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Research Article

Control of Concrete Structure of Drums Turbines of Inga II Hydroelectric Power Station by the Ultrasound Non-Destructive Testing Method

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Abstract

The Hydroelectric power station of Inga II is constituted by 8 groups of drums turbines to produce electricity of 1420 MW. These drums turbines are sustained by reinforced concrete constructions that, with time of service, present surface and internal cracks. The origin of those cracks at the same height for each group seems to be the distribution of internal vibrations in the concrete due to turbines rotation motion. The reinforced concrete constructions width is 4 m.

For the hydroelectric power station maintenance, in April 2019, a control by ultrasounds was conducted for assessing the depth of visible surface cracks on the reinforced concrete construction. The control consisted in the determination of the uniformity of the concrete by B SCAN. The elasticity modulus and the Poisson's ratio of the concrete are determined by calculation using longitudinal and transverse velocities obtained by concrete A SCAN. All of 8 controlled drums turbines show cracks depth between 15 and 50 cm and measured ultrasounds longitudinal velocities are in the interval [9398 m/s - 9401 m/s], those values are acceptable for the reinforced concrete construction depth of 4 m.

Keywords: Hydroelectric Power Station; Drums Turbines; Reinforced Concrete; Non-Destructive Testing; Ultrasound

Introduction

The material and structural parameters of concrete structures vary in time due to inevitable aging. Damage in concrete occurs as a result of overloading, shrinkage, temperature, chemical attacks or fatigue. Surface-breaking cracks belong to the most commonly encountered kind of defects in civil engineering structures [1]. Before the emergence of an open crack (macro-crack), zones of micro-cracks of size not larger than aggregate size develop within a concrete element. Detection of such micro-scale damage is not a trivial task and it is of great interest in civil engineering. There are numerous non-destructive testing (NDT) methods currently applicable to the evaluation of concrete structures, e.g. acoustic emission [2-4], infrared thermography [5,6] or ground penetrating radar [7,8]. The techniques of particular interest concern various aspects of the elastic wave propagation [9,10] including the impact-echo method [11] and the Lamb wave modes [12]. A standard non-destructive technique is based on non-automatic periodic measurements. The methodology assumes that the insitu measurements are conducted according to a regular schedule, for example once a year. Data are analyzed after the inspection and then conclusions about the structure condition are drawn by an experienced engineer. The measurements and the damage detection methodologies are the most difficult tasks and they can be improved by automation of procedures.

Recent studies have highlighted a novel approach to the non-destructive evaluation of concrete based on the continuous monitoring technology applied at all stages of a structure life. Ultrasonic techniques have been proposed for monitoring and controlling the time-varying degradation of mechanical properties of concrete. Antonaci., *et al*. [13] monitored a damage process induced by applying a mono-axial compressive load along the longitudinal direction of a cylindrical concrete specimen. After reaching each load level the specimen was removed from the loading frame and a burst of 10 sinusoidal cycles at a frequency of 55.5 kHz was propagated through the specimen. Shah and Ribakov [14] conducted ultrasonic evaluation of cube concrete specimens under uniaxial compression stepped loading. The damage assessment was performed by the analysis of the reduction in the amplitude of the waveform transmitted through the specimen at different power levels. The evaluation of thermal damage in concrete by the nonlinear ultrasonic method was investigated by Yim., *et al*. [15]. Cylindrical samples were exposed to temperature up to 600 ∘ C. After cooling to temperature of 20°C, samples were subjected to the impact-modulation method that combined the propagation of a sinusoidal continuous signal of frequency of 180 kHz with low-frequency vibrations induced by a hammer and registered by an sclerometer. Molero., *et al*. [16] applied ultrasonic imaging to evaluate damage in concrete cylindrical samples subjected to freeze–thaw cycles. The results of monitoring of self-healing in concrete are shown in the paper by In., *et al*. [17]. The experiments were conducted on tensile through-thickness cracked and flexure partial-thickness cracked concrete specimens. The specimens with cracks were subjected to axial load by applying restressing force to control the crack widths and ponded with seawater solution for 120 days to initiate self-healing. Next two transducers placed on both sides of the crack were used for ultrasonic measurements. Generally speaking, research on the evaluation of damage in concrete specimens under bending load is limited to acoustic emission methods [18] or combined AC impedance and ultrasonic methods [19]. Recently Adhikari., *et al*. [20] have presented automated crack detection in bending beams using digital images. The present work concerns the control of 8 group of drums turbines of INGA II by ultrasounds. Section II describes material and methods. Section III concerns measurement results. According to B-scans, internal cracks vary between 0 and 50 cm. They are not very deep regarding the concrete thickness (4m). Values of longitudinal velocity are about 9400m/s. They are acceptable because superior to 4.5 km/s. A brief discussion is provided in section IV and a conclusion is given in section V.

Material and Methods

Material

Reinforced concrete of drums turbines of groups G21, G22, G23, G24, G25, G26, G27 and G28 of the hydroelectric power station Inga II have been inspected using following equipment: pulse-echo PROCEQ Pundit PL-200E (Figure 1c).

Figure 1: Figure 1a) shows the entrance of the group G22. Figure 1b) shows the characteristic open surface crack found in each group at the same height. Figure 1c) shows the used equipment (Pulse-echo Proceq Pundit PL-200E.

Method

Calibration

A sample of concrete without defects of 4m has been used to calibrate the equipment. The value of its thickness (4m) was introduced in the equipment. The velocity and fly time of 9400 m/s and of 85 µs have been measured.

Measurements methods

The flaw detector Proceq Pundit PL-200PE display gives a left area for B-scan (The transversal section of the concrete structure represents the different densities of the structure by different colors) and a right area for A-scan (The pulse-echo method that represents the amplitude of the echo in the structure). Note that the A-scan permits to determine the longitudinal velocity in the concrete of a known width. B-scan is obtained by changing the scan direction (Figure 2).

The transversal velocity , the Elasticity modulus and the Poisson coefficient are obtained by following formulas:

Figure 2: Figure 2 represents a measurement by ultrasound. The B-scan is a succession of several A-scan.

$$v_t \cong 0.55\, v_l \cdot$$ --------- (1)

$$E = v_l^2 \cdot \rho \cdot (1+\nu)(1-2\nu)/(1-\nu)$$ ------------ (2)

$$E = v_l^2 \cdot \rho \cdot (1+\nu)(1-2\nu)/(1-\nu)$$ --------------- (3)

Where ρ is the structure volumic mass. Note that 5 measurements have been done for each drum turbine concrete structure. For almost parts of drums turbines result was good. However, only 5 measurements done at the open crack level for each drum have been retained for this study. Following table 1 represents results obtained for each group for $\rho = 2400\, Kg/m^3$. Table 2 gives the average of each group.

Results

Figure 3: Figure 3 shows the B-scan and A-scan of group 21 (G21).

Figure 4: Figure 4 shows the B-scan and A-scans of group 22 (G22).

Figure 5: Figure 5 shows the B-scan and A-scan of group 23 (G 23).

Figure 6: Figure 6 shows the B-scan and A-scans of group 24 (G24).

Figure 7: Figure 7 shows the B-scan and A-scans of group 25 (G25).

Figure 8: Figure 8 shows the Bscan and Ascan of group 26 (G26).

Figure 9: Figure 9 shows the B-scan and A-scan of group 27 (G27).

Figure 10: Figure 10 shows the B-scan and A-scan of the group 28 (G28).

Name of group	v_l (m/s)	v_t (m/s)	Poisson Coefficient (ν)	
G21	9400,9400,9400,9400, 9400	5170,5170,5170, 5170, 5170	0.28	$1,65.10^{11}$
G22	9399, 9398, 9399, 9398,9398	5169.45, 5168.9 ,5169.45, 5168.9, 5168.9		$1,65.10^{11}$
G23	9401,9401,9401,9401, 9401	5170.55, 5170.55, 5170.55, 5170.55, 5170.55		$1,65.10^{11}$
G24	9399, 9399, 9399, 9399, 9398	5169.45, 5169.45, 5169.45, 5169.45, 5168.9		$1,65.10^{11}$
G25	9400, 9400, 9400, 9400, 9400	5170, 5170, 5170, 5170, 5170		$1,65.10^{11}$
G26	9401, 9402, 9401, 9401, 9401	5170.55, 5171.1, 5170.55, 5170.55, 5170.55		$1,65.10^{11}$
G27	9400, 9400, 9400, 9400,9400	5170, 5170, 5170, 5170, 5170		$1,65.10^{11}$
G28	9398, 9398, 9399, 9398, 9399	5168.9, 5168.9, 5169.45, 5168.9, 5169.45		$1,65.10^{11}$

Table 1: Table 1 represents measured longitudinal velocities and calculated transversal velocities, Poisson coefficient and elasticity modulus of concrete structure.

Turbine	(v_{lmn}m/s	(v_{tmn}0.28%)m/s	(E_{mn}0.5%) Pa
G21	9400	5170	$1.65.10^{11}$
G22	9399	5169	$1.65.10^{11}$
G23	9401	5170.55	$1.65\ 10^{11}$
G24	9398	5169.90	$1.65\ 10^{11}$
G25	9401	5170.55	$1.65\ 10^{11}$
G26	9401	5170.55	$1.65\ 10^{11}$
G27	9400	5170	$1.65\ 10^{11}$
G28	9398	5169.90	$1.65\ 10^{11}$

Table 2: Table 2 shows values of v_{lmn}, v_{tmn} and E_{mn}.

v_{lmn} is the mean longitudinal velocity of ultrasonic waves.

v_{tmn} is the mean transversal velocity of ultrasonic waves.

ν is the Poisson coefficient concrete of drums turbines.

E_{mn} is Elasticity modulus concrete of drums turbines.

Following figures represent an example of one B-scan and A-scan of the 8 groups (Figure 3, 4, 5, 6, 7, 8, 9, 10). Note that reinforcements are visible in each B-scan.

Discussions

- Given turbines functioning temperature of 34°C, a permanent follow up method of ultrasonic tomography is recommended. It will permit to follow the temperature spectrum and the launch of first cracks.
- Periodic ultrasonic controls (6 to 12 month) are necessary to follow the evolution of parameters of table 1 for repairs actions if any.

Conclusion

The obtained velocity values by A scan permit to calculate parameters of tables 1 and 2. For a given concrete, velocities vary according to concrete internal variation given the fact that measurements were done during turbines were turning.

Considering B-scans, internal cracks (yellow-red color) vary between 0 and 50 cm and are not very deep regarding the concrete thickness (4m).

Transducer frequency (pulse-echo) being of 50 kHz and the propagation velocity being about 9400m/s, the calculated wavelength is about 0,188 m. This means that cracks less than 0,188 m cannot be detected, given the detection limit. The values of longitudinal velocity for good concrete are in the interval [3.5 – 4.5] km/s [1, 24].

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