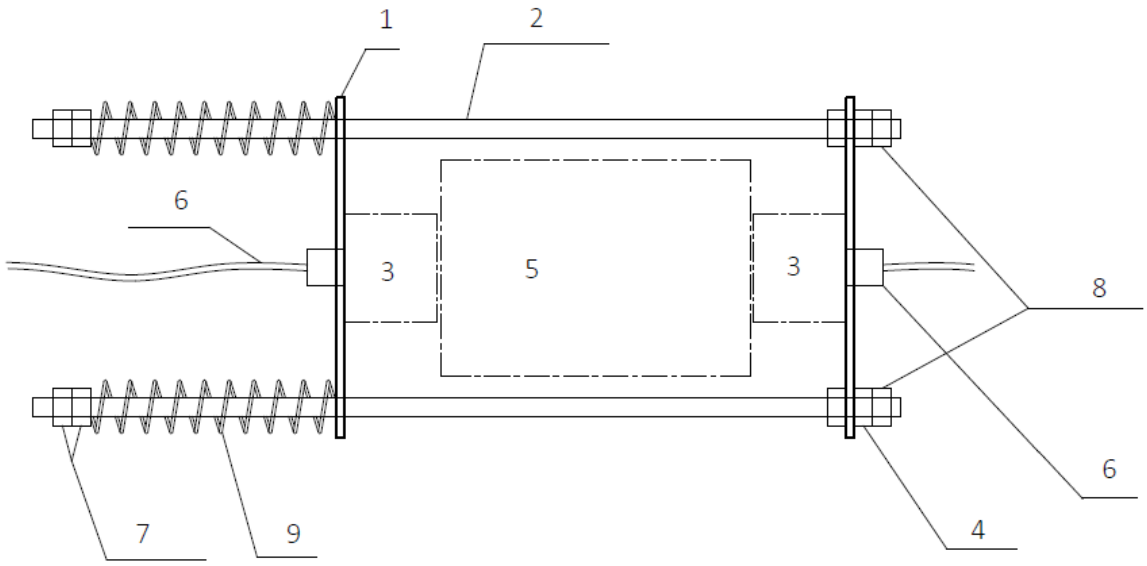

Figure 2. Design of special holder for ultrasonic transducers

Scheme of fixing steel frame description: 1 – slab; 2 – stick; 3 – US transducer; 4 – bolts; 5 – concrete sample of calibration etalon; 6 – cable with connector; 7 and 8 – bolt + contra-bolt for its fixing.

Figure 3. Special steel holder of ultrasonic transducers capable to the hot cells for concrete samples testing

2.3 Steel holder testing

Just after the fabrication of the first parts of the holder, it was proved whether it is capable to lead the ultrasonic transducers towards the sample or not and whether the contact to the sample is sufficient, see Figure 4.
Initial testing was not very persuading but after few iterations the frame was able to measure even with higher accuracy than during usual testing by hands, see Table 1.

Figure 4. Testing of special steel holder function by ultrasonic instrument PUNDIT plus.

Table 1. Comparison of the results taken by the steel holder and by hands, transmission time in microseconds, coefficient of variation in percentage

Transducer holding	Mortar prism testing	COV	Etalon testing	COV
Steel holder	25,00 ± 0,05 μs	± 0,2 %	23,47 ± 0,03 μs	± 0,15 %
By hands	25,05 ± 0,15 μs	± 0,6 %	23,50 ± 0,05 μs	± 0,20 %

The results of testing by newly developed and fabricated steel holder are (1,3 ÷ 3,0) × more accurate than the results of in hand testing. The mean value differs bellow the sensitivity of the ultrasonic instrument.

3. Conclusions and remarks

This article presented ultrasonic pulse method methodology and special steel holder development. Combination of both gives possibility of high dose active samples testing in the hot cells using robotic manipulators instead of human hands. This spares the effective dose to the operators body and enables to start an interesting projects of irradiated concrete testing and its pathology investigation.

3.1 Capability of non-destructive testing methods

Non-destructive tested methods are effective in the case of comparative measurement, i.e. when more samples are tested or when one specimen is tested repetitively. Relative dynamic modulus RDM shows the change of the material properties. In case of constant conditions only transmission time's second power shall be compared.
Ultrasonic impulse method can be used in situ as well as in vitro (present case).
It allows detection of poor quality of building material or possible defect as honeycomb, void or crack. In combination with one or more non-destructive methods it is possible to determine kind of cavity and its location.

4. Acknowledgement

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5. References

1. Svoboda, D.; Cikrle, P. Zjišťování poruch v masivních betonových blocích s využitím ultrazvukové impulsové metody. In *Sborník konference Juniorstav 2007*. Brno: VUT v Brně FAST, 2007. s. 173-173.

2. Svoboda, D.; Cikrle, P.; Suza, P.; Hlaváč, Z. Identification of holes in concrete blocks using ultrasonic method. In *VVER 2007*. Praha, ČEZ. 2007. p. 125 - 129.

3. Hlaváč, Z. Srovnání a optimalizace zjišťování modulu pružnosti betonu. Abstracted In *Sborník, Juniorstav 2007*. Brno, FAST, VUT v Brně. 2007. Full version of article on CD p. 1 – 5.

4. Cikrle, P.; Hlaváč, Z.; Králová, L.; Bílek, V. Sledování vnitřních poruch struktury zmrazovaného betonu. In *Experiment ´07 – Sborník*. Brno, Akademické nakladatelství CERM. 2007. p. 53 - 58.

5. 2009 - Zavalis, Robertas. Aukštos temperatūros įtaka gelžbetoninėms konstrukcijoms. *12-osios Lietuvos jaunųjų mokslininkų konferencijos „Mokslas – Lietuvos ateitis“ 2009 m*. teminės konferencijos " Statyba". Vilnius : Technika, 2009. p. 75-80.

6. Hlaváč, Z. Ratio Between Static and Dynamic Modulus of Elasticity of Concrete. In *Sborník recenzovaných příspěvků konference Zkoušení a jakost ve stavebnictví 2010*. Brno, VUT v Brně. 2010. p. 33-42.

7. Anton, O a kol. *Základy zkušebnictví, Návody do cvičení*. CERM. Brno. 2002.

8. Žďárek, J. et alt. Mock-up Experiments for the Project of High Dose Irradiation of the RPV Concrete. *Contribution of Materials Investigations and Operating Experience to LWRs' Safety, Performance and Reliability*. France. 2013.

9. Hlaváč, Z a kol. *Stanovení stejnorodosti betonu biologického stínění reaktoru LR-0 ultrazvukovou průchodovou metodou*. In webové stránky Centra výzkumu Řež s.r.o., www.cvrez.cz. 2015.

10. ČSN 731371 Ultrazvuková impulzová metoda skúšania betónu. Československá štátna norma. 1981.

11. Zapletal, V. Zkušebnictví I, skriptum VUT v Beně, Ediční stedisko VUT Brno. 1982.

12. Cikrle, P.; Hlaváč, Z.; Králová, L. Porovnání citlivosti NDT metod při sledování poruch struktury betonu. In *Workshop NDT 2007 Non-Destructive Testing in Engineering Practice Proceedings*. Brno, Brno University of Technology. 2007. p. 233 - 236.

13. Pospíchal, O.; Kucharczyková, B.; Misák, P.; Hlaváč, Z.; Vymazal, T. Influence of Periodic Freezing on the Value of the Elastic Modulus of the Light-weight Fibre Concrete. In *7th NDT Workshop Non-Destructive Testing in Engineering Practice 2009 Proceedings*. Brno, Brno University of Technology. 2009. p. 56 - 63.