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1 General Information on the Ultrasonic Method

1.1 Ultrasonic Pulse Velocity (UPV) Method – Basic Description

The ultrasonic pulse velocity (UPV) method is a key non-destructive testing technique in construction, based on transmitting repeated ultrasonic pulses through the tested material and measuring the velocity of wave propagation. This velocity varies between materials and changes with their properties; for instance, it decreases in lower-quality materials or at points of defects. UPV can be used to assess:

- concrete uniformity,
- presence of cracks or voids (to a limited extent),
- material characteristics, such as modulus of elasticity, compressive, and tensile strength,
- time-based changes in these properties (e.g., concrete degradation).

The main advantages of the UPV method are its fully non-destructive nature, ease of repeat measurements at the same location, and rapid application in both lab and construction site. Testing can follow standard EN 12504-4 or the Czech national standard ČSN 73 1371, which additionally includes guidelines for calculating the dynamic modulus of elasticity, E_{cu}. This calculation absents EN 12504-4, however this standard provides valuable analysis of factors influencing pulse velocity measurements. It is advantageous to be familiar with both standards and refer to them during testing.

1.2 Measurement Principle of the UPV Method

The method operates by transmitting repeated ultrasonic pulses through the material and detecting them. For concrete and similar materials, the through-transmission technique is commonly used, involving a transmitter and receiver on opposite sides of the element. This setup is ideal for elements with parallel surfaces. Transmission time, T, is recorded from pulse emission to reception. The pulse transmits most efficiently perpendicular to the transmitter, but if both sides are inaccessible, other directions are possible. Direct through-transmission measurement will be exclusively used in this laboratory exercise.

1.3 Measuring the Ultrasonic Pulse Velocity

Direct transmission measurements will be conducted on bases of known length, with acoustic coupling medium applied between probes and the concrete surface. Probes are pressed lightly onto the concrete, and acoustic contact can be adjusted by slight rotation. Ultrasonic waves pass through a thin layer of coupling medium (e.g., gel), which introduces a “dead time” T_0, which must be subtracted from results. Dead time T_0 is calculated as:

$$T_0 = T_e - E, \tag{1}$$

where T_0 is dead time in µs, T_e is the transmission time through a reference standard in µs, and E is the standard’s known time characteristic in µs.

The UPV for each measurement base is calculated as:

$$v_L = \frac{L_i}{T_i - T_0}, \tag{2}$$

where v_L is the ultrasonic pulse velocity in m/s, L_i is the base length in m, T_i is the measured time through concrete in s, and T_0 is the dead time in s. Measurements will be performed using the Pundit PL-200 device, which supports calibration using a reference standard, eliminating the need for dead time correction if calibrated.

2 Determination of Dynamic Modulus of Elasticity

2.1 Measurement Procedure

The modulus of elasticity is typically determined by direct through-transmission measurement on cylindrical or prismatic test specimens and is calculated according to ČSN 73 1371 standard specifications. For this lab exercise, prismatic specimens with nominal dimensions of $100 \times 100 \times 400$ mm will be used. Cross-sectional dimensions are measured with calipers to an accuracy of at least 0.1 mm, while length is measured with a steel ruler to at least 0.5 mm accuracy. Concrete density is required for calculating the dynamic modulus of elasticity, so specimen mass will also be recorded.

For measurement, ultrasonic probes (transmitter and receiver) are placed on opposite sides of the specimen or structure, aligned along the axis. The transmission time of ultrasonic waves through the material is then measured. From this, the UPV is calculated first, followed by the dynamic modulus of elasticity as the sought mechanical property of the material. Testing will occur along the longitudinal axis on three measurement bases labeled 1, 2, and 3, as shown in Figure 1.

Figure 1: Schematic of UPV measurement with measurement lines indicated; T is the transmitter and R is the receiver.

For each measurement base, UPV is calculated as per Equation (2). The average velocity v_L in m/s is then determined from the three calculated velocities, rounded to the nearest m/s.

2.2 Evaluation

The concept of "dimensionality" of the medium is critical in ultrasonic pulse velocity measurements in concrete. For example, measurements taken on a large block will differ from those on a thin rod of the same material, as dimensionality affects UPV, depending on the object's size relative to the ultrasonic wavelength. In prismatic specimens, the environment can be three-dimensional, one-dimensional, or indeterminate (transitional).

To determine dimensionality, the ultrasonic wavelength in the test specimen is first calculated using:

$$\lambda_L = \frac{v_L}{f}, \tag{3}$$

where λ_L is the wavelength in m, v_L is the average UPV in m/s, and f is the frequency of the ultrasonic probes in Hz.

The environment is one-dimensional if:

$$a, b, \text{or } d \leq 0.2 \cdot \lambda_L, \tag{4}$$

and three-dimensional if:

$$a, b, \text{or } d \geq 2 \cdot \lambda_L. \tag{5}$$

If neither condition (4) nor (5) is met, the environment is considered indeterminate.

Dimensionality affects the coefficient k. For one-dimensional environments, $k = 1$, while in three-dimensional environments, k depends on Poisson's ratio μ. Values for k for concrete are provided in Table 1.

Table 1: Coefficient k in relation to Poisson's ratio μ for concrete.

μ	k	μ	k	μ	k	μ	k	μ	k
0.00	1.0000	0.12	1.0168	0.22	1.0685	0.32	1.1963	0.42	1.5978
0.04	1.0017	0.14	1.0236	0.24	1.0857	0.34	1.2406	0.44	1.8002
0.06	1.0039	0.16	1.0319	0.26	1.1061	0.36	1.2964	0.46	2.1502
0.08	1.0070	0.18	1.0420	0.28	1.1307	0.38	1.3682	0.48	2.9637
0.10	1.0113	0.20	1.0541	0.30	1.1602	0.40	1.4639	0.50	-

In the laboratory exercise, an ultrasonic device with probes operating at a frequency of 150 kHz will be used. If the **UPV for concrete** is found to be a **maximum of 7500 m/s**, Equation (5) will apply, indicating a **three-dimensional environment**.

The dynamic modulus of elasticity is calculated using:

$$E_{cu} = \rho \cdot v_L^2 \cdot k, \tag{6}$$

where E_{cu} is the dynamic modulus of elasticity in N/mm^2, ρ is the density of concrete in kg/m^3, v_L is the ultrasonic pulse velocity in km/s, and k is the dimensionality coefficient (dimensionless). The calculated value of the dynamic modulus of elasticity is rounded to three significant figures.

3 Determination of Concrete Uniformity

To assess the uniformity of concrete (consistency of concrete quality) within a structure, results from the following concrete properties can be used:

- compressive strength,
- tensile strength,
- density,
- UPV (ultrasonic pulse velocity).

Due to its non-destructive nature, the UPV method is particularly advantageous. Ideally, the area under assessment (part of the structure) should be accessible from both opposite sides (e.g., columns, walls). In such cases, an appropriate grid of measurement points is marked on the structure, at which the ultrasonic pulse velocity v_L is determined. The collected data is then statistically evaluated—if the coefficient of variation V_x and the difference between neighboring values Δ do not exceed the threshold values as per standard specifications, the concrete can be considered uniform. Refer to Table 2 for these threshold values.

Table 2: Limits for evaluating uniformity of concrete in structures based on ultrasonic measurements according to standard specifications.

Concrete Class	**Coefficient of Variation V_x [%]**	**Difference Between Neighboring Points Δ [%]**
C 12/15	4.0	7.5
C 16/20	4.0	7.5
C 25/30	3.5	7.5
C 30/37 to C 50/60	3.0	7.5

To illustrate the data on the frequency of individual ultrasonic pulse velocity values v_L (in m/s or km/s), a frequency histogram can be created. For a meaningful histogram, it is essential to choose appropriate class boundaries. The class size depends on the measured values of v_L and is typically set to "round" numbers, such as intervals of 100 or 200 m/s (or 0.1 or 0.2 km/s) within the measurement range. An example of measurement and uniformity evaluation of a concrete wall made from concrete of strength class C 25/30 is provided in Table 3 and Figure 2.

Table 3: Example of uniformity measurement of a concrete wall using a 5 × 5 grid of test points, showing measured ultrasonic pulse velocities in m/s.

Test Point	**A**	**B**	**C**	**D**	**E**
1	3695	3765	3612	3753	3856
2	3858	3879	3756	3871	3889
3	3902	3971	3805	3978	3971
4	3948	4026	3987	4112	4003
5	3943	3906	4058	4087	4111

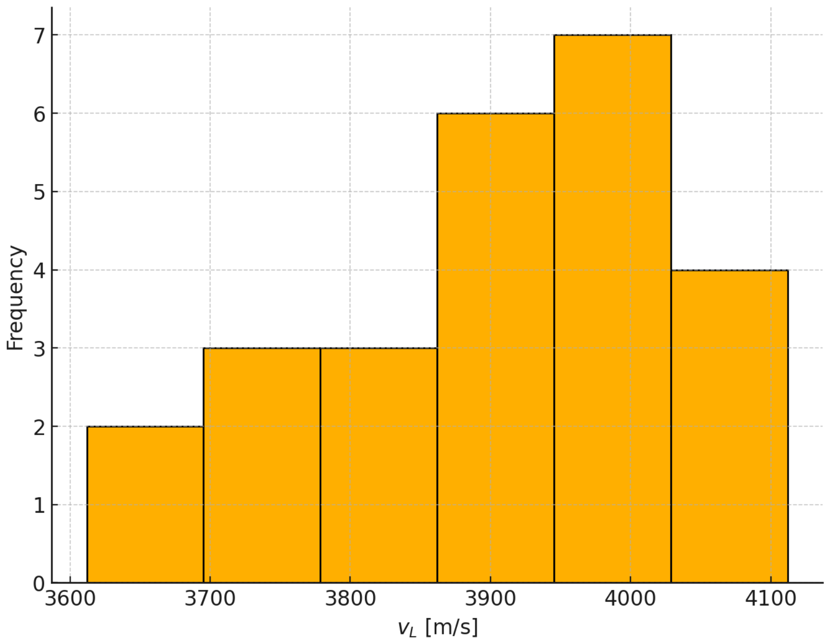

Figure 2: Frequency histogram of ultrasonic pulse velocities through a concrete wall in m/s

The measurement results show that the average ultrasonic pulse velocity across all measured points is 3910 m/s (rounded to three significant figures), with a coefficient of variation $V_x = 3.31\%$. The maximum difference between neighboring points (C3 and C4) is 182 m/s, yielding a difference $\Delta = 4.78\%$. Since the tested concrete is class C 25/30, and the threshold values according to standard specifications are 3.5% for V_x and 7.5% for Δ, the concrete can be considered uniform.

The frequency histogram can indicate if the ultrasonic measurement results follow a normal distribution, though a statistical normality test is preferable. The spatial distribution of v_L values within the structure can be visualized with isovels–lines of equal ultrasonic velocity. By varying color shades between isovels, concrete quality is visually represented: darker areas indicate higher quality, and lighter areas indicate lower quality. Basic graphic editors, including Microsoft Excel, can create this visualization effectively. The Pundit PL-200 ultrasonic device, used in this exercise, also provides such graphical output, offering an immediate overview of concrete quality across elements or entire structures (see Figure 3).

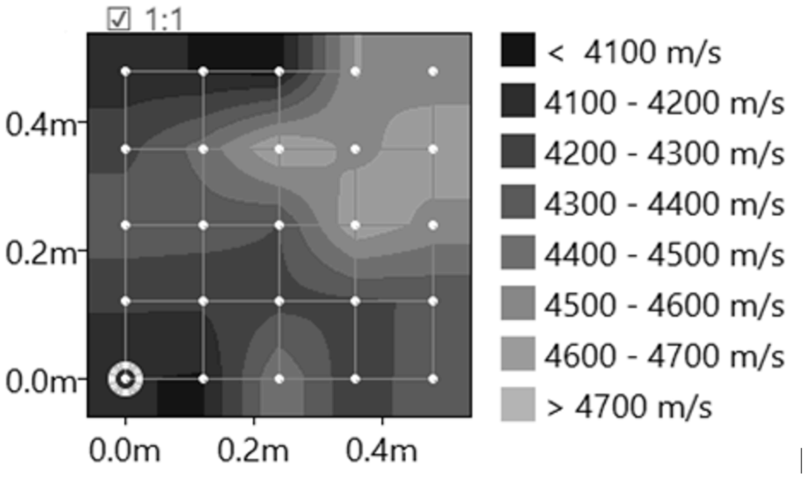

Figure 3: Surface plot of UPV through concrete of the tested area.

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Instructor:

Dynamic Modulus of Elasticity of Concrete

Determine the dynamic modulus of elasticity E_{cu} of the tested concrete using the ultrasonic pulse velocity (UPV) method, assuming a three-dimensional environment.

Dimensions, mass, calculation of density, measurement diagram:

Prism	b	h	L	m

Determination of dead time and ultrasonic wave transmission time through test specimens (remember to include units):

Prism	t_E	Standard	T_0

Prism	t_1	t_2	t_3	Corrected t_1	Corrected t_2	Corrected t_3

Evaluation of E_{cu}:

Determination of concrete uniformity

On a concrete test block with the specified strength class marked on it, create a grid of measurement points. Using the ultrasonic pulse velocity method (with the Pundit PL-200 device), determine the ultrasonic pulse velocities v_L at these points.

Calculate the statistical values of the measured data set and determine, according to standard specifications, whether the concrete meets the criteria for uniformity as per ČSN 73 2011.

Create a frequency histogram of measured values.

Create a graphical representation of the distribution of v_L values in the concrete block using isovels with a surface plot (you may photograph the display of the Pundit PL-200 device or create the plot using suitable software).

Conclusion:

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Tests conducted and report prepared by:

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