AGED CONCRETE STRENGTH AND PROPAGATION VELOCITY RATIO OF LONGITUDINAL AND TRANSVERSE WAVE

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Abstract: There are about eighty thousand dangerous districts of landslides in Japan. We have constructed a great number of concrete earth holding dams for the purpose of disaster prevention. Most dams will be damaged over time by degradation, such as Alkali-aggregate reaction, salt, etc. Nondestructive dam inspection was done by the government. Many discussions have taken place to find the best solution to determine; where the damage is, how to strengthen and how to repair the dams economically versus new construction.

Sampling cores from one of the aged dams were extracted at the fourteen spots on the sidewall of the dam. Ultrasonic wave was propagated to the core specimen and the velocity ratio of the longitudinal and transverse wave was calculated. After the development of Alkali-aggregate reaction in each core specimen was investigated, the compressive load was applied to these cores and failed.

Results show compressive strength and the degree of Alkali-aggregate reaction are correlated to the sound velocity. Lower sound velocity measurements correspond to lower strength in compression tests correlates in Alkali-aggregate reaction. Ultrasonic velocity measurement use for monitoring the concrete dam integrity has been found useful to repair damage areas using concrete velocity data standards to correspond to strength.

Introduction: Some JAPANESE residential areas have expanded to the mountains base having many streams. The mountain streams have overtaken residential areas after heavy rains causing landslides. It is said dangerous districts of landslides are about eighty thousand in Japan. Many concrete earth dams have been constructed to prevent these residential disasters. It was known concrete structure durability can grow weak over time by Alkali-aggregate reaction, salt, etc. and inspections must be performed.

Ultrasonic method is one of the nondestructive evaluations and used to know the concrete thickness, crack depth, and cover of reinforcing rod. Velocity measurement is said to be insufficient because of change at the construction condition, place and change in the property by mixture. Another problem is ultrasonic tester. As the traveling wave is scattered and decays in concrete, there are few transducers for the pulser and receiver to transmit the transverse wave for long distances.

Currently, we have been contracted to evaluate a twenty years old dam for damage location and repair the dam's strength. Sampling cores were extracted at fourteen spots on the dam, and the velocity was measured to those cores. Compression test was also carried out in addition to the mark of Alkali-aggregate reaction.

The ratio between the longitudinal and transverse wave velocity is constant on each core and correlates to the concrete strength and to the degree in Alkali-aggregate reaction. Dam damaged areas can be located by wave velocity.

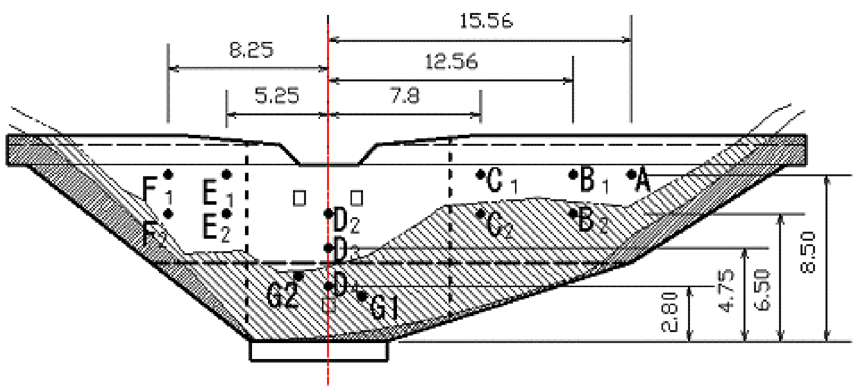


Fig.1 Structural drawing of dam and location of sampling cores (m)

Aged concrete dam and sampling cores: The aged dam that we are now investigating was constructed in 1980. It is 9 m in height and 40 m in width and its certification tell us that its strength is 18 N/mm^2 and grain size in concrete less than 20 mm. Sampling cores were extracted at 14 spots on the sidewall for the nondestructive evaluation, and its sampling locations is shown in Fig.1, in which location A, B_1, C_1, E_1, F_1 is 8.5 m and B_2, C_2, D_2, E_2, F_2 is 6.5 m from the bottom respectively. Though each extracted core length is 1 to 1.5 m, some of cores have cracks and some are damaged in the way of extracting, and so complete cores are useful from 3 to 5 at each location spot. These cores are worked and polished at 100 mm in diameter and 200 mm in height.

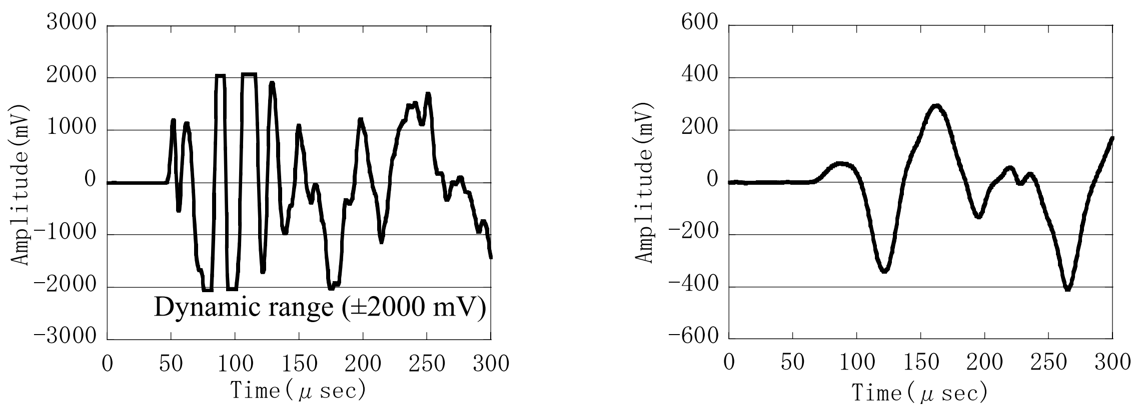
Results:

(1) Longitudinal and Transverse velocity ratio R: We use digital ultra wideband ultrasonic tester named UCT12db (I.S.L Co .Ltd Japan) with active transducer developed by one of the papers authors. Wide band uni-pole step function pulser in the active transducer generates wave and sound with a transmitting frequency range from DC to 5MHz. Another receiver with active transducer receives the travelling waves. Its effective frequency range is from 20kHz to 3 MHz.

Two examples of receiving waves are shown in Fig. 2. One is the longitudinal wave at the location G1, and the other at E1. You will see later the concrete at location G1 is good and E1 is an Alkali-aggregate reaction area. We can determine the concrete condition by observing the travelling wave. The velocity is calculated from the travelling wave time-of-flight and the core path length.

Fig. 3 shows longitudinal and transverse velocities distribution at the location on each spot. Each plot is the average in sampling cores. When the longitudinal velocity is over 4300 m/s at a location, the transverse velocity is also over 2400 m/s at the same location. You will find that cores extracted from the wall location at A, E1, F1, B2, and D2 have lower velocities than that of the other location, for example, at G. These are discussed later again (in Fig.10, 11).

We plotted longitudinal and transverse velocities to the same core as shown in Fig.4. We can see the two groups of plots in the Figure. One of the groups with the symbol ○ that has higher than 4300 m/s in the longitudinal wave velocity, the other with the symbol □ which has lower velocity. Later, in discussion, we will mention about the new test specimen with the certificated strength 18 N/mm^2. Its velocity is 4300 m/s in longitudinal and 2400 m/s in transverse wave respectively. This is shown in Fig.4 with the symbol of double circle. Comparing the certificated model specimen with the group of the symbol □ in Fig.4, some of them have cracks and the Alkali-aggregate reactions are observed in these cores. Also, wave velocities are slower than the model specimen. We concluded that the concrete of sampling core location with the symbol □ is in poor condition and had to be considered for repair. They are at A, E1, F1, B2, and D2. The inclination is about 1.79 in Fig.4. That will mean the velocity ratio between the longitudinal and transverse wave is constant in this concrete, though the travelling wave is propagated through the damaged concrete of the group with the symbol □.



(a) Longitudinal wave (G1) (b) Longitudinal wave (E1)

Fig.2 Example of received waves

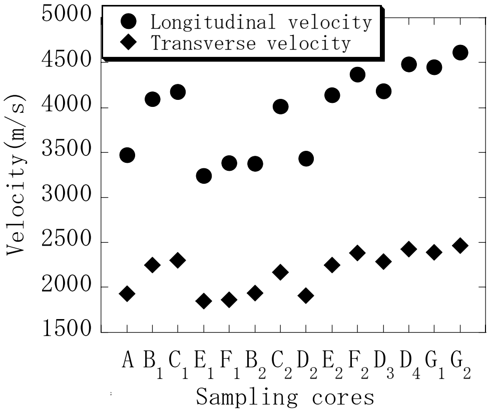


Fig.3 Longitudinal and Transverse velocity at the sampling core location

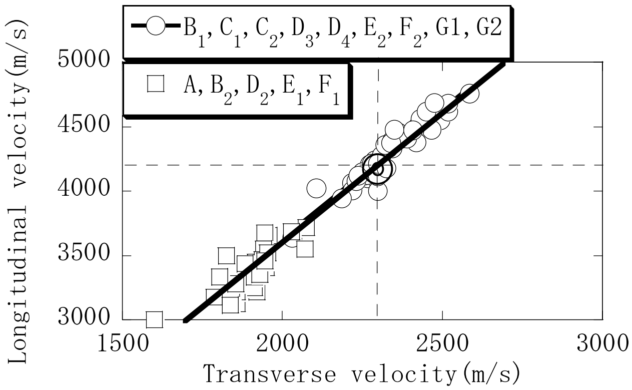


Fig.4 Longitudinal and Transverse velocity

(2) Compressive strength and Poisson's ratio ν: Each core was applied to compressive load and failed. Cores strength at wall location B1, C1, C2, D3, D4, E2, F2, G1 and G2 is larger than at the location A, B2, D2, E1 and F1. These results correspond to the velocity measurement that longitudinal and transverse velocities are larger at the former location than latter.

Fig.5 shows compressive strength vs. the longitudinal and transverse velocity Ratio. Also shown are the compressive strength $18N/mm^2$ model specimen with solid line and the velocity ratio with the dotted line. You will observe the symbol □ group has a lower velocity ratio and in strength except one. They are from the same sampling core locations shown in Fig 4.

Poisson's ratio ν was measured by strain gage method in compressive test at the same time. An example of stress-strain curve at G1 core is shown in Fig.6. Longitudinal and lateral strain is plotted to the applied load and its Poisson's ratio is 0.24. On the other hand, we can get it using the velocity ratio R by equation (1) for the isotropic elastic material.

$$\nu = \frac{1}{2}\left\{1 - \frac{1}{\left(R^2 - 1\right)}\right\} \tag{1}$$

Table 1 shows Poisson's ratio ν by strain gage and ultrasonic method to the wall location. Ultrasonic method is a little larger than gage method.

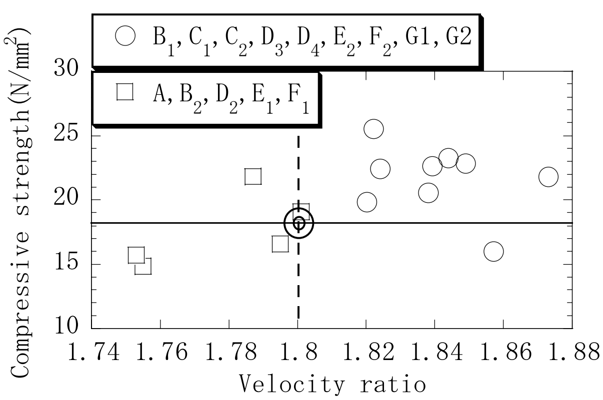


Fig.5 Velocity ratio R and compressive strength

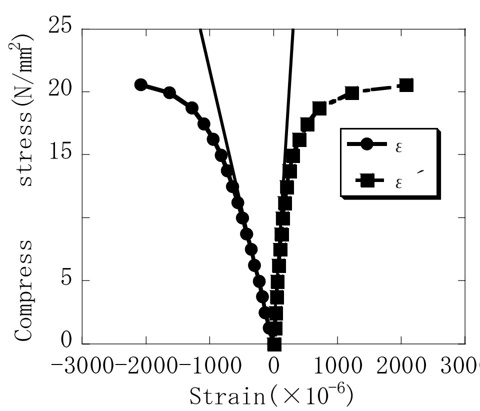


Fig.6 Example of stress-strain curve

Table 1 Poisson’s ratio ν by Strain gage and Ultrasonic method

		Extracted cores						
		A	B1	C1	E1	F1	G1	G2
Poisson's ratio ν	Strain gage		0.14	0.19	0.25	0.30	0.21	0.21
	Ultrasonic	0.27	0.29	0.28	0.26	0.27	0.29	0.30

Alkali aggregate reaction and velocity ratio: We now, try and quantify the Alkali-aggregate degradation. It will be done by observing the core surface aggregate. Paying attention to ten small areas and evaluating the stage according to Table 2 for each area. For example it is a 20 score, if, all areas are Stage I and 160 score, if all areas are Stage IV. Fig.8 shows aggregate marks α vs. velocity ratio R in all cores. Figure shows going to the Alkali-aggregate reaction will make a decrease to velocity ratio.

Table 2 Alkali-aggregate reaction stages

Stage	Observation of aggregate	Score
I	White spot	$2^1=2$
II	White ring	$2^2=4$
III	Crack	$2^3=8$
IV	Grow of crack	$2^4=16$

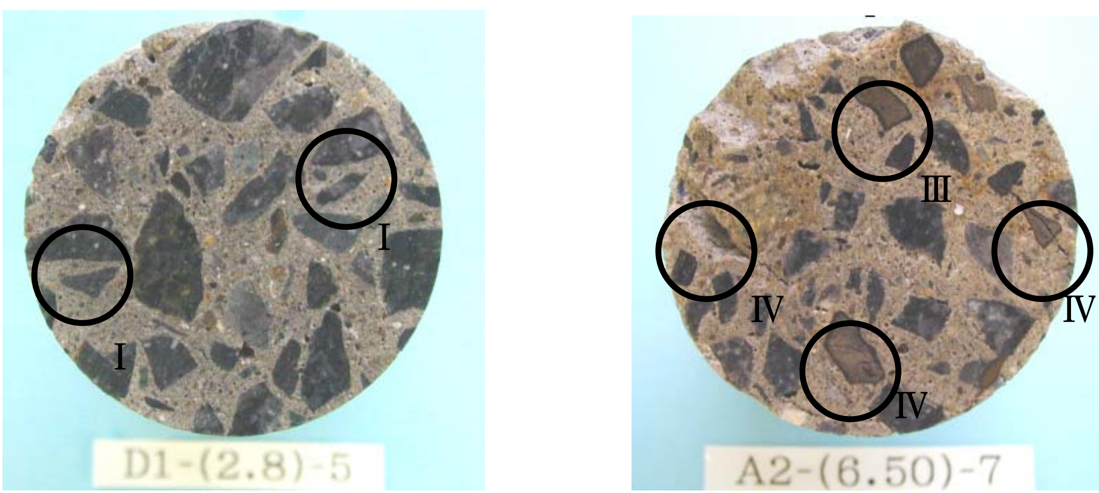


Fig.7 Example of core surface and Alkali-aggregate reaction stage

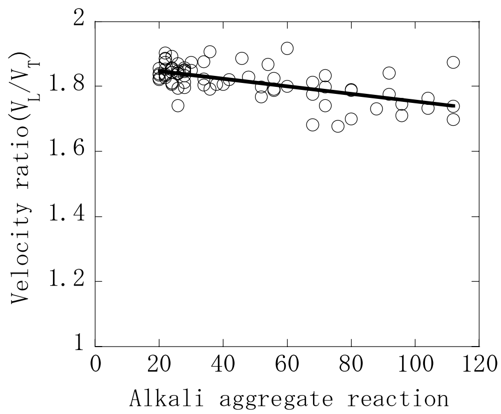


Fig.8 Alkali-aggregate reaction and velocity ratio

Fig.9 Standard concrete block test specimen and sampling core

Discussion: To Determine

1) What is the velocity of the certified strength 18N/mm^2 concrete?
2) Had been maintained the certified strength after 20 years?

We placed a new concrete block standard test specimen according to certification. The specimen is 600 mm x 800 mm with 400 mm thickness (Fig.9) and was cured for four weeks.

We achieved the longitudinal and transverse velocity measurement. They are 4300 m/s, 2400 m/s in longitudinal and transverse velocity respectively and its ratio is 1.8. Fig.10 and 11 show again longitudinal and transverse wave at the core location with additional date of the standard specimen shown by the symbol of double circle. Comparing sampling cores date with the standard model, date at the location D4, F2, G1and G2 is larger than that of model in velocity and strength. We maintain the concrete has still kept its strength after 20 years and need not be repaired. Velocity at B1, C1, D3 and E2 is in between 3500 m/s and 4300 m/s for longitudinal. They are becoming weak due to alkali aggregate reaction and will need to be repaired in the future. On the other hand, velocity at location A, B2, D2, E1 and F1 is lower about from 700 to 1000 m/s in longitudinal and from 400 to 500 m/s in transverse as shown by hatched line shown in Figures. These locations must be considered to repair and strengthen.

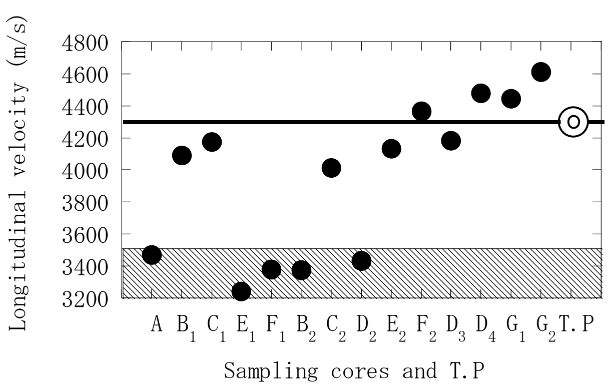


Fig.10 Longitudinal velocity of sampling cores and standard concrete block test specimen

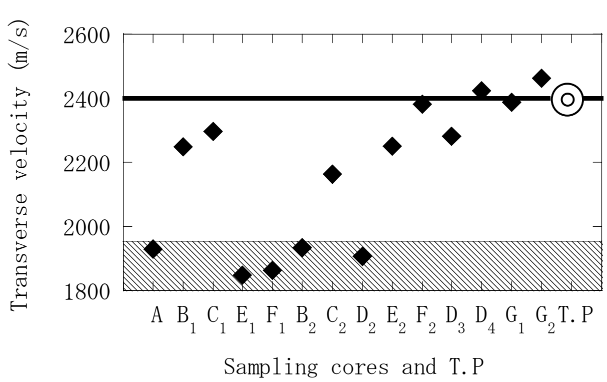


Fig.11 Transverse velocity of sampling cores and standard concrete block test specimen

Conclusion: Safety inspection is ordered on concrete earth dams constructed in 1980. Sampling cores are extracted from 14 locations in the dam. We measured the longitudinal and transverse wave velocity propagating each core and applied to compressive load, and failed, after the scoring of the degree in Alkali-aggregate reaction.

Conclusions are summarized as following.

(1) Velocity ratio R between longitudinal and transverse is 1.80 in these concrete cores (Fig.4), and its average Poisson's ratio $\nu = 0.27$ from eq (1). And the velocity in the damaged concrete is slower than that in good concrete (in Fig.10, 11).

(2) Longitudinal and transverse velocity was 4300 m/s and 2400 m/s respectively in the model concrete specimen certificated that is strength at 18 N/mm^2. Aged concrete would have been placed at the same strength, and some of cores extracted from the aged dam are larger than model concrete in velocities and compressive strength and some of them the similar velocity and strength.

(3) From the nondestructive point of view at the aged dam, comparing the standard model. Velocity and strength at location D4, F2, G1 and G2 is larger than model and there is no need of repair now. Location B1, C1, D3 and E2 is in the between health and damaged. They will be repaired in the future and A, B2, D2, E1 and F1 has lower velocity and strength. They have to be repaired.

(4) Numerical scoring method is proposed to the Alkali-aggregate reaction. It is also correlated to the velocity ratio. Further investigation will be needed to find the numerical way of concrete degradation.

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We will hold these experimental date in common with above mentioned.

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