RESONANCE METHOD | R

1 General Principle

Resonance is the tendency of a system to vibrate with a larger amplitude at certain frequencies than at others, meaning that it vibrates more at these specific frequencies. The principle of the resonance method is to determine the natural frequencies of test specimens. To evaluate the dynamic material properties of specimens with regular geometric shapes, the natural frequencies of longitudinal vibration f_L, transverse (flexural) vibration f_f, and torsional vibration f_t are used. **Frequency** is a physical quantity that indicates the number of repetitions of a periodic event within a given time interval. The unit is Hz ($= \mathrm{s}^{-1}$).

2 Determination of Dynamic Properties of Concrete

2.1 Measurement Procedure

The determination of the dynamic modulus of elasticity of concrete is performed according to standard ČSN 73 1372. The principle of the method involves calculating the modulus of elasticity, the shear modulus, and Poisson's ratio from the natural frequencies of a concrete test specimen.

First, the dimensions of the test prism are measured. The transverse dimensions are measured with an accuracy of at least 0.1 mm, and the length with an accuracy of at least 0.5 mm. Then, the mass of the test specimen is determined.

Before performing measurements using the resonance method, the expected value of the natural frequency of longitudinal vibration f'_L must be calculated. This can be done, for example, by using the transmission time of ultrasonic waves through the specimen:

$$f'_L = \frac{500}{T} \tag{1}$$

where f'_L is the approximate (expected) value of the natural frequency of longitudinal vibration in kHz, and T is the travel time of the ultrasonic wave through the test specimen in the "L" direction, measured in μs.

During the measurement of resonant frequencies, the test specimen is set into vibration, with known **nodal and antinodal points of oscillation**. Depending on the type of oscillation being examined–whether longitudinal, transverse, or torsional–the positions of the exciter and sensor are chosen accordingly. In the case of impulse-based measurement, the exciter is an impact from an impulse (impact) hammer, while the sensor is a piezoelectric sensor. The measurement of the natural **frequency of longitudinal vibration** is illustrated in Figure 1. After the impact, the signal is recorded using an oscilloscope.

This signal is then converted into a curve using a Fast Fourier Transform (FFT) in computer software, representing the response of the specimen to individual frequencies across the entire frequency spectrum.

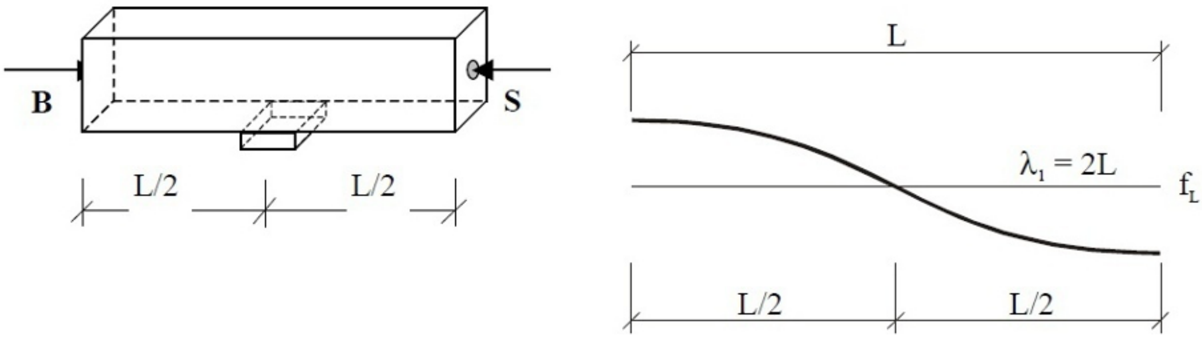


Figure 1: Placement of the exciter (B) and sensor (S) for measuring the first natural frequency of longitudinal vibration (left); shape of the first natural frequency of longitudinal vibration (right).

From the actual natural frequency of longitudinal vibration f_L, the approximate frequency of torsional vibration f_t' is then calculated as follows:

$$f_t' = \alpha \cdot f_L, \tag{2}$$

where f_t' is the approximate frequency of torsional vibration,

f_L is the measured natural frequency of longitudinal vibration, and

α is the transverse shape coefficient, which has a value of 0.59 for a prism.

Similarly, the approximate frequency of transverse vibration f_f' is calculated as follows:

$$f_f' = \beta \cdot f_L, \tag{3}$$

where f_f' is the approximate frequency of transverse vibration,

f_L is the measured natural frequency of longitudinal vibration, and

β is the slenderness coefficient of the test specimen. For a prism with a slenderness ratio of 4 (length 400 mm, transverse dimension 100 mm), β has a value of 0.43.

The placement of the sensor and exciter for torsional vibration is shown in Figure 2, and for transverse vibration in Figure 3. The measurement procedure is otherwise identical to that for measuring the natural frequency of longitudinal vibration.

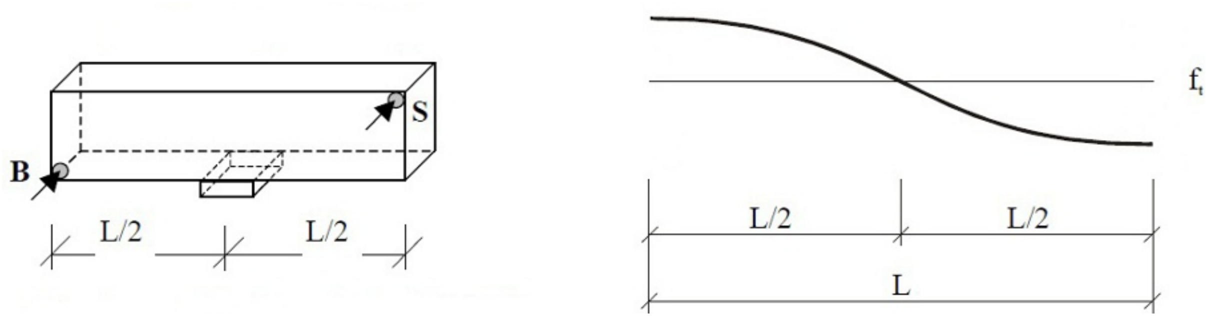


Figure 2: Placement of the exciter (B) and sensor (S) for measuring the first natural frequency of torsional vibration (left); shape of the first natural frequency of torsional vibration (right).

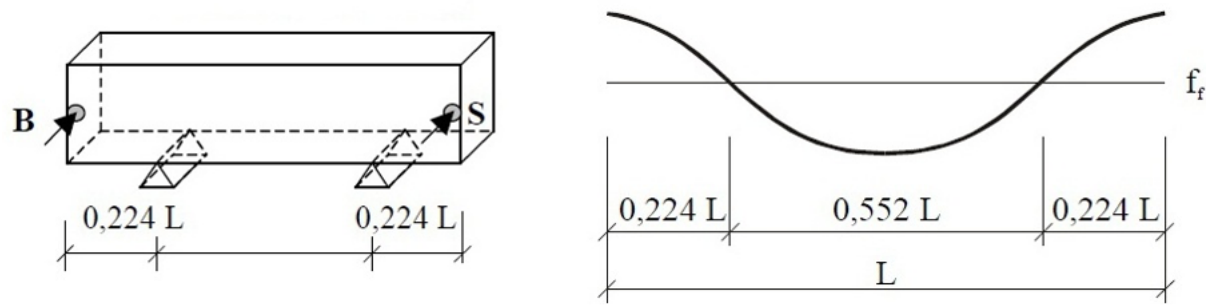


Figure 3: Placement of the exciter (B) and sensor (S) for measuring the first natural frequency of transverse vibration (left); shape of the first natural frequency of transverse vibration (right).

2.2 Calculation of Dynamic Properties from Measured Values

The value of the dynamic modulus of elasticity of concrete E_{cr} can be calculated in two ways. The first option is to determine the modulus of elasticity using longitudinal vibration according to the formula:

$$E_{crL} = 4 \cdot L^2 \cdot f_L^2 \cdot D \tag{4}$$

where E_{crL} is the dynamic modulus of elasticity in Pa, L is the length of the test specimen in m, f_L is the measured natural frequency of longitudinal vibration in Hz, D is the density of the material in kg/m^3.

The value of the dynamic modulus of elasticity of concrete can also be determined using transverse vibration, as follows:

$$E_{crf} = 0.0789 \cdot c_1 \cdot L^4 \cdot f_f^2 \cdot D \cdot \frac{1}{i^2} \tag{5}$$

where E_{crf} is the dynamic modulus of elasticity in Pa, L is the length of the test specimen in m, c_1 is the correction factor, for a prism $100 \times 100 \times 400$ mm, $c_1 = 1.40$, f_f is the measured natural frequency of transverse vibration in Hz, D is the density of the material in kg/m^3, i is the radius of gyration of the cross-section of the test specimen in m.

The radius of gyration of the cross-section of the test specimen is given by the formula:

$$i = \frac{a}{\sqrt{12}} \tag{6}$$

where a is the transverse dimension of the prism.

After calculating E_{crL} and E_{crf}, it is useful to determine the extent to which the calculated values of the dynamic moduli of elasticity differ from each other. The deviation ΔE_{cr} is given by:

$$\Delta E_{cr} = \frac{|E_{crL} - E_{crf}|}{E_{crL}} \cdot 100 \tag{7}$$

The value of ΔE_{cr} is given in % and can be either positive or negative. However, if its absolute value exceeds 10% with properly executed calculations, it indicates that either the measurement was incorrect (at least one natural frequency was determined incorrectly) or the test specimen does not have uniform concrete throughout its volume (or is damaged, e.g., by microcracks).

In addition to the modulus of elasticity, the dynamic shear modulus of elasticity G_{cr} of concrete can also be determined based on measurements using the response method, according to the formula:

$$G_{cr} = 4 \cdot k \cdot L^2 \cdot f_t^2 \cdot D \tag{8}$$

where G_{cr} is the dynamic shear modulus in Pa, k is the coefficient dependent on the shape of the cross-section of test specimen, for a square $k = 1.183$, L is the length of the test specimen in m, f_t is the measured natural frequency of torsional vibration in Hz, D is the density of the material in kg/m^3.

An additional advantage of the response method is the ability to determine Poisson's ratio of the tested material. The values of the dynamic Poisson's ratio μ_{cr} of concrete can be determined as follows:

$$\mu_{cr} = \frac{E_{crL}}{2 \cdot G_{cr}} - 1 \tag{9}$$

Poisson's ratio μ_{cr} for common materials can only take values within the interval $(0; 0.5)$. The calculated Poisson's ratio is rounded to 0.02.

3 Determination of Concrete Frost Resistance

If a concrete structure or part of it is exposed to water and alternating positive and negative temperatures, it is necessary to evaluate its resistance to freezing and thawing.

3.1 Principle of the Test

The core principle of the frost resistance test for concrete lies in assessing the relative changes in the observed properties of concrete after repeated cycles of freezing and thawing. The observed property may be the flexural strength, as well as the results of non-destructive electroacoustic methods.

One freeze-thaw cycle according to ČSN 73 1322 consists of 4 hours of freezing in air, where the air temperature ranges between -15 °C and -20 °C, and 2 hours of thawing in water at a temperature of +20 °C. One freeze-thaw (F-T) cycle therefore lasts 6 hours. The test specimens undergo the required number of cycles in stages, most commonly every 25 cycles, i.e., weekly.

3.2 Relative Change in Dynamic Modulus of Elasticity

To evaluate the change in the dynamic modulus of elasticity of concrete, i.e., to determine the relative dynamic modulus of elasticity (RDM) using the response method, it is necessary to measure the natural frequency of longitudinal vibration f_L and the natural frequency of torsional vibration f_t of the test specimen both before the start of the test and after freezing and thawing. The degree of internal structural damage can be determined based on the calculation according to the formula:

$$\mathrm{RDM}_n = \left(\frac{X_n}{X_0}\right)^2 \cdot 100\,\% \tag{10}$$

where RDM_n is the relative dynamic modulus of elasticity in %, X is the measured natural frequency in Hz, n is the measurement after n freeze-thaw cycles, 0 is the initial measurement.

3.3 Measurement Procedure

All test specimens in the form of prisms with nominal dimensions of 100 × 100 × 400 mm are first measured non-destructively. The measurement of the natural frequencies of longitudinal and torsional vibration is carried out according to the procedure described in section 2.1. This initial measurement is referred to as the “zero” measurement, and subsequent measurement results are referenced to it.

Then, all prisms are placed in an automatic freeze-thaw cabinet, and freezing and thawing are initiated. After the appropriate number of F-T cycles, the specimens are removed from the freezing cabinet. Subsequently, all non-destructive measurements described in the “zero” measurement are repeated. The specimens are then placed back in the automated testing device to continue freezing anf thawing.

3.4 Processing of Measurement Results

From the determined natural frequencies f_L and f_t, the relative change in the modulus of elasticity of concrete RDM_n is calculated according to (10). The calculated values are plotted on a graph as the dependence of the relative change in modulus of elasticity on the number of freeze-thaw cycles. An example of such a graph is shown in Figure 4. The results in the selected graph clearly show that concrete "A" is not frost-resistant, as its dynamic modulus of elasticity decreased below 70% of its original value after 100 F-T cycles. Conversely, the tested concrete "B" shows almost no internal structural damage and is therefore frost-resistant.

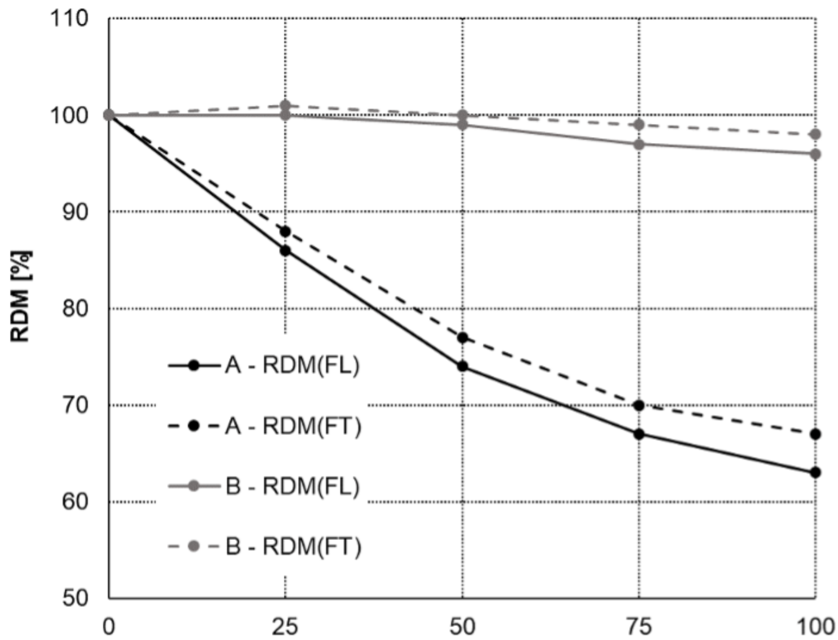


Figure 4: Example of graphical representation of the relative dynamic moduli of the tested concretes in dependency with number of F-T cycles.

According to standard ČSN 73 1322, if the decrease in flexural strength is greater than 25%, the concrete is not considered frost-resistant. For the purposes of this exercise, the same condition will be applied to RDM — **the concrete can be declared frost-resistant if the RDM does not fall below 75% after the required number of F-T cycles**.

RESPONSE METHOD	H

Instructor:

Determination of Dynamic Properties of Concrete

Determine the dynamic properties on the test prism: modulus of elasticity, shear modulus, and Poisson's ratio.

Dimensions, mass, calculation of density, measurement diagram:

Determination of Natural Frequencies of the Test Prism:

Evaluation:

$E_{crL} =$

$E_{crf} =$

$G_{cr} =$

$\mu_{cr} =$

$\Delta E_{cr} =$

Determination of Concrete Frost Resistance

Determine the extent of internal structural damage in concrete mixtures ”A” and ”B” due to freezing and thawing. To assess the frost resistance of the evaluated concrete mixtures, use the Relative Dynamic Modulus of Elasticity (RDM), and conduct the assessment after 100 freeze-thaw (F-T) cycles.

Description of Concrete A:

Description of Concrete B:

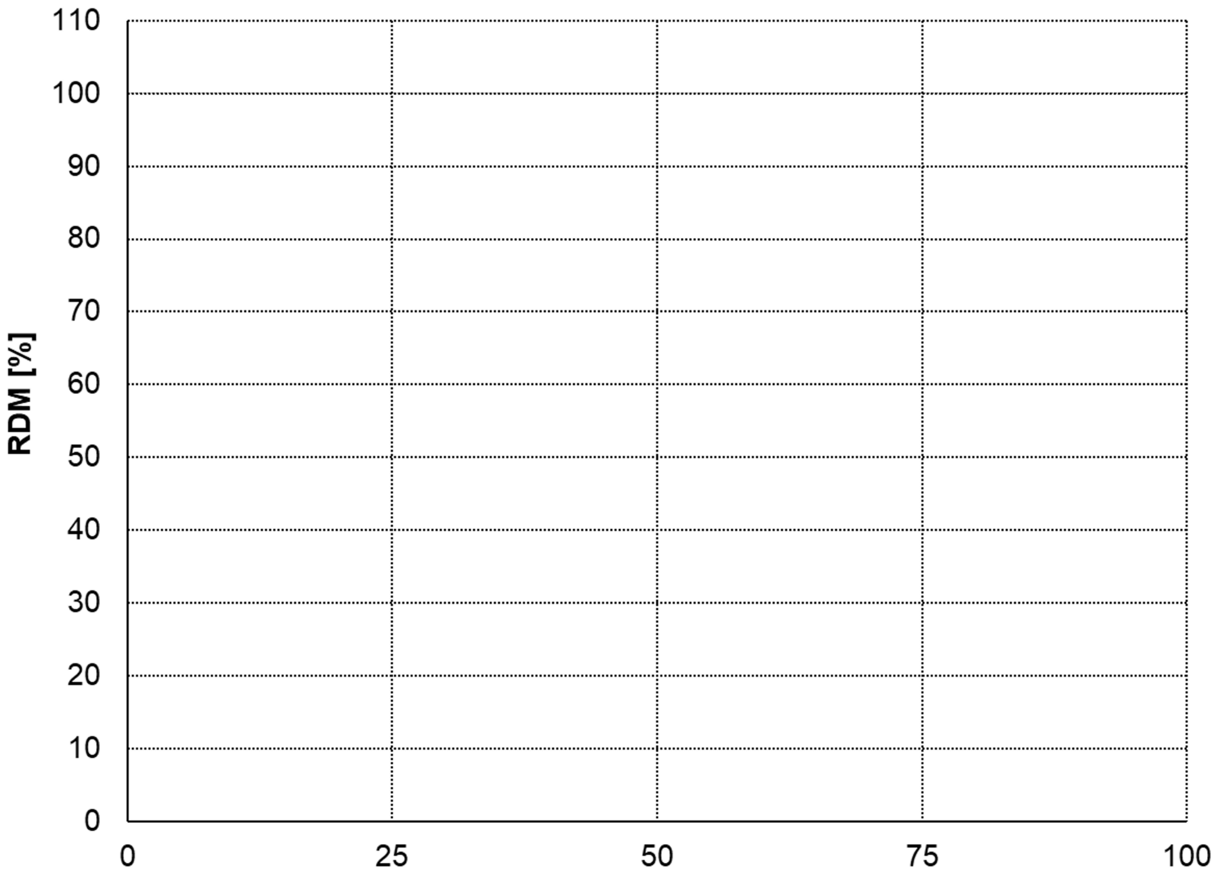
Determination of Natural Frequencies after 0, 25, 50, 75, and 100 F-T Cycles:

Number	**Concrete A**		**Concrete B**	
of Cycles	f_L [Hz]	f_t [Hz]	f_L [Hz]	f_t [Hz]
0				
25				
50				
75				
100				

RDM Calculation:

Number	**Concrete A**		**Concrete B**	
of Cycles	RDM(FL)	RDM(FT)	RDM(FL)	RDM(FT)
0				
25				
50				
75				
100				

Graphical Evaluation:



Conclusion:

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Tests conducted and report prepared by:

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