Defect detection of noncontact acoustic inspection using spectral entropy and spatial spectral entropy
スペクトルエントロピーと空間スペクトルエントロピーによる非接触音響探査の欠陥検出

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1. Introduction

In our noncontact acoustic inspection[1)], we have been studying a method to detect internal defects in composite materials in a remote manner without contact. This time, we investigated the internal defects of a shotcrete structure, analyzed the data using SSE analysis, and compared the result with the hammering test.

2. Experimental method

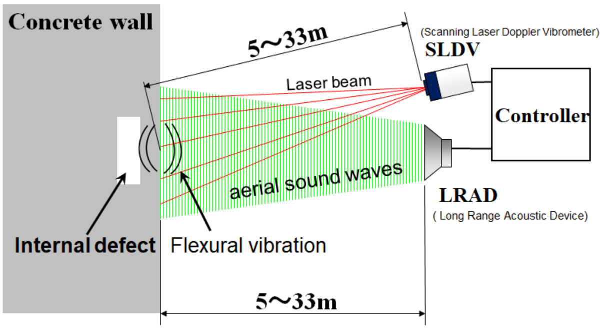

Fig. 1 Experimental setup.

In order to detect Internal defects of shotcrete, strong plane waves were irradiated from a long-range acoustic device (LRAD; LRAD corp., LRAD-300X) set at a distance of about 2.9 m from the measured plane, and the measuring surface of shotcrete was acoustically excited. A scanning laser Doppler vibrometer (SLDV; Polytec, RSV-500Xtra scanning vibrometer) was installed at a distance of about 7.33 m from the measured surface, and the two-dimensional vibration velocity distribution on the measured plane was measured. After time-frequency gate processing to reduce noise from surroundings, vibration velocity spectrum was calculated. Transmit waveform is multi-tone burst wave (transmission frequency range 300-2000Hz, modulation frequency 100Hz, interval time 30ms, pulse width 5ms, duration time of waveform 270ms).

3. SSE (Spatial Spectral Entropy) analysis[4)]

Using all the vibration velocity spectrum at each measured point, SSE analysis can detect not only the resonance frequency of internal defects of concrete but also the resonance frequency of a laser head of SLDV. SSE was defined by the following equation.

$$H_{SSE}(f) = -\sum_{i=1}^{m}\sum_{j=1}^{n} P_{i,j}(f)\, log_2\, P_{i,j}\,(f) \qquad (1)$$

$$P_{i,j}(f) = \frac{S_{i,j}(f)}{\sum_{i=1}^{m}\sum_{j=1}^{n} S_{i,j}(f)}$$

Where $H_{SSE}(f)$ is spectral entropy extended to real space. $S_{i,j}(f)$ is the frequency component of power spectrum of vibration velocity at each measurement point$r_{i,j}$. $P_{i,j}(f)$ is probability that $S_{i,j}(f)$ exists in the measured plane. Therefore, $H_{SSE}(f)$ indicates the information entropy calculated for the frequency component f of vibration velocity spectrum at all measured points.

4. Experimental analysis results

Shotcrete is constructed by spraying concrete, and the surface is uneven. Inside the underground facility, shotcrete wall was measured at the arch leading to the side wall from the ceiling. Fig.2 shows CCD camera image of the measured surface of shotcrete. According to the hammering test, the blue line running vertically showed cracks, and there was a float in the area surrounded by the white line.

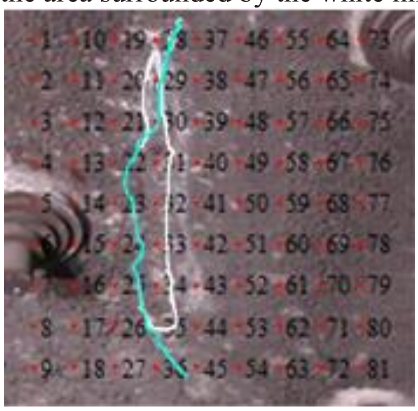

Fig. 2　CCD camera image of the measured surface. Red + is the measured point and the number next to it is the measured point number.

Fig.3 is an acoustic image of internal defects

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of shotcrete. This result matches the result of the hammering test at terms of the location of cracks or a float in Fig.2. The ellipse at the left end of Fig. 3 shows the position of the bolt that crimps bedrock and shotcrete.

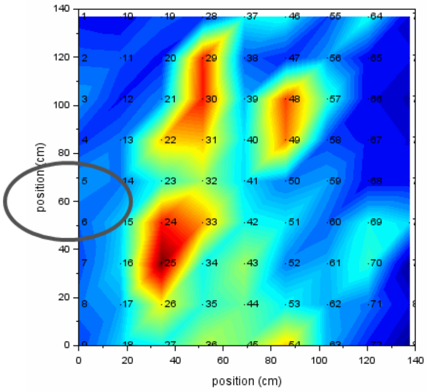


Fig. 3 Acoustic image of internal defects in shotcrete.

Fig.4 shows a scatter plot using spectral entropy and vibrational energy ratio on the vertical or the horizontal axis. Our previous studies[2,3] have shown that a healthy part of concrete tends to have low vibrational energy ratio and high entropy, and a defective part tends to have high vibrational energy ratio and low entropy. Similar result was obtained for shotcrete.

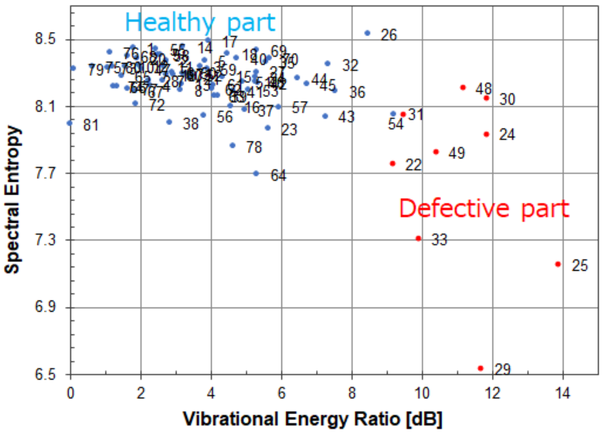


Fig. 4 Correlation diagram of spectral entropy and vibration energy ratio.

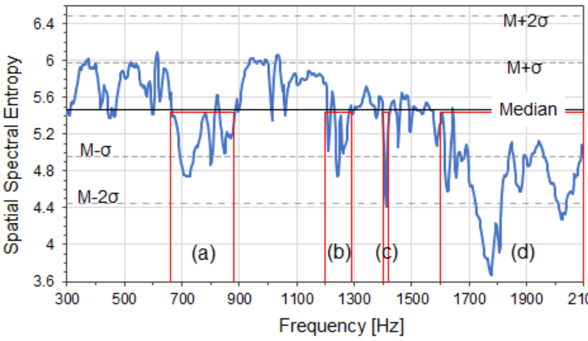
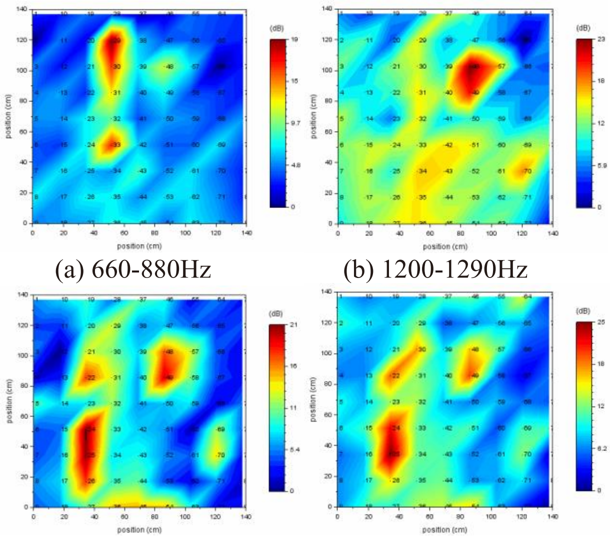


Fig. 5 SSE analysis result.

Figure 5 shows SSE analysis result. The median indicates the median of distribution of SSE values in the transmission frequency range. M, σ show median and its standard deviation, respectively. Focus on the frequency range where SSE value is below the median, and each frequency range are considered as resonance frequency band. The imaging frequency range (a) to (d) in Fig.6 is set to each resonance frequency band. Fig.6 shows acoustic images of internal defects at each resonance frequency band.



(a) 660-880Hz (b) 1200-1290Hz

(c) 1400-1420Hz (d) 1600-2100Hz

Fig. 6 Acoustic images of internal defects at each resonance frequency band.

In the hammering test, high vibration amplitude was detected around 637 Hz, and cracks or float were detected in the vertical direction. The position and size of defect agree well with the high vibration energy area in Figs. 6(a), (c), and (d).

5. Conclusions

The analysis method we have performed is effective not only for ordinary concrete with smooth surface but also for shotcrete. One of our analysis methods can distinguish between a defective part and a healthy part using vibrational energy ratio and spectral entropy, and another is SSE analysis which can detect resonance frequency of internal defect. By combining the two, a clear visualization of internal defects can be achieved.

Acknowledgment

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References

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