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Cavity position and size identification using the observed sound pressure in hammering test based on the adjoint variable and the finite element methods

Takahiko Kurahashi[1], Eiki Matsuoka[1], Youichi Hirose[1], Yuki Murakami[2], Shigehiro Toyama[2], Fujio Ikeda[2], Tetsuro Iyama[2] and Ikuo Ihara[1]

[1] Nagaoka University of Technology, 1603-1, Kamitomioka-machi, Nagaokashi, Niigata, 940-2188, Japan, kurahashi@mech.nagaokaut.ac.jp

[2] Nagaoka Institute of Technology, Nagaoka College, 888, Nishikatakai-machi, Nagaoka-shi, Niigata, 940-8532, Japan

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1 Introduction

In this study, we present the identification of the cavity position and the cavity size in structures based on the adjoint variable and the three dimensional finite element methods. The performance function is defined by square sum of residual between the observed and the computed sound pressure, and the unknown cavity position and cavity size is obtained by the iterative calculation of the minimization of the performance function. The observed sound pressure is measured by using the microphone in hammering test[1]. The formulation is carried out by the adjoint variable and the finite element methods[2]. The wave equation is adopted as the governing equation. Some case studies for the identification of the cavity position and the cavity size for a partial problem is shown in this study.

2 Identification of cavity position and size based on the adjoint variable and the finite element methods

2.1 Governing equation

Formulation in the cavity position and size identification analysis is described below. In this study, the whole domain of the test piece is denoted as Ω. The sound pressure distribution p therefore satisfies the wave equation shown in Eq.(1).

$$\ddot{p} - c^2 p_{,ii} = 0 \tag{1}$$

For the wave equation, the initial condition and the boundary condition are defined as in Eqs.(2)-(5).

$$p = \hat{p} \quad \text{at} \quad t = t_0 \quad \text{in } \Omega \tag{2}$$
$$\dot{p} = \hat{\dot{p}} \quad \text{at} \quad t = t_0 \quad \text{in } \Omega \tag{3}$$

$$p = unknown \qquad \text{on } \Gamma_1 \tag{4}$$

$$b = c^2 p_{,i} n_i = \hat{b} \qquad \text{on } \Gamma_2 \tag{5}$$

where c, n_i Γ_1, Γ_2 and Γ_3 denote wave velocity, unit normal vector, input signal point, outer boundary and boundary on cavity surface, respectively. The boundary definition and the finite element mesh used in this study are shown in Fig. 1. Hat mark indicated the known value.

2.2 Definition of performance function and stationary condition

The performance function is defined as shown in Eq.(6).

$$J = \frac{1}{2} \int_{t_0}^{t_f} \int_{\Omega} (p - p_{obs.})\, Q\, (p - p_{obs.})\, d\Omega dt \tag{6}$$

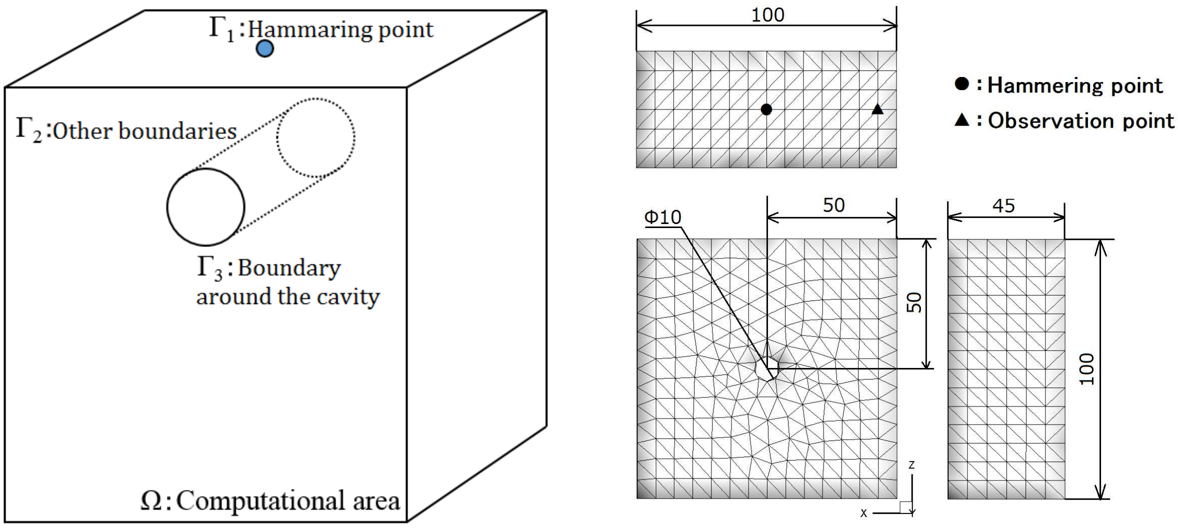
where t_0, t_f, $p_{obs.}$ and Q indicate initial time, terminal time, observed sound pressure and weighting constant, respectively. The weighting constant is set 1 at node of the observation point, and is set 0 at the other nodes. The problem is to find the appropriate the cavity position and size so as to minimize the performance function J. The physical meaning of minimization of the performance function is that the computed sound pressure is close to the observed sound pressure. The performance function is calculated based on the governing equation and the initial condition and the boundary condition. Therefore, this is a minimization problem with constraint conditions, and the adjoint variablem method is introduced. The detail of the formulation based on the adjoint variable method is shown in reference[2]. Apart from the cavity position and the cavity size, The unknown input sound pressure on $Gamma_1$ is also identified based on the adjoint variable method.

3 Numerical experiments

The boundary definition and the finite element mesh is shown in Fig.1, and the computational condition is shown in Tab.1. In the test piece, the distance from the top surface to the cavity center is 30mm, and the diameter of the cavity is 15mm, and the sound pressure is measured by microphone at the observation point. As the initial condition in the identification analysis, the distance from the top surface to the cavity center is set 50mm, and the diameter of the cavity is 10mm. This initial condition is determined based on the result of the self-organizing map[3]. Consequently, the time history of the sound pressure at the observation point was obtained by the iterative computation as shown in Fig.2. It is seen that the computed sound pressure is good agreement with the measured sound pressure. In addition, mesh configuration at 40 and final(50) iterations is shown in Fig.3. The cavity position was identified 35mm, and the cavity size was identified 12.14mm, respectively. Though the unknown parameters, i.e., the cavity position and size, was not completely agreement with the target values, it appears that the unknown parameters is appropriately identified.

4 Conclusions

In this study, identification of the cavity position and the cavity size was carried out based on the adjoint variable and the finite element methods in three dimensional model. The test piece of SS400 including a cavity was employed, and the time history of the sound pressure on the material surface was measured by microphone in the hammering



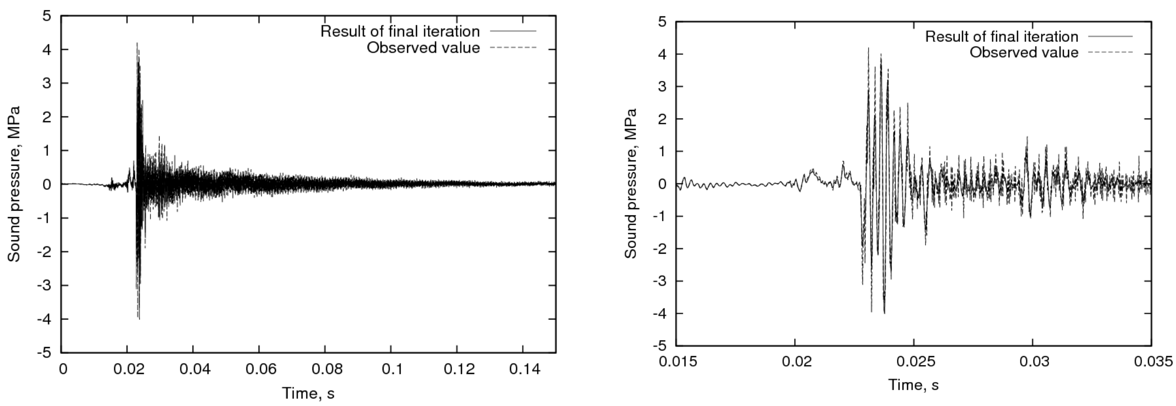
Boundary definition.

Finite element mesh.

Figure 1: Boundary definition and finite element mesh.

Table 1: Computational conditions.

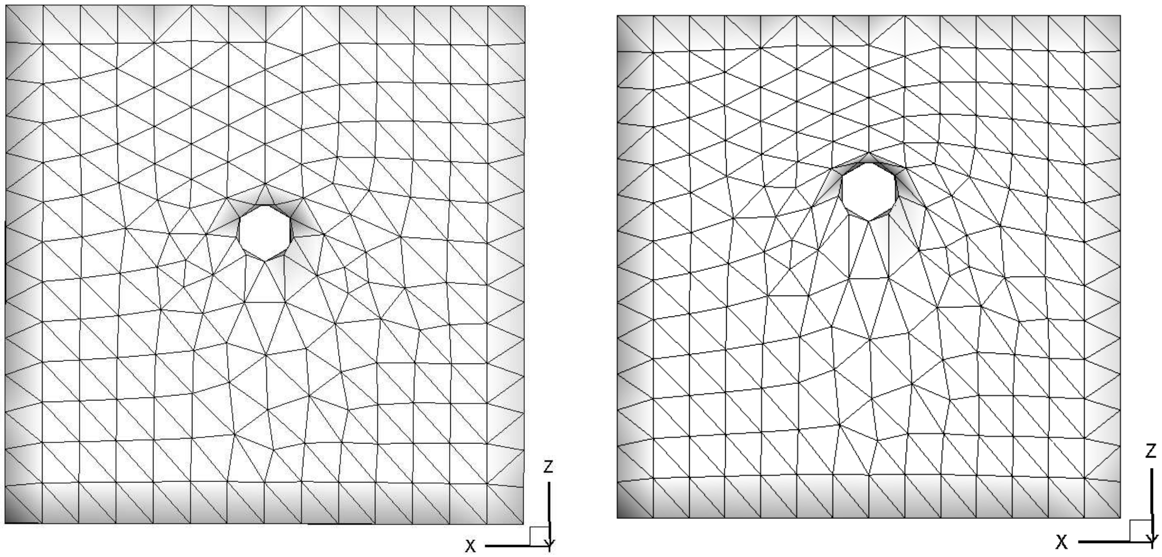
Total nodes	3544
Total number of elements	17312
Time increment Δt, s	0.000025
Wave velocity c, m/s	5106
Time step	6000
Sound pressure at the first iteration at hammering point, Pa	0.0
Convergence criterion 1 ε_1	10^{-3}
Convergence criterion 2 ε_2	10^{-7}



Comparison of sound pressure.

Magnified figure of left hand side figure.

Figure 2: Time history of sound pressure at observation point



Finite element mesh at 40 iterations. Finite element mesh at final iteration.

Figure 3: Variation of cavity position and size

test. As the governing equation, the wave equation was adopted, and was discretized by the finite element method. Consequently, the cavity position and the cavity size could be appropriately obtained by the iterative computation based on the steepest descent method. On the other hand, the cavity position and the cavity size was not completely identified to the target value due to the mesh distortion. Therefore, it is necessary to apply nodes relocation process in the iterative computation as the future work.

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