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Detection of internal defects in concrete and evaluation of a healthy part of concrete by non-contact acoustic inspection using normalized spectral entropy

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Introduction

Non-Destructive Testing method applying the principle of entropy : By our noncontact acoustic inspection [1-4], internal defects of composite materials, especially concrete structures such as tunnels, bridges, buildings, can be detected and visualized in a non-contact and non-destructive manner. Our method can detect and visualize internal defects (up to a depth of about 8-10 cm from the surface) from a distance of 5-33m. Maintenance and inspection are required for concrete structures because they have internal defects such as cracks or peelings due to aging and salt damage, and their durability is weakened. To detect the internal defects of concrete structures, we have proposed the defect detection algorithm that combines spectral entropy and vibrational energy ratio. In our measurement, a strong aerial sound waves are irradiated to the measured surface, then shallow layer is forcibly vibrated, and a two-dimensional vibration velocity distribution is measured using a high-precision scanning laser Doppler vibrometer. Using properties of spectral entropy, data analysis is performed. If an internal defect exists, for an example, in a case of hollow defect, a slight flexural vibration occurs in a shallow layer, and internal defects are detected and visualized by noticing a slight difference in vibration between the defects and a healthy part of concrete. Under the same measurement conditions and for the same measurement object, spectral entropy shows similar value and fluctuation. But under a different measurement condition or object, the magnitude and fluctuation range of spectral entropy values change, and it is not possible to compare and examine in the same field. Therefore, we examined to normalize spectral entropy, as a unified index even for a different target and under different measurement conditions, in order to detect defect or evaluate a healthy part of concrete.

Experimental setup

Figure 1 shows an experimental setup for noncontact acoustic inspection. The target concrete surface is vibrated by acoustic irradiation excitation using aerial plane sound wave from a long range acoustic device (LRAD300X, LRAD) and the vibration velocity distribution on the measurement surface is measured by a scanning laser Doppler vibrometer (PSV-500Xtra, Polytec). The obtained vibration velocity waveform data was analyzed to detect and visualize internal defects.

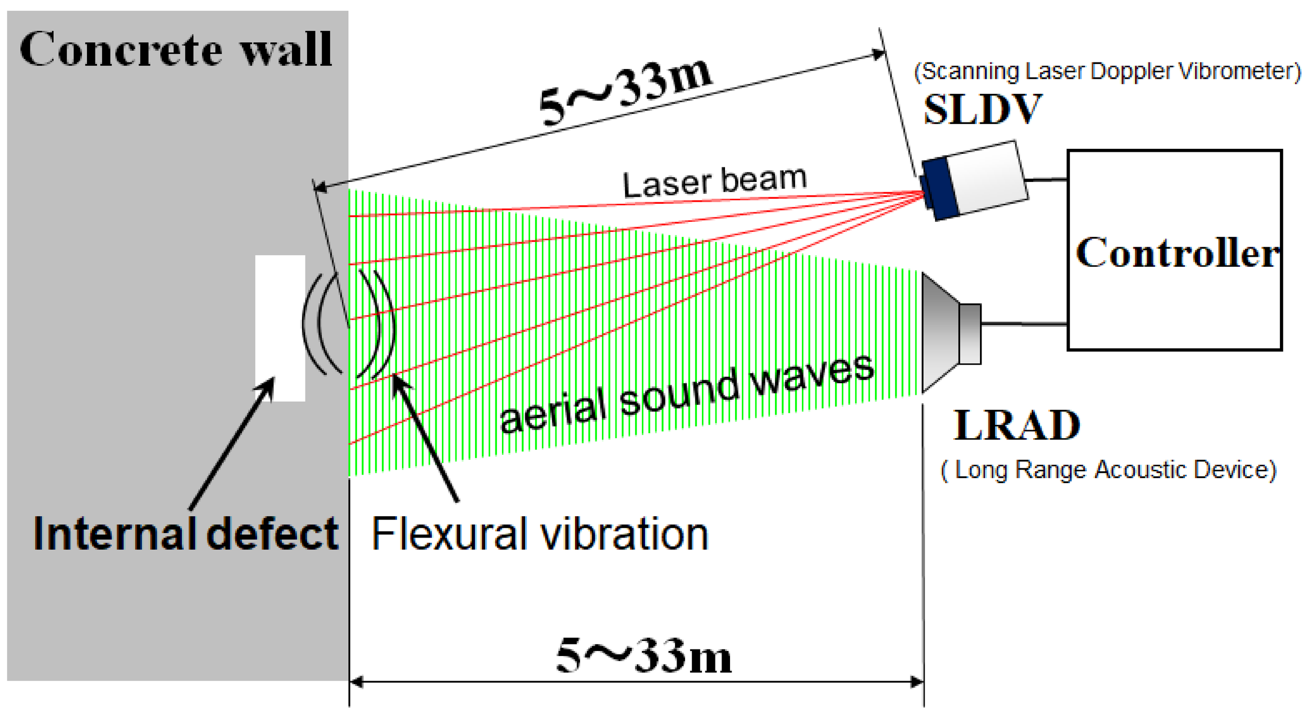

Fig.1 Experimental setup

Normalized spectral entropy

Spectral entropy is a feature quantity that represents the whiteness of a signal. A signal with a uniform spectrum such as white noise has a high value, and a signal with a non-uniform spectrum such as an audio signal has a low value. The normalized spectral entropy is expressed by the following equation.

$$H = \frac{\sum_f P_f \log_2 P_f}{\log_2 N} \qquad P_f = \frac{S_f}{\sum_f S_f}$$

S_f is power spectrum of vibration velocity at a measurement point. N is the number of sampling points. The information entropy is calculated by regarding the spectrum of signal as a probability distribution.

Vibrational energy ratio

Vibrational energy ratio is represented as the following equation:

$$[VER]_{dB} = 10\log_{10}\frac{\int_{f_1}^{f_2}(PSD_i)df}{\int_{f_1}^{f_2}(PSD_{health})df}$$

PSD : Power Spectral Density

As shown in Fig. 2, at a healthy part, two resonance peaks due to a laser head are seen. At defective part, resonance peaks due to internal defects are also seen. Vibrational energy at a defective part or a healthy part of concrete is calculated by integrating in a measuring frequency range, except for the resonance frequency of a laser head. Then, the ratio of vibrational energy at each measuring point to a healthy part is obtained.

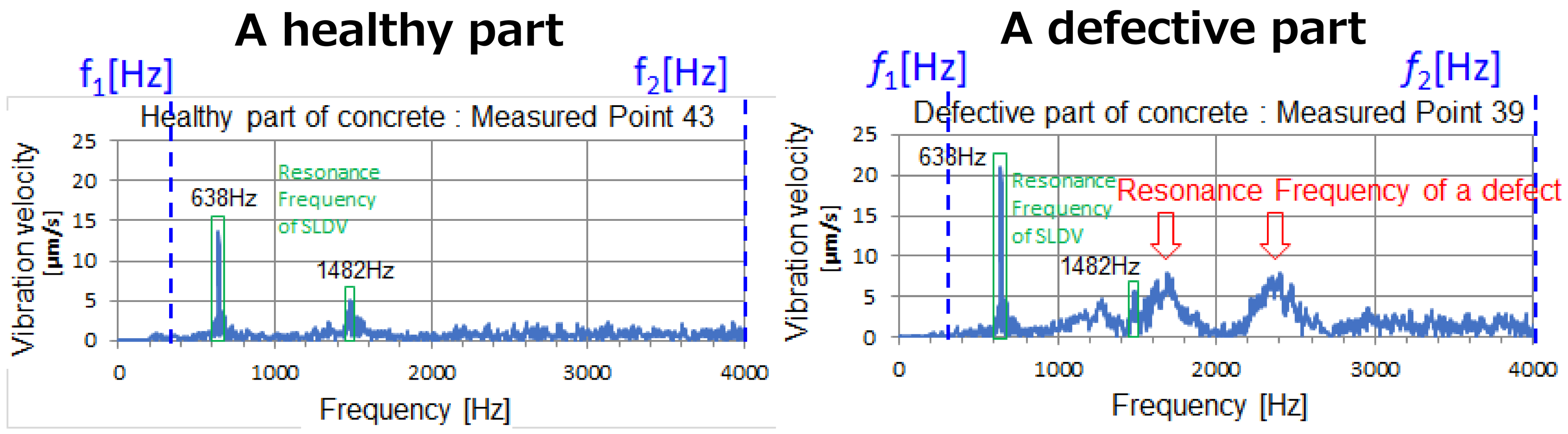

Fig.2 An example of detected vibration velocity spectrum (SLDV: Polytec, PSV-500Xtra)

Defect detection and result

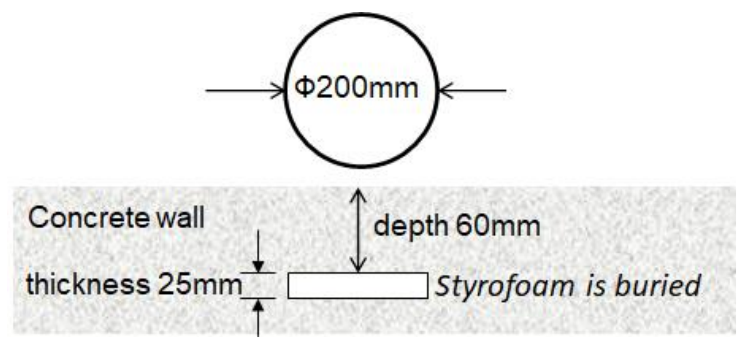

Fig.3 A circular cavity defect

As shown in Fig.3, to imitate a circular cavity defect with a diameter of 200 mm, styrofoam is buried in concrete at a depth of 60 mm.

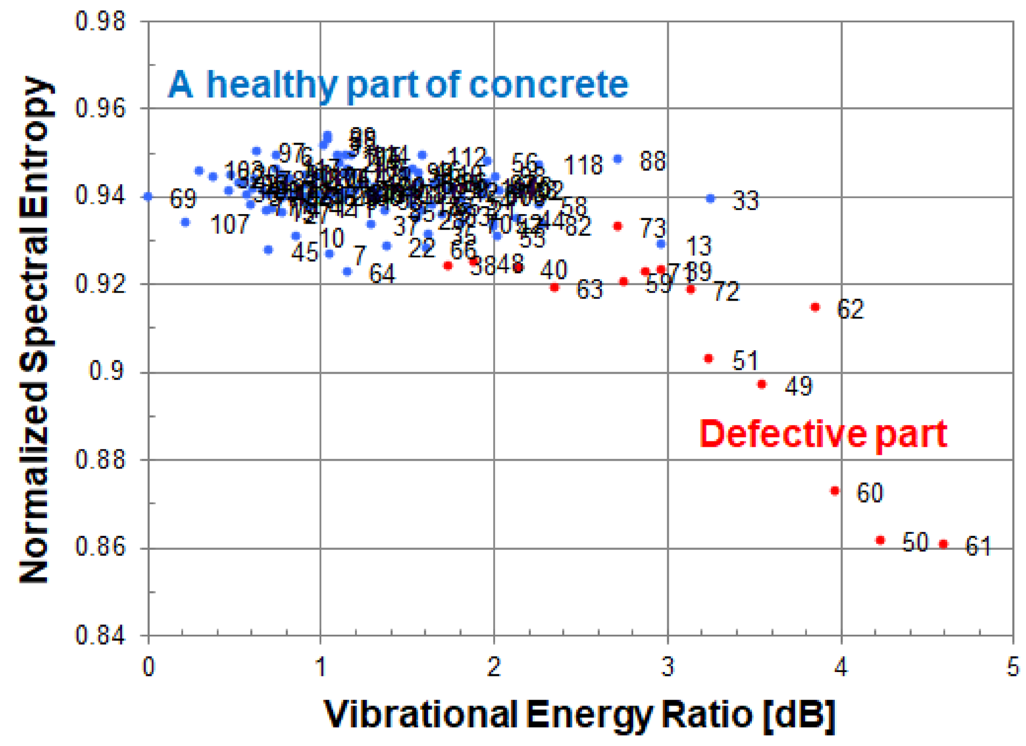

Fig.4 Scatter plot of normalized spectral entropy and vibrational energy ratio

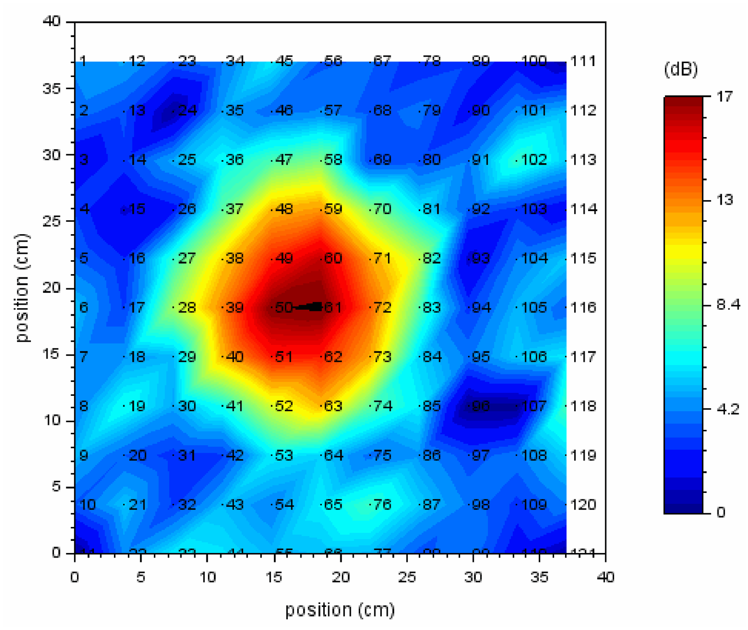

Fig.5. Acoustic image of a circular cavity defect

Table 1. Trends in acoustic features for defect detection

	Healthy part	Defective part
Normalized spectral entropy	high	low
Vibrational energy ratio	low	high

Fig.4 is a scatter plot, the vertical axis is normalized spectral entropy and the horizontal axis is vibrational energy ratio. A healthy part and defective parts can be separated by using two acoustic features. As shown in table 1, they are identified by combination of the value magnitude of two acoustic features. Fig.5 is an acoustic image of a circular cavity defect.

Conclusion

A healthy part and defective parts can be separated by using two acoustic features, that is, normalized spectral entropy and vibrational energy ratio. A normalized spectral entropy was introduced to evaluate the vibrational state of a healthy part of concrete. It shows a value of [0,1]. It is possible to make a comparison each other with a different actual concrete structure under a different measurement condition.

Acknowledgment

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