Compressive Strength and Dynamic Modulus of Elasticity of the Concrete from the Dam Orlík

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Abstract: This paper describes the analysis of the concrete properties of the body of the dam Orlik - specifically its compressive strength and dynamic modulus of elasticity. Two non-destructive methods have been used for measurement and evaluation of the dynamic modulus of elasticity - the resonant and ultrasonic methods. The concrete of the body of the dam has high values of compressive strength and dynamic modulus of elasticity after more than 50 years in operation.

Keywords: Concrete; Compressive strength; Dynamic modulus of elasticity.

1 Introduction

The Orlik Dam belongs among the most important civil engineering works in the Czech Republic. This construction was built between the years 1956 - 1961 and about 1 million m^3 of concrete [1] was consumed on the body of the dam. The dam has several functions - water regulation, electricity supply, water transport and recreation [2]. The body of the dam is straight gravitational concrete dam 81.5 m high and 450 m long [3]. Monitoring the behavior of the whole work and knowledge of the properties of the used concrete is needed with regard to the importance of this strategic construction. The mechanical and material properties of the concrete of the dam have been analyzed and this material is of high quality [4]. This paper presents results of measuring the compressive strength and dynamic modulus of elasticity.

2 Compressive Strength

The compressive strength was measured on cubes with an edge 200 mm. Cubes were cut out with a diamond saw from the cylinders with diameter 300 mm. The photo of the test cube No. 3 after the test of compressive strength is in Fig. 1 and course of loading is shown in Fig. 2.

Fig. 1:Tested cube No. 3

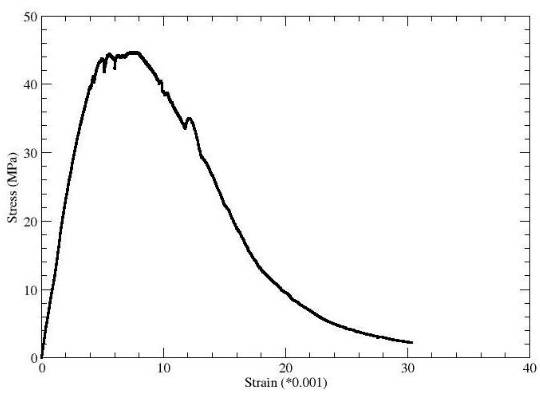


Fig. 2: Dam Orlík, Cube No. 3

Evaluation of the characteristic compressive strength was carried out according to standards EN 13791 and EN 1990 [5, 6]. Values are provided in Tab. 1.The concrete used for the body of the dam was designed as the concrete of strength class B80 (currently C8/10). The resulting strength of the concrete corresponds to a standard much higher strength class [7].

Tab. 1: The measured and characteristic compressive strength of the concrete of the body of the dam Orlik.

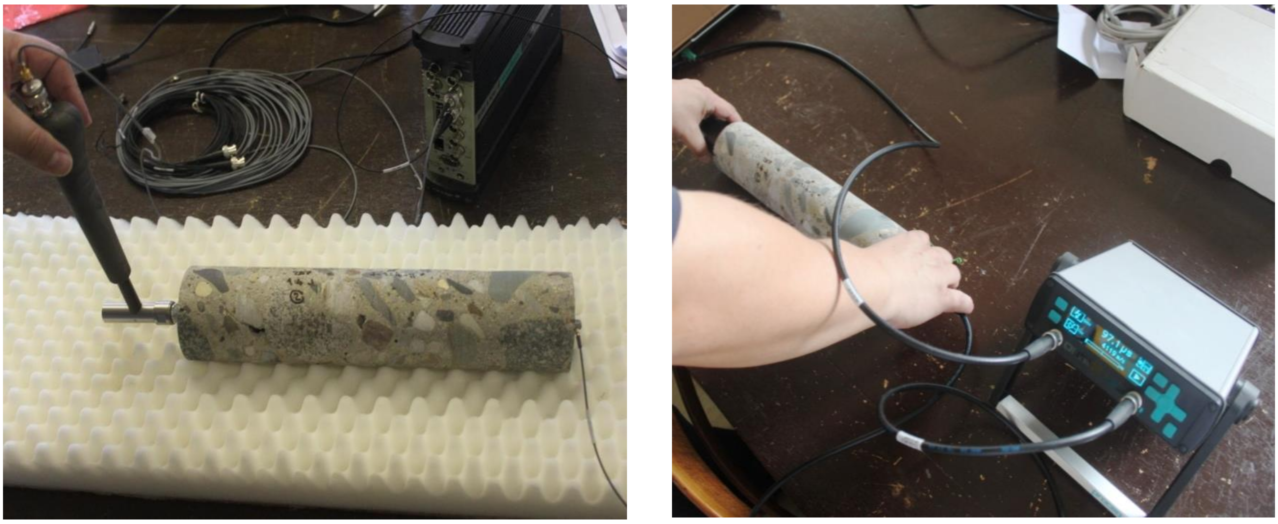
Designation of cube [-]	Measured f_c [MPa]	f_{ck}(ČSN EN 13791)		f_{ck} (ČSN EN 1990)	
1	52	n	4	m_x	47.5
2	51	k	7	s_x	4.8
3	45			V_x	0.10096
4	42	**40.5 MPa**		**38.7 MPa**	
$f_{cm}(s_x)$	**47.5** (4,8)				

3 Dynamic Modulus of Elasticity

The dynamic modulus of elasticity was evaluated from two non-destructive methods - resonant and ultrasonic. The specimens with the different lengths were prepared for the experiment from the borehole with a diameter of 80 mm.

3.1 Resonant Method

The first used method was the resonant method. The cylindrical specimen was lying on a very soft pad (Fig. 3 – on the left) to not influence the fundamental longitudinal mode of the specimen vibration. The acceleration transducer Brüel&Kjær of Type 4519-003 was placed at the center of one of the end faces of the specimen (Fig. 3 – on the left). The end face of the concrete specimen opposite to the face, where the transducer was located, was struck by the impact hammer Brüel&Kjær of Type 8206 (Fig. 3 – on the left). Both signals, the excitation force and the acceleration, were recorded and transformed using the Fast Fourier Transform (FFT) to the frequency domain, and the Frequency Response Function (FRF) was evaluated from these signals using the vibration control station Brüel&Kjær Front-end 3560-B-120 and program PULSE 14.0. The test was repeated five times for each specimen and resultant readings were averaged. From an averaged FRF, the fundamental longitudinal resonant frequency was determined for each specimen.



a) Resonant method

b) Ultrasound method

Fig. 3: Measurement of dynamic modulus of elasticity

Based on the equation for longitudinal vibration of the beam with continuously distributed mass with free-free boundary condition, the dynamic Young's modulus E_{dl} can be determined using the relation

$$E_{dl} = \frac{1.2732 l m f_l^2}{r^2 K} \quad , \tag{1}$$

where l is the length of the specimen [m], m is the mass of the specimen [kg], f_l is the fundamental longitudinal resonant frequency of the specimen [Hz], r is the radius of the specimen [m] and K is the correction factor for the fundamental longitudinal mode to account for the finite diameter-to-length ratio and Poisson's Ratio:

$$K = 1 - \frac{\pi^2 \mu^2 r^2}{2 l^2} \quad , \tag{2}$$

where μ is the Poisson´s ratio, r is the radius of the specimen [m] and l is the length of the specimen [m].

3.2 Ultrasound Method

The second nondestructive method used for dynamic modulus determination was the ultrasound method. The ultrasound analyzer with two probes of the frequency 55 kHz was used. One probe was placed at the center of one of the end faces of the concrete specimen (Fig. 3 – on the right). The second probe was placed at the end face of the concrete specimen opposite to the face, where the first probe was located. One probe (transmitter) sends ultrasound through the specimen and the second probe (response transducer) detects the time of signal traveling through the specimen. The dynamic Young's modulus E_{du} can be determined using the equation

$$E_{du} = \frac{m l}{\pi r^2 t^2 k_3^2} \quad , \tag{3}$$

where m is the mass of the specimen [kg], l is the length of the specimen [m], r is the radius of the specimen [m], t is the time of signal traveling through the specimen [s] and k_3 is the correction factor for 3D environment, which should be used for short specimens:

$$k_3 = \sqrt{\frac{1-\mu}{(1+\mu)(1-2\mu)}} \quad , \tag{4}$$

where μ is the Poisson´s ratio.

4 Conclusion

The compressive strength and the dynamic modulus of elasticity were verified on the concrete of the body of the dam Orlík old more than 50 years. The characteristic compressive strength of concrete has value 38.7 (40.5) MPa. The dynamic modulus of elasticity has an average value by resonance method 24.8 and by ultrasonic method 32.9. This difference is caused due to different resonant frequency for the resonant method and much higher frequency of the ultrasound signal [8]. This concrete demonstrates very good mechanical properties.

Tab. 2: The values of dynamic modulus of elasticity obtained by resonance (E_{dR}) and ultrasound (E_{dU}) methods.

Designation of the specimen	Mass [kg]	Length [m]	Diameter [m]	E_{dR} [GPa]	E_{dU} [GPa]
J-1-1-I	0.646	0.0657	0.0737	25.0	34.2
J-1-1-II	0.631	0.0667	0.0737	21.2	31.1
J-1-1-III	0.684	0.0694	0.0738	21.0	32.2
J-1-1-IV	0.704	0.0714	0.0738	23.7	33.0
J-1-1-V	0.676	0.0712	0.0732	24.6	32.8
J-1-1-VI	0.725	0.0716	0.0738	25.8	34.5
J-1-2-I	1.359	0.1413	0.0732	25.9	33.4
J-1-2-II	1.565	0.1601	0.0738	25.9	31.5
J-1-2-III	1.528	0.1587	0.0737	25.2	31.4
J-1-4-I	3.161	0.3215	0.0738	26.2	34.0
J-1-4-II	3.090	0.3203	0.0735	23.5	31.1
J-1-4-III	3.150	0.3205	0.0737	30.1	35.1

Acknowledgement

This work has been supported by the Ministry of Education, Youth and Sports within National Sustainability Programme I, project No. LO1605 and by the Faculty of Civil Engineering, Czech Technical University in Prague (SGS project No. SGS16/201/OHK1/3T/11).

References

[1] J. Keil: Výstavba vodního díla Orlík – sborník statí, Národní podnik vodní stavby, 1966 (in Czech)

[2] vd-tbd a.s.: Manipulační řád VD Orlík, june 2009 (in Czech)

[3] Povodí Vltavy s. p., information materials, pp. 9-10 (in Czech)

[4] O. Zobal et al.: Analysis of Concrete from the Body of the Orlík Dam after Fifty Years. In: Beton – technologie, konstrukce, sanace, 02/2014, pp. 19-25. ISSN 1213-3116 (in Czech)

[5] ČSN EN 13791: Assessment of in-situ compressive strength in structures and precast concrete components, Prague, 2007 (in Czech)

[6] ČSN EN 1990:Basis of structural design, Prague, 2004 (in Czech)

[7] ČSN EN 206-1: Concrete – Specification, performance, production and konformity, Prague, 2014 (in Czech)

[8] G. Martinček: Nedeštrukívné dynamické metódy skúšania stavebných materiálov, (in Slovak), Bratislava, SAV, 1962