QUANTITATIVE ANALYSES OF AGING STATUS OF DAM CONCRETE FOR A 25-YEAR-OLD DAM

Shuguang Li (1), Jinsheng Jia (1), Yaoqun Xu (1), Xiangjun Zhai (2), Xiulin Li (1), Gaixin Chen (2)

(1) State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, China Institute of Water Resources and Hydropower Research, Beijing, China

(2) PowerChina Kunming Engineering Corporation Limtied, Kunming, China

Abstract

In order to evaluate the aging status of the dam concrete for a 25-years-old concrete dam, the internal concrete and surface layer of the dam were tested by elastic wave computerized tomography (CT) and spectral analysis of surface wave (SASW). Also mechanical strength and elastic wave velocity were tested for the concrete cores from the dam. The CT results show that the elastic wave velocities of the three dam sections are basically around 4400~4500m/s and no obvious low-speed zone could be detected, indicating the quality of the internal concrete is good without aging signs. The SASW results show that the Rayleigh wave velocity of the surface layer (deeper than 25cm) is about 2500 m/s (the corresponding P wave velocity is 4500 m/s) which is basically consistent with the CT results. The average compressive strength of the concrete cores is over 40 MPa (higher than the design values) while the elastic wave velocities are between 3600 and 4400 m/s. Microstructural analysis results show that the a few microcracks could be observed in all the 16 cores from the upstream, the downstream, the gallery and the spillway. The overall results indicate that the dam concrete is of good quality and no obvious aging signs could be found.

Keywords: Dam concrete; Aging status; CT test; SASW; Microcrack analysis

1. INTRODUCTION

Most of the concrete dams built between over a decade ago in China are inevitably aging and the ageing status of these old dams is becoming the focus of the society. The first step to evaluate the aging status of old dams is to quantitatively evaluate the aging status of the dam concrete.

To evaluate the quality and aging status of a concrete dam in south China which was built 25 years ago, elastic wave CT test, spectral analysis of surface wave (SASW) test were performed on selected dam blocks as well as the dam outer layer. Mechanical tests, elastic wave tests and quantitative microcrack analysis were also performed on typical concrete cores to get a comprehensive evaluation of the dam quality.

2. COMPUTERIZED TOMOGRAPHY (CT) TEST AND SPECTRAL ANALYSIS OF SURFACE WAVE (SASW) TEST

2.1 CT test by elastic wave

Seismic Tomography (CT) test by elastic wave is conducted between the upstream and downstream faces of selected dam blocks (#3 and #16), to show the distribution of elastic wave (P-wave) velocities inside the dam block, and then to reflect the physical property (such as the modulus of elasticity) of each unit cell of the dam body [1]. Details of the CT test could be found on Ref. [1].

2.2 SASW test

SASW is a powerful method when only a single side access is available. Unlike CT test which employs P-wave velocity, Rayleigh wave (surface wave, or shear wave) is employed to reflect the physical property such as modulus of elasticity of concrete [1].

SASW test was performed on the upstream outer layer of the dam. The schematic of the test and the location of the sensors on the dam surface are shown in Figure 1 and Figure 2.

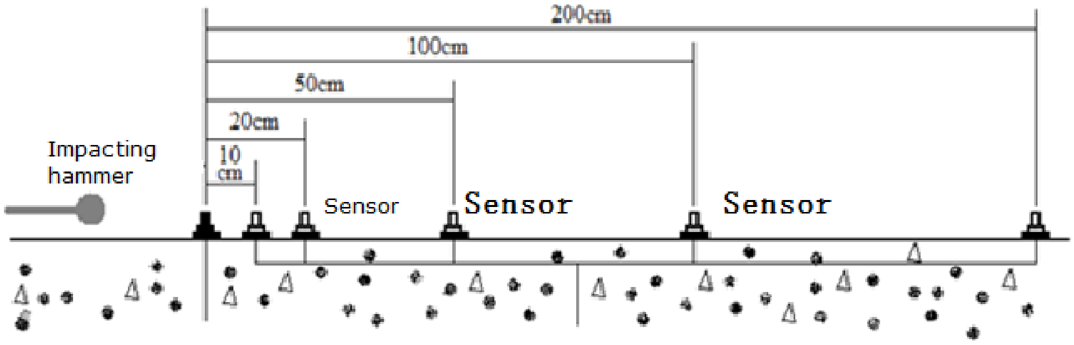


Figure 1: Schematic of SASW test

Figure 2: Sensor location on the dam surface (pointed by red arrow)

2.3 Tests on concrete cores

(1) Coring location

Cores were extracted from the upstream, the downstream, the gallery and the spillway, respectively. The depths of the cores drilled from the upstream and downstream are both 24 m, while the depths of the cores from the spillway and gallery are both 2m. Diameters of the cores are 219mm.

(2) Mechanical tests

The cores were cut and grounded according to test codes for hydraulic concrete in China (SL352-2006) [2] and mechanical tests were performed on the cylindrical cores whose height was the same with diameter.

(3) Elastic wave velocity tests

Previous studies have revealed that quadratic correlation could be established between the dynamic modulus of elasticity of concrete and the P-wave velocity [3]. It suggests that P-wave velocity can be used to quantify damage extent in concrete like the resonant frequency method.

The elastic wave velocity testing system is composed of five components, the sensor, the hammer, the data collecting device and the controlling computer, as shown in Figure 3.

Figure 3: Elastic wave velocity testing device

(4) Microcrack analysis

An automated panoramic fluorescent microscope was designed and developed to get a panoramic image of the microcrack pattern in the concrete automatically.

The cores are sliced into 2cm thick disks and cut into square slices 10cm*10cm in dimension as microscopic specimens. Once the impregnated microscopic specimen (by fluorescent epoxy resin) is put on the stage, the stage will automatically move in two directions in the range of 10cm x 10cm. All the clear microscopic image will be captured and stored in the computer. More than 4000 images will be obtained for a slice 10cm*10cm in dimension and the images can be stitched into one panoramic mega-image automatically by DIP technique. The specimens are scanned automatically on the stage at a magnification of 40x which was sufficient to detect microcracks as thin as 2 μm in width. Typical microscopic image of the concrete slice can be seen in Figure 4.

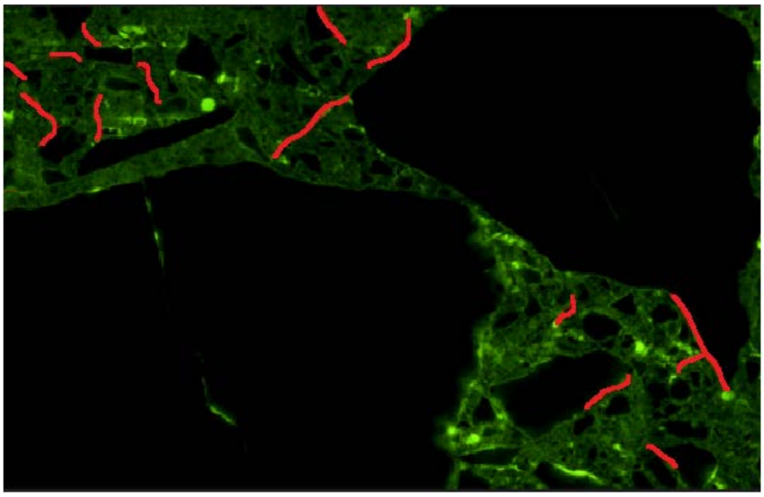


Figure 4: Microscopic image of core from the gallery (2cm*2cm in dimension, microcracks are highlighted by red lines)

A program called QUANSMIC is developed to extract microcracks on the panoramic mega-image and quantify microcrack patterns. Microcrack length density is used to quantify the microcrack structure and it is calculated by the following equation,

$$D=L/A \quad (1)$$

Where, D is the microcrack length density, L is the total length of the extracted microcracks in the slice image, and A is the total area of the slice. Details of the processing chart and the program could be found in Ref [4] and [5].

3. RESULTS AND DISCUSSION

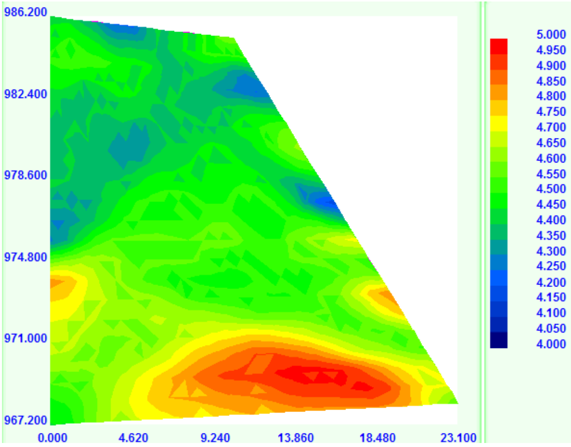
3.1 CT test results

After reconstruction, the velocity distributions in each dam block section is shown in Figure 5.

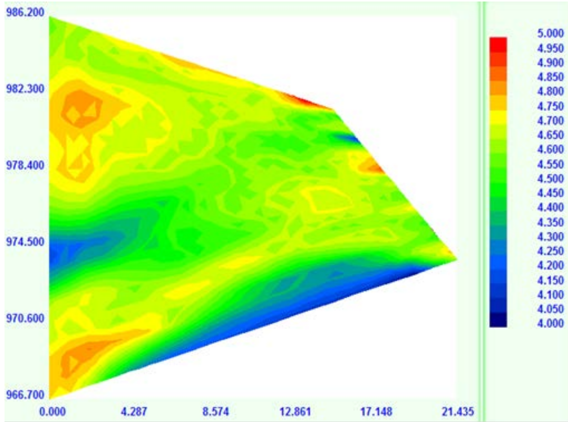
For concrete with good quality, the P-wave velocity is between 3600 m/s and 4500 m/s [1]. As seen from Figure 5, the velocity in each dam section is around 4400~4500m/s and the minimum value is greater than 4023 m/s. It indicated that the dam concrete in these two blocks are in good quality and no defects could be found.

3.2 SASW results

Eight locations were tested by SASW in the upstream of the dam. The frequency dispersion curve of the Rayleigh-wave for the eight locations were shown in Figure 6 (only two were shown because of the page limit).

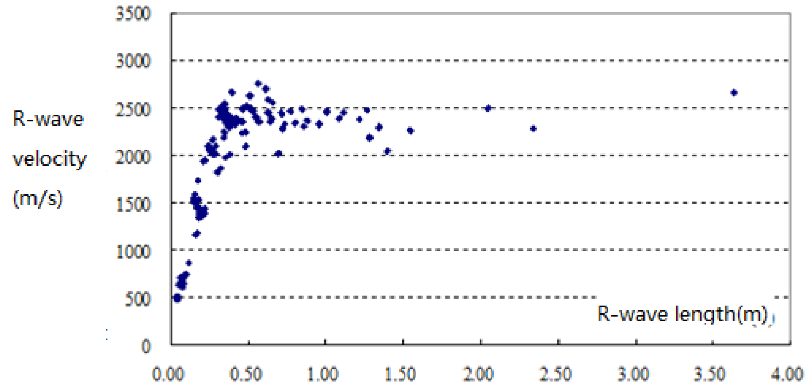


(a) #3 dam block, P-wave velocity: average value 4541 m/s, maximum value 4983 m/s, minimum value 4172 m/s

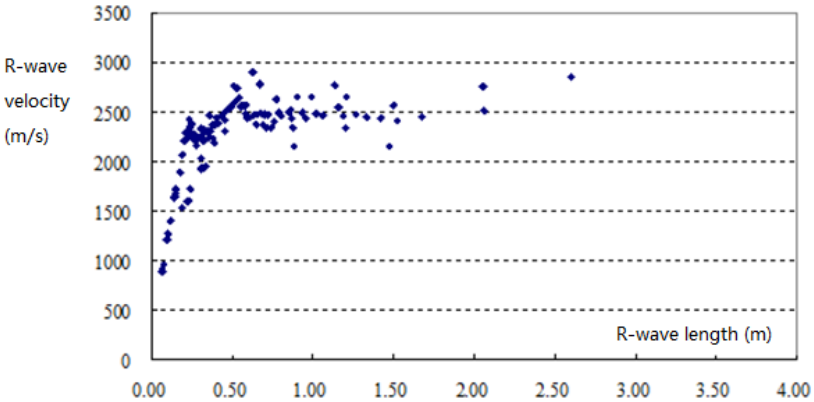


(b) #16 dam block, P-wave velocity: average value 4596 m/s, maximum value 4974 m/s, minimum value 4023 m/s

Figure 5: Elastic wave velocity distribution in dam blocks



(a) Location 1 (#18 dam block)



(b) Location 2 (#17 dam block)

Figure 6: R-wave frequency dispersion curve

As seen from Figure 6, the variation of the R-wave frequency dispersion curve is similar. When the wave length is greater than 50cm, the velocity is fluctuating around 2500m/s. The velocity decreases as the wave length decreases when the wave length is smaller than 50cm. It indicated that the superficial layer (about 25cm thick) of the concrete in the upstream is weathered and aging, so it's not as dense as the concrete inside. According to the relationship between the P-wave velocity and the R-wave velocity[1], the corresponding P-wave velocity is around 4500m/s and it is consistent with the testing results obtained by elastic wave CT. Also we can see from Figure 6 that the internal concrete whose depth is bigger than 2.0m is of good quality and no aging sign could be found.

3.3 Analysis for the cores

(1) Mechanical tests

The compressive strength of the cores are obtained and compared with the design value as well as the testing values right after the completion, as shown in Figure 7.

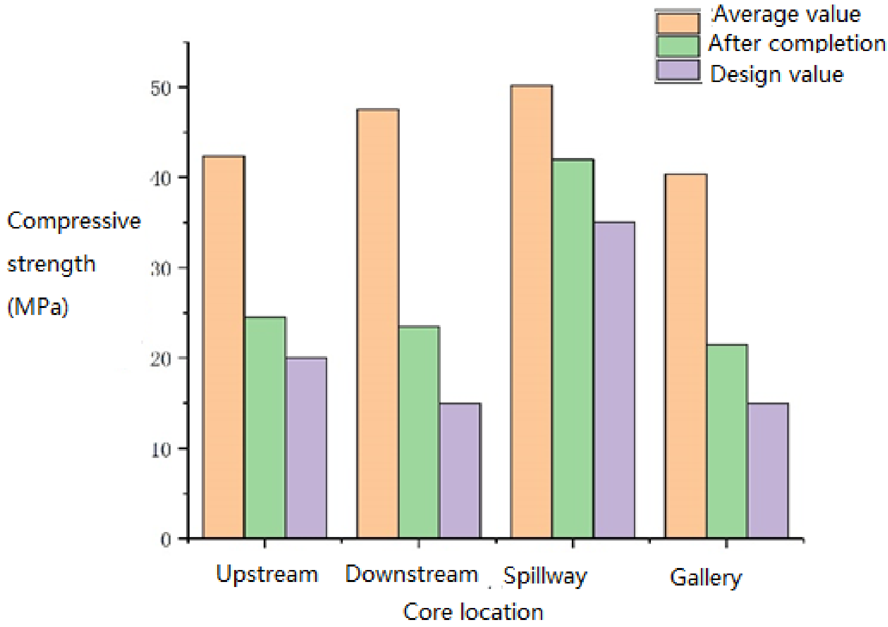


Figure 7: Comparison of the compressive strength of the dam concrete cores

As seen from Figure 7, the average compressive strength of the concrete cores from the upstream, the downstream, the spillway and the gallery is 42.3MPa, 47.5MPa, 50.2MPa and 40.4MPa, respectively. And the compressive strength values are all much higher than the design values as well as the values obtained right after the completion of the dam 25 years ago.

(2) Elastic wave velocity

The elastic wave velocities of the cores are shown in Table 1.

Table 1 Elastic wave velocities of the concrete cores

Upstream		Downstream		Gallery		Spillway	
NO.	Velocity (m/s)	NO.	Velocity (m/s)	NO.	Velocity (m/s)	NO.	Velocity (m/s)
S1	4133	X1	4408	L1	3952	Y1	4301
S2	3629	X1	4580	L2	4222	Y2	4164
S3	3735	X3	3890	L3	3349		
S4	3894	X4	4376	L4	3762		
S5	4198	X5	3337				

As seen from Table 1, the P-wave velocity values of the cores are mostly between 3600 m/s and 4400 m/s, indicating most of them are of good quality (only two values are lower than 3600). It is also in good agreement with the CT results shown in Section 3.1.

(3) Microcrack analysis

The microcrack density of the concrete cores from different locations are shown in Table 2.

Table 2 Microcrack density for different specimens

Upstream		Downstream		Gallery		Spillway	
NO.	Density/ mm/mm^2	NO.	Density/ mm/mm^2	NO.	Density/ mm/mm^2	NO.	Density/ mm/mm^2
S1	0.0124	X1	0.0740	L1	0.0916	Y1	0.1029
S2	0.0558	X1	0.0875	L2	0.0665	Y2	0.0620
S3	0.0615	X3	0.0353	L3	0.0303		
S4	0.0101	X4	0.0282	L4	0.0388		
S5	0.0188	X5	0.0335				
Average	0.0317	Average	0.0517	Average	0.0568	Average	0.0824

As seen from Table 2, microcracks could be observed on all the 16 concrete core slicess and the microcrack density varies from 0.0101 mm/mm^2 to 0.1029 mm/mm^2. The average density value for the concrete cores from the spillway is the highest, 0.0824mm/mm^2 , while the average density for the upstream is the smallest, 0.0317 mm/mm^2. The reason is perhaps that concrete from the spillway has low water/cement ratio, high compressive strength and complicated loading conditions resulted from discharging.

4. CONCLUSIONS

Comprehensive inspecting tests were performed on a 25-years-old concrete dam. The CT results as well as the SASW results show that the superficial layer of the upstream (25cm thick) is weathered and degraded. For the internal concrete (whose depth is greater than 2.0m) the elastic wave is around 4400~4500m/s and no low-speed zone could be detected. The average compressive strengths of the 16 concrete cores from the upstream, the downstream, the gallery and the spillway are over 40 MPa (all are higher than the design values) while the elastic wave velocities are between 3600 and 4400 m/s. Microstructural analysis results show that the a few microcracks could be observed in all the cores. The overall results indicate that the dam concrete is of good quality and no obvious aging signs could be found.

ACKNOWLEDGEMENTS

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