# 1Pa2-7

# Defect detection of shotcrete specimen by noncontact acoustic inspection using spatial spectral entropy

Kazuko Sugimoto† and Tsuneyoshi Sugimoto†† (Grad. School Eng., Toin Univ. of Yokohama)

## 1. Introduction

Noncontact acoustic inspection method has been studied in a non-contact, non-destructive, a remote manner to detect and visualize internal defects in composite materials, especially concrete. Shotcrete is used for large-scale concrete structures. This time, precise frequency analysis is realized by preparing a shotcrete specimen and performing SSE analysis by removing outliers exceeding 3σ in order to eliminate the influence of unevenness on the surface of shotcrete.

## 2. Experimental method

2.1 An experimental setup of noncontact acoustic inspection method [1,2] is shown in Fig.1. Strong aerial plane waves are emitted from a long-range acoustic device (LRAD; Genasys Inc.; LRAD-300X) to the measurement surface about 5 m away and the surface are acoustically excited. A scanning laser Doppler vibrometer (SLDV; Polytec; PSV-500Xtra) are installed at a distance of about 5.6 m from the measurement surface, and the two-dimensional vibration velocity distribution on the measurement surface was measured. After time-frequency gate processing to reduce noise from surroundings, vibration velocity spectrum was calculated.

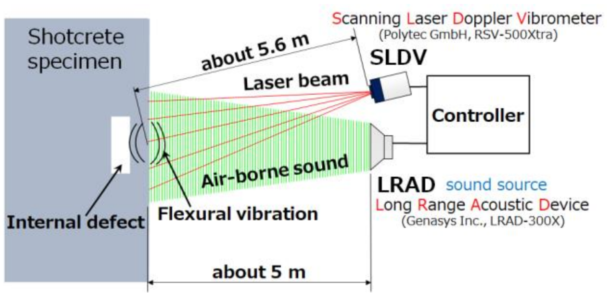


Fig. 1 Experimental setup.

2.2 Shotcrete specimen with three circular cavity defects embedded was manufactured as shown in the design drawing of Fig. 2. Styrofoam with a thickness of 10 mm was installed on a concrete cylinder, and it was made by a manual spraying process so that the cover thickness was 40, 60, 80 mm. The notation (Φ200, 40) indicates that the diameter of a circular cavity defect is 200 mm and the cover thickness is 40 mm.

†kazukosu@toin.ac.jp, ††tsugimot@toin.ac.jp

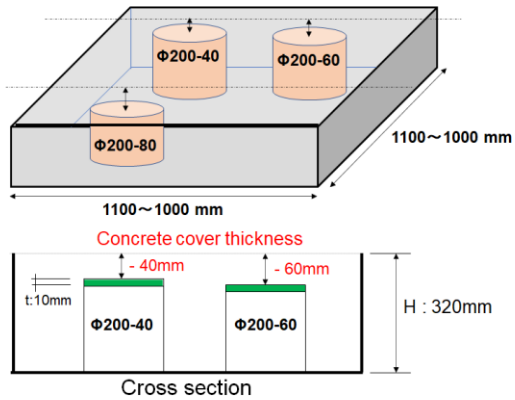


Fig. 2 Shotcrete specimen.

## 3. Analysis method

3.1 Normalized Spatial Spectral Entropy (SSE) [3,4] can detect not only the resonance frequency of internal defects but also the resonance frequency of a laser head of SLDV. Normalized SSE is defined by the following equation.

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

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

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 $f$ component of vibration velocity spectrum at all measured points.

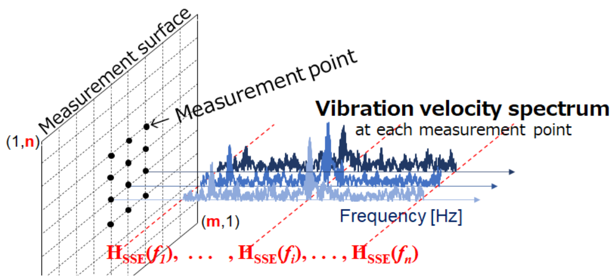


Fig. 3 SSE principle explanatory diagram.

Fig. 3 is an explanatory diagram of the principle of SSE analysis. m and n are the number of measurement points in the horizontal and vertical directions of the measurement grid surface. Due to normalization of SSE, the SSE value fluctuates in the range of [0,1].

3.2 The amount of laser return light may decrease depending on the surface condition (reflectance, unevenness, etc.) of the measurement target, and optical noise due to light reception leakage may occur. In such a case, an apparently large vibration velocity is observed. Preprocessing of probability statistics for SSE analysis is showed in Fig.4. Figure 4 (a) is an image of matrix, in which the measured vibration velocity spectrum components are arranged by taking the analysis frequency in the vertical direction and the measurement point number in the horizontal direction. As shown in Fig. 4 (b), a frequency distribution can be drawn for the vibration velocity spectrum component of all measurement points for each frequency. The extremely large vibration velocity component in the frequency distribution is detected as an outlier. Actually, the detected outliers are not excluded, but replaced with the average value of the distribution, and SSE analysis is performed to detect the resonance frequency band.

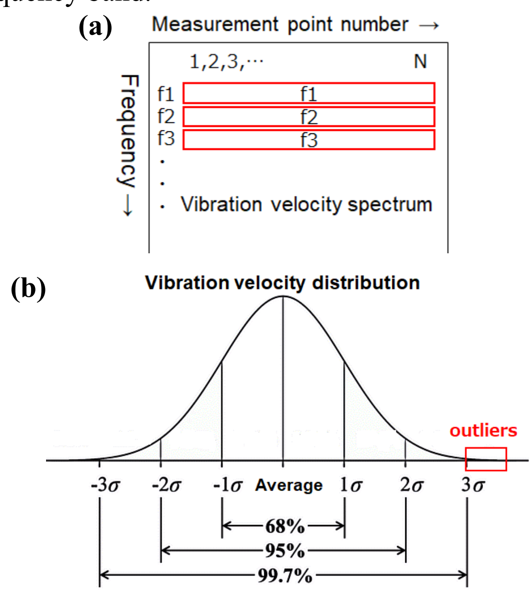


Fig. 4 Preprocessing to remove outliers over 3σ.

## 4. Experimental & analysis results

Figure 5 shows the result of SSE analysis. The horizontal axis is the frequency and the vertical axis is the SSE value. The median of the SSE value fluctuation is shown by the black horizontal line. There is a frequency band of internal defect in the frequency band where the SSE value is decreasing, and it is surrounded by a red frame. Figure 6 shows an acoustic image by calculating vibration energy ratio in these frequency bands. The black dotted circle line indicates the exact size of the circular defect and its approximate location. The deeper the depth, the worse the image, but defects at any depth can be distinguished from healthy part of concrete.

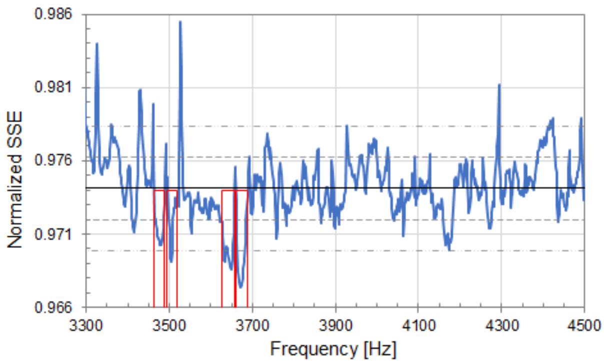


Fig. 5 The result of SSE analysis.

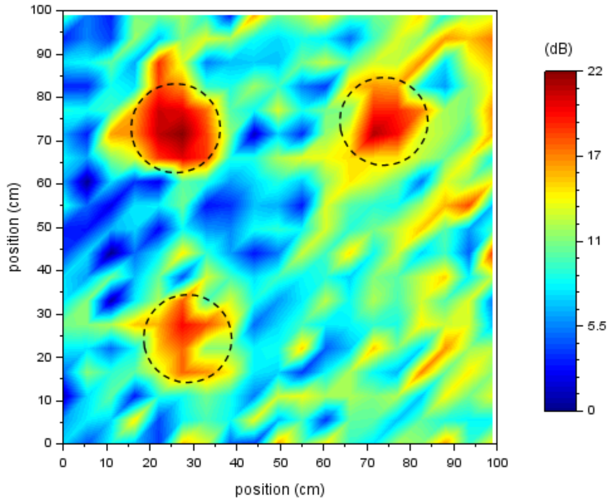


Fig. 6 The acoustic image of internal defect.

## 5. Conclusion

In order to reduce the effect of unevenness on the surface of shotcrete in laser measurement, the detectability of the resonance frequency band of internal defects is maintained by performing SSE analysis after removing the outliers of the vibration velocity distribution. It is confirmed to be able to detect and visualize the circular cavity defects with a depth of 40, 60, 80 mm and the diameter of 200 mm.

**Acknowledgment**

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**References**

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