Verification of the Usefulness of Dynamic Modulus of Elasticity with Different Evaluation Methods for Assessing the Concrete Damage Degree

評価方法の異なる動弾性係数のコンクリート損傷度評価への有用性の検証

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1. Introduction

The dynamic modulus of elasticity is a useful material property index for quantitatively assessing concrete damage. Two evaluation methods have been proposed: one is based on the resonance vibration method according to JIS A 1127[1] and the other is derived from the Ultrasonic pulse velocity method. Differences and theoretical challenges were discussed within JSCE's 326 Committee[2], but empirical investigations on concrete with accumulated damage have not been conducted. The authors conducted a comparative study of both parameters on RC structures that had been in service for about 50 years and revealed the effects of accumulated crack formation and coarse aggregate distribution[3), 4)]. In this study, core samples were taken from two in-service concrete headworks with different damage conditions, and the relationship between the actual damage degree and the dynamic modulus of elasticity were compared and verified.

2. Materials and Methods

2.1. Concrete Core

The concrete cores were obtained from the Yashirogawa Headworks (Y-HW) and the Tanihama Headworks (T-HW), located in Joetsu City, Niigata Prefecture (Fig. 1). From Y-HW, a total of 19 cores were collected: 8 from the right and left pier, and 3 from the bottom. From the T-HW, a total of 14 cores were collected: 7 from the right pier, 5 from the left pier, and 2 from the bottom. The distribution of lengths is from 91 to 242.5 mm, diameters is from 99.80 to 100.20 mm, and mass is from 1.50 kg to 4.42 kg. No significant surface damage was observed at the T-HW but at the Y-HW was evident, with more pronounced damage observed on the left pier than on the right pier and also efflorescence was observed in the upper part of the pier. Therefore, it is assumed that deterioration at the Y-HW is caused by not only due to freeze-thaw cycles but also due to alkali-aggregate reaction.

2.2. Resonance Vibration Test

Based on JIS A 1127[1)], measurements of the primary resonant frequency were conducted using vertical vibration. Eq. 1 is used to determine the dynamic modulus of elasticity E_{D} from the primary resonant frequency.

$$E_{\mathrm{D}} = 4.00 \times 10^{-3} \frac{L}{A} m f^2, \qquad (1)$$

where L is the length (mm), A is the area (mm^2), m is the mass (kg), and f is the primary resonant frequency (Hz).

2.3. Ultrasonic Pulse Velocity Test

Measurements of the P-wave velocity were conducted to evaluate concrete properties. The dynamic modulus of elasticity E_{d} is calculated using Eq. 2 based on the propagation velocity V_{p}.

$$E_{\mathrm{d}} = \frac{{V_{\mathrm{p}}}^2 \rho (1-2\gamma)(1+\gamma)}{(1-\gamma)}, \qquad (2)$$

where ρ is density (m^2/kg), and γ is the Poisson's ratio (= 0.2).

3. Results and Discussion

3.1. Mechanical Properties

Fig. 2 shows the distribution of dynamic modulus of elasticity for Y-HW and T-HW. The difference (T-HW－Y-HW) is 8.9 GPa for E_{D} and 2.4 GPa for E_{d}. These trends correspond to the observed damage conditions on the exterior. The difference due to the evaluation method is 20.5 GPa at Y-HW and 2.4 GPa at the T-HW. From this, it can be inferred that the resonance vibration

Fig. 1. Tanihama (left) Yashirogawa (right) Headworks.

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method tends to underestimate dynamic modulus of elasticity compared to the P-wave velocity method, with some cores being underestimated by up to 56.5 GPa.

3.2. Discussion of The Primary Resonant Frequency

In Fig. 3, the primary resonant frequencies calculated from P-wave velocity (theoretical values) and from resonance vibration method (actual values) are plotted on the first vertical axis, while the vertical vibration wavelengths calculated from the measured resonant frequencies and propagation velocities are plotted on the second vertical axis. Each is then depicted in relation to the sample length. It should be noted that the theoretical values are calculated using Eq. 3.

$$f_0 = \frac{v}{2 \times d}, \quad (3)$$

where v is velocity (m/s), and d is length (m).

From Fig. 3, theoretically, as the length decreases, the behavior of the primary resonant frequency tends to increase. However, in the actual values, it exhibited a different behavior where it shifted from an increase to a decrease around 160 mm. It has been reported that the resonance vibration method produces differences in frequency response due to porosity, and the aspect ratio (Length/Diameter) affects the propagation direction of waves[5]. The factor causing the actual values to be lower than the theoretical values is to reflect an increase in porosity due to the progression of cracking with aging deterioration.

From the calculation formula of Resonance vibration test (Eq. 4):

$$\lambda = \frac{V}{f} = 2L, \quad (4)$$

where λ is the wavelength (m), V is velocity (m/s), f is the primary resonant frequency (Hz), and L is the sample length (m).

In the core used in this research, the diameter is considered constant, thus the aspect ratio depends on the length. From Fig.3, it is inferred that the primary resonant frequency observed in the region below approximately 160 mm (aspect ratio: 1.25) does not satisfy the relationship in Eq. 4. This suggests that dominant vibration modes other than vertical vibration were presented, resulting in different numerical values that do not meet Eq. 4.

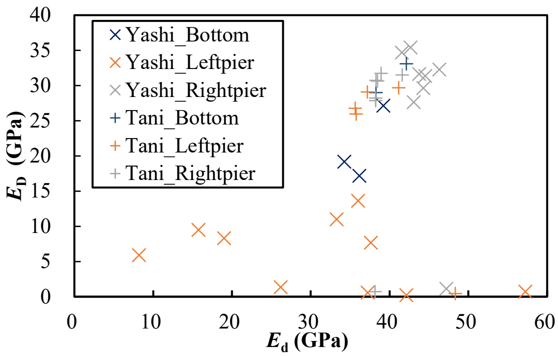

Fig. 2. Comparison dynamic modulus of elasticity.

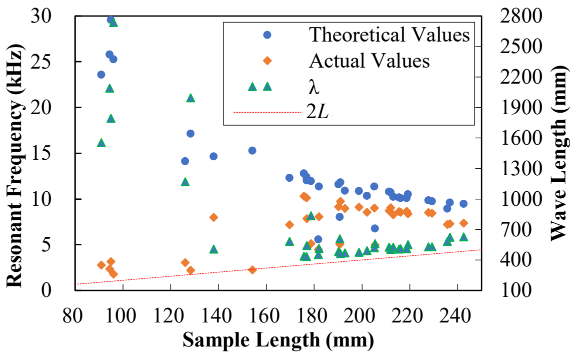

Fig. 3. Relationship between theoretical and actual value.

4. Conclusions

In this study, the dynamic elastic modulus is calculated using the resonance vibration method and P-wave velocity, and the degree of damage to concrete cores is evaluated. The resonance vibration method tends to overestimate damage degree in concrete cores compared to the P-wave velocity, and it is confirmed that accurate damage assessment cannot be achieved when the aspect ratio falls below a certain threshold due to deviation from longitudinal oscillation.

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