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Basic study of measurement for fire damage level of concrete using high-intensity aerial ultrasonic waves

強力空中超音波を用いたコンクリートの火害度推定の検討

Ayumu Osumi[1‡], Yasuhiro Nojima[1] and Youichi Ito[1] ([1]Coll.Sci. and Tech., Nihon Univ.)
大隅 歩[1‡], 野嶋 泰宏[1], 伊藤 洋一[1] ([1]日大 理工)

1. Introduction

In this study, we consider a new method[1-3] is a nondestructive, contactless inspection for detecting fire damage level of concrete by analyzing frequency information obtained from the vibration of concrete excited with high-intensity ultrasonic waves (frequency: 27 kHz). In this report, we clarify the relationship between sound pressure and vibration velocity on the surface of the object. We also use this method to estimate fire damage level of concrete.

2. Experimental set up and method

Figure 1 shows a schematic view of the experimental setup. The ultrasonic waves (frequency: 26.8 kHz) radiated from a point converging ultrasonic source[4] are focused onto a circular area, 10 mm in diameter at a distance of 130 mm from this acoustic source.

Figure 2 shows, for a free field, the characteristics of sound pressure at the convergence point, analyzed using a fast Fourier transform spectrum analyzer. The intensity of this ultrasonic waves is about 5 kPa at an input power of 15 W. In addition, the figure shows that the sound pressure at the fundamental frequency (26.8 kHz) increases in proportion to the 1/2 power of input power, while the sound pressure for the higher harmonics increases in proportion to a higher order of input power.

In this measuring system, the surface of a sample is vertically set to coincide with the *x*-axis. The sample was continuously irradiated with ultrasonic waves, and the vibration velocity on the surface of the irradiated sample was measured with a laser Doppler vibration meter (LDV) located behind the acoustic source. The laser beam gets through the acryl pipe in the experimental device because sound waves from the vibration plate have the potential to affect the LDV laser (Fig. 1). The frequency of the measured vibration velocity was analyzed with a fast Fourier transform spectrum analyzer.

3. Sound pressure and vibration velocity on the surface

We examined the relation between sound pressure and vibration velocity on the surface of an object at the same measurement point when the relationship distance between the sound source and the object changed along the *x*-axis. The sound pressure is measured using probe microphones (diameter: 1 mm) and the vibration velocity is simultaneously measured using LDV. In this experiment, we used an acrylic plate with thickness of 30 mm and dimensions of 150 mm × 150 mm as the measurement target.

Figure 3 shows the results. The sound pressure and vibration velocity at each frequency change with the distance from the sound source, and sound pressure peaks appear periodically because a resonance system is formed between the sound source and the object. In addition, the vibration velocity distribution at each frequency corresponds with the sound pressure distribution.

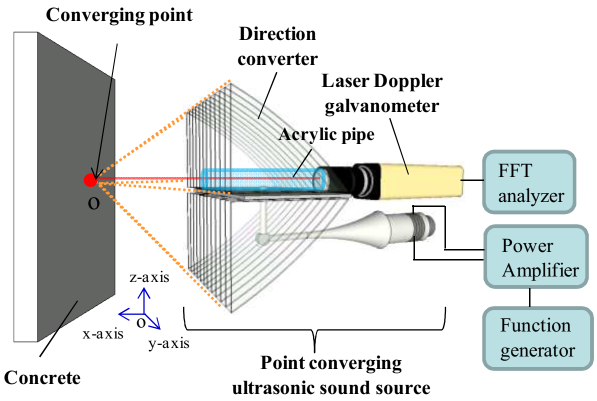

Fig. 1 Schematic of the experimental device

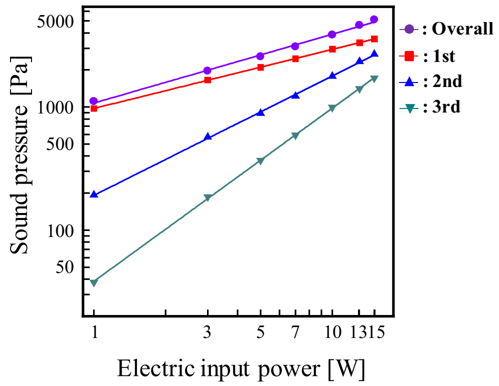

Fig. 2 The characteristics of sound pressure at the convergence point (fundamental frequency and harmonic frequencies)

E-mail:oosumi@ele.cst.nihon-u.ac.jp

4. Detect fire damage of concrete

We aimed to detect fire damage level of concrete samples. In Fig. 3, points P1 and P2 are the maximum and minimum points, respectively, of the sound pressure and vibration velocity at the surface of the object. The 50-mm-thick concrete sample has dimensions 120 mm × 80 mm. We prepared a burning concrete sample (BCS) by using an electric furnace. BCSs were exposed to temperature of about 800 ºC for 30 min, after which they were suddenly cooled for 5 min in water and then naturally dried in air for 120 min, as in an actual fire site.

Figure 4 shows characteristics of vibration velocity when the normal concrete sample (NCS) is set at points P1 and P2. The vibration velocity when the concrete sample is set at point P1 is larger at each frequency than when the concrete sample is set at point P2. We also examined BCS in the same experiment. The result followed the same trend as in Fig. 4.

Figure 5 shows the distortion rate of the NCS and BCS vibration velocity at points P1 and P2. In this experiment, the distortion rate is defined as the ratio between the square root of the sum of the vibration velocities of second and third harmonic components and the vibration velocity of the fundamental frequency. As a result, the distortion rate of BCS is larger than that of NCS. Therefore, we considered the BCS as having fire damage because the strength of the concrete decreased when exposed to higher temperature and the vibration of concrete occurred more easily at each frequency. In addition, while the distortion rate at point P1 is a little larger than at point P2, both results are almost no difference. Therefore, it is not almost necessary to consider the distance between the sound source and the object in order to detect the fire damage level of concrete if attention is focused on the distortion rate of vibration velocity in the actual measurements.

5. Conclusion

We investigated the relationship between sound pressure and vibration velocity on the surface of an object, and we used this method to detect fire damage level of concrete. As a result, it is found that sound pressure and vibration velocity at each frequency change with the distance from the sound source, because a resonance system is formed between the ultrasonic sound source and the object. In addition, the vibration velocity distribution at each frequency corresponds with sound pressure distribution. Moreover, it is possible to detect fire damage level of concrete without considering the distance between the sound source and the object in the actual measurement if attention is paid to the distortion rate of vibration velocity.

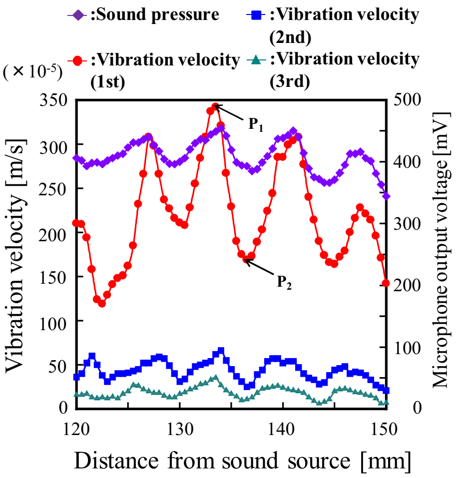

Fig.3 Sound pressure and vibration velocity on the surface of an object at various distances to the acoustic source

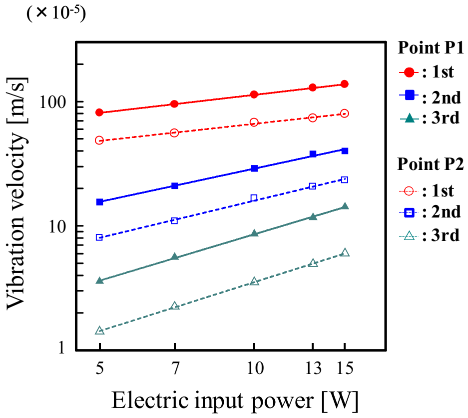

Fig. 4 Relationship between vibration velocity and electric input power at points P1 and P2 (NCS)

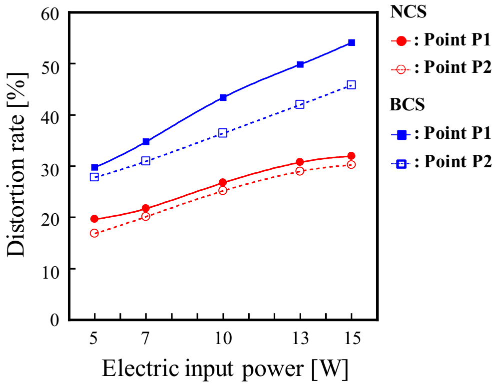

Fig. 5 Relationship between distortion rate of vibration velocity and electric input power at point P1 and P2 (NCS and BCS)

References

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