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Investigation of Propagation Velocity Distribution of Surface Acoustic Waves inside Fire-damaged Mortar by Numerical Simulation

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1. Introduction

The fire damage diagnosis of concrete structures is very important to determine the scale of repair. In a previous study[1)], we have studied the non-contact and non-destructive method to diagnose the fire damage by using high-intensity airborne ultrasounds.

In this report, we investigated the fire damage distribution inside the fire-damaged mortar by numerical simulation. Specifically, we estimated the propagation velocity distribution of surface acoustic waves by applying the block matching method to the simulation results.

2. Principles of fire damage diagnosis applying block matching method

2.1 Surface acoustic waves propagation inside fire-damaged mortar

The propagation velocity C_R of surface acoustic waves of an isotropic medium is given by

$$C_R = \frac{0.87 + 1.12\nu}{1+\nu}\sqrt{\frac{E}{\rho}\cdot\frac{1}{2(1+\nu)}}, \qquad (1)$$

where E is its elastic modulus, ρ is its density, and ν is its Poisson's ratio.

In general, the moisture inside the mortar evaporates when that is heated at high temperatures. Due to the above phenomenon, fine voids appear inside the mortar. Therefore, the elastic modulus of the mortar is largely decreased. In addition, the density of the mortar is slightly decreased.

That is, Eq. (1) indicates that the propagation velocity of surface acoustic waves relatively decreases inside the fire-damaged mortar. From the above, the degree of the fire damage can be estimated from the propagation velocity. Therefore, the fire damage distribution can be estimated from the propagation velocity distribution.

2.2 Block matching method

The block matching method[2)] can estimate the displacement based on the function to evaluate the similarity between signals in two frames. In this study, the Sum of Absolute Difference (SAD) function was used as an evaluation function.

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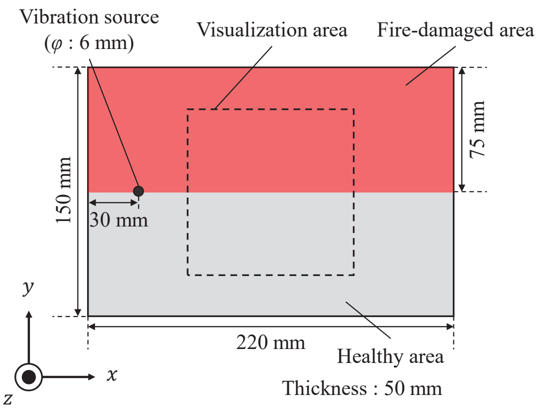


Fig.1 Top view of the simulation model.

Table I Material Properties.

Area	Healthy area	Fire-damaged area
Elastic modulus[GPa]	25	5.01 ~ 14.55 (Fig. 2)
Density[kg/m^3]	2300	2070
Poisson's ratio	0.20	0.10

Table II Simulation conditions.

Frequency [kHz]	80
Preassure [Pa]	100
Input signal	Sinusoidal wave
Number of cycles	10
Number of elements	About 220,000
Mesh shape	Tetrahedron
Time resolution [μs]	1

First, the signal of the frame at the time t is defined as $s(x, y, t)$, where (x, y) are horizontal and vertical positions of a certain point, respectively. The signals of the frames at the time t_0 and t_1 are multiplied by the spatial window $w(i,j)$ centered on (x,y) to obtain a template signal T_0 and a target signal T_1. The template signal is shifted two-dimensionally in the search area of the frame at the time t_1, and the SAD function between the template signal and the target signal at each position is evaluated. The SAD function is given by

$$SAD(m,k) = |T_1 - T_0|$$
$$= \sum_{i=-w_x}^{w_x}\sum_{j=-w_y}^{w_y} |w(i,j)s(i+m,j+k,t_1) - w(i,j)s(i,j,t_0)|, \qquad (2)$$

where the $SAD(m,k)$ is the SAD function of these signals of the frames at the time t_0 and t_1.

This algorithm searches for the combination of m and k with the minimum SAD function as an estimated displacement. The estimated displacement divided by the time interval of two frames is a motion velocity. In this report, the motion velocity equals the propagation velocity of surface acoustic waves.

3. Numerical simulation

Figure 1 shows a simulation model. The simulation model comprised of a healthy area and a fire-damaged area. The dimensions of the simulation model were 150 mm × 220 mm × 50 mm. In addition, the lower half area of the simulation model was the healthy area, and the upper half area of that was the fire-damaged area. **Table I** shows the material properties of the simulation model. The elastic modulus of the fire-damaged area was simulated using the elastic modulus distribution[3] shown in **Fig. 2**. In addition, **Table II** shows the simulation conditions. The vibration source is the location shown in Fig. 1.

Finally, the block matching method was applied to the simulation results.

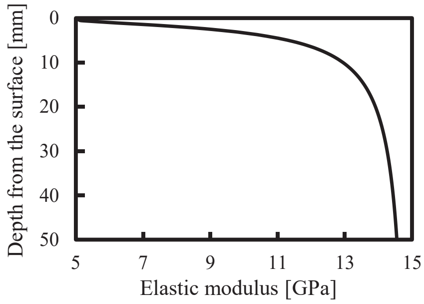
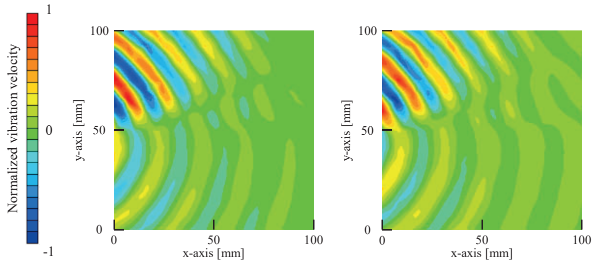


Fig.2 Elastic modulus of fire-damaged area.



(a) $t_0 = 100$ µs. (b) $t_1 = 105$ µs.

Fig.3 Distribution of vibration velocity.

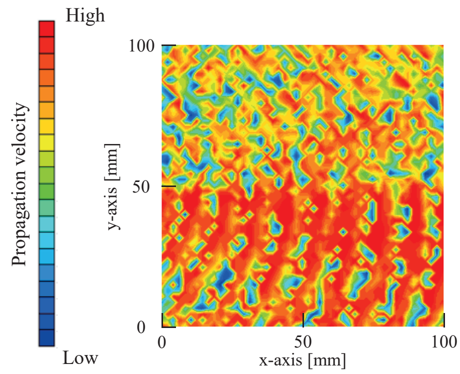


Fig.4 Distribution of Propagation velocity.

4. Result

At first, **Fig. 3** shows the vibration velocity distribution in the dotted frame (Fig. 1) obtained by the numerical simulation. Fig. 3 (a) and (b) show the results at $t_0 = 100$ µs and $t_1 = 105$ µs, respectively. Here, t_0 and t_1 are shown in Eq. (2). As the results, surface acoustic waves propagate inside the simulation model. In addition, it is confirmed that the wavelength in the lower half area (healthy area) is longer than that in the upper half area (fire-damaged area).

Next, **Fig. 4** shows the propagation velocity distribution estimated by applying the block matching method to the results of Fig. 3 (a), (b). The colormap shows the propagation velocity of surface acoustic waves. As the results, it is confirmed that the propagation velocity in the fire-damaged area is slower than that in the healthy area.

Therefore, we demonstrated the effectiveness to diagnose the fire damage distribution by applying the block matching method.

5. Conclusion

In this report, we investigated the visualization of the propagation velocity distribution of surface acoustic waves applying the block matching method to the fire damage distribution inside the mortar sample by numerical simulation. As the results, we demonstrated to realize the visualization of the propagation velocity distribution of surface acoustic waves in the healthy area and the fire-damaged area. This shows that the possibility of the fire damage distribution diagnosis by applying the block matching method.

Acknowledgment

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References

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