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Influence of experimental data and FE model on updating results of a brick chimney

T. Aoki [a,*], D. Sabia [b], D. Rivella [b]

[a] Graduate School of Design and Architecture, Nagoya City University, Kitachikusa 2-1-10, Chikusa-ku, Nagoya 464-0083, Japan
[b] Department of Structural and Geotechnical Engineering, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Turin, Italy

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Abstract

The present study deals with dynamic identification and model updating of the Howa brick chimney to preserve brick chimneys. From the results of dynamic tests, the fundamental frequencies of the Howa brick chimney are estimated to be about 3.06 Hz and 2.69 Hz in north–south and east–west directions, respectively. The natural modes and damping factors are identified by ARMAV (auto-regressive moving average vectors) model. The numerical model updating based on IEM (inverse eigensensitivity method) is applied to two models with two updating procedures; using only frequencies and both frequencies and mode shapes. The updating results show the mode shapes are very important to obtain the good results for the numerical model updating. From the results of the numerical model updating, the damaged areas are identified; these are found to correspond well to the position of the cracks of the static collapse test.

Keywords: Brick chimney; Dynamic test; Dynamic identification; ARMAV; IEM; Model updating

1. Introduction

Tokoname has been known for its ceramic ware production, and its history dates back to nearly a 1000 years. Even today, ceramics is one of the major industries in Tokoname where the tradition and culture of Tokoname ware are still alive. Until the first half of the Showa period, there were over 300 chimneys in Tokoname. Some of them were destroyed by typhoons and/or earthquakes. Unfortunately, due to their vulnerability to typhoons and/or earthquakes, chimneys that were not used were pulled down or reduced to half their height; therefore, the number of chimneys has now decreased to 119, including 45 perfect brick chimneys in January 2003 [1]. On the offshore waters of Tokoname, the Central Japan International Airport was opened on 17 February 2005.

Fig. 1a shows the Howa brick chimney and its proportion is standard in Tokoname. The Howa brick chimney was destroyed due to the construction of an access road to the Central Japan International Airport in January 2003. Fortunately, an opportunity to investigate this brick chimney presented itself. An electromagnetic radar was used in order to estimate the thickness of the chimney. As shown in Fig. 1b, its thickness varies at four points from top to bottom. A profile of the Howa brick chimney is shown in Fig. 1c. At the corners, four iron angles that measure 75 mm × 75 mm × 6 mm are fastened by a series of 12 iron ties of ϕ 16 mm.

In the previous study, various tests and measurements as well as experimental and theoretical dynamic analyses are performed to assess the structural stability of the Howa brick chimney [2–5]. The purpose of this paper is to estimate the structural characterization of the Howa brick chimney by numerical model updating and to clarify the influence of experimental data and FE (finite element) model on updating results.

* Corresponding author. Tel.: +81 (0) 52 721 3157; fax: +81 (0) 52 721 3110.
E-mail address: aoki@sda.nagoya-cu.ac.jp (T. Aoki).

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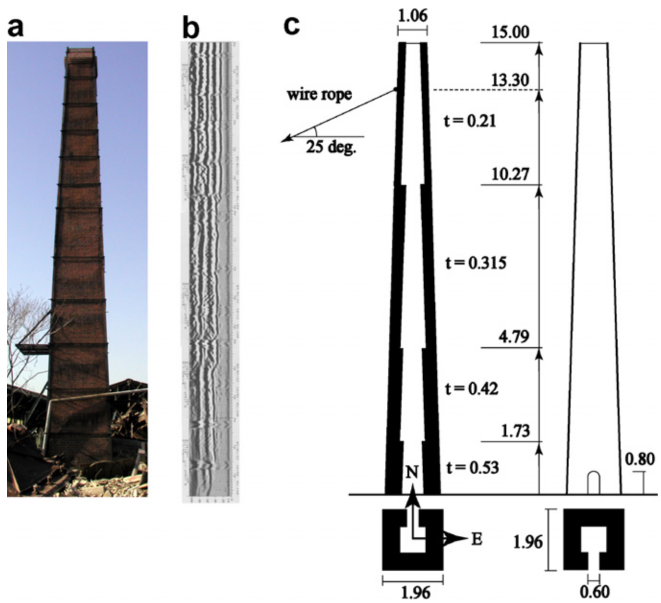

Fig. 1. Howa brick chimney and its profile: (a) Howa brick chimney, (b) result of radar and (c) profile of chimney.

2. Dynamic tests

2.1. Microtremor measurement

In order to obtain data on the dynamic structural properties of the Howa brick chimney, in the first stage of dynamic testing, microtremors are measured from the ambient vibrations at the top. Smoothed spectra obtained using Parzen spectral window of 0.5 Hz are presented in Fig. 2. In this figure, the bold solid line, bold dotted line and fine solid line represent the spectra in the north–south, east–west and vertical directions, respectively. From the microtremor measurements, the fundamental frequencies of the Howa brick chimney are estimated to be about 3.06 Hz and 2.69 Hz in the north–south and east–west directions, respectively. A difference exists between two directions due to the window in the north side (Fig. 1).

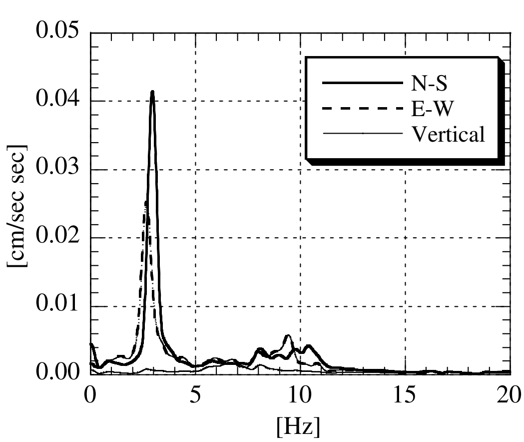

Fig. 2. Spectra observed in microtremors.

2.2. Acceleration measurement

In the second phase of dynamic testing, acceleration is simultaneously measured at six points in the north–south or east–west directions. One sensor is placed at the base of the chimney and another is placed at the top. The other sensors are located at regular intervals along the chimney. Ground vibrations created by a derrick car serve as the excitation.

3. Dynamic identification

3.1. ARMAV technique

The ARMAV (auto-regressive moving average vectors) model is one of the most widely used to determine the modal parameters of a dynamic system, such as the fundamental frequencies, mode shapes and damping factors, based on the description of its behaviour in the space between the phases [6,7].

3.2. Results of dynamic identification

Fig. 3 shows the frequency distributions of the Howa brick chimney in the north–south and east–west directions, as determined by the ARMAV model considering the complete time record. Fig. 4 shows the natural mode shapes in both the orthogonal directions identified by the ARMAV model. The fundamental frequencies and damping factors identified by the ARMAV model are shown in Table 1.

4. Numerical model updating

4.1. Theoretical background

Model updating aims to minimize the differences between the experimental measurements and the theoretical dynamic response of a model [8]. In this section, IEM (inverse eigensensitivity method) is briefly introduced [9,10] and applied to the Howa brick chimney.

The model updating procedure is based on the computation of suitable correction coefficients a_i and b_i; these coefficients are associated with the mass and stiffness of the ith element, respectively, such that all the relations that refer to the corrected matrices of the model are satisfied as follows:

$$[M_u] = \sum_{i=1}^{L} a_i \cdot [M]_i, \quad [K_u] = \sum_{i=1}^{L} b_i \cdot [K]_i \tag{1}$$

where L is the number of elements or macro elements in the structure.

Matrices $[M]_i$ and $[K]_i$ are sub-matrices of the system and may correspond to the matrices of *sub-elements*, *elements* or *macro elements* (substructures).

All models that employ sensitivity-based methods are generally based on the use of expansions in the Taylor