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VIBRATIONAL PROPERTIES OF EARLY SHOWA PERIOD BILLBOARD ARCHITECTURE FOR RENOVATING DENSELY BUILT-UP WOODEN HOUSE AREAS

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We report the progress of our research on buildings and their surroundings for disaster prevention in Chuo-3, Ota City, which is an area in Tokyo, Japan with densely built-up wooden house areas. In a previous paper, we reported the results of an exhaustive survey of 383 buildings and roads in the northwest area of Chuo-3. As a continuation, in this paper, we present findings from an exhaustive survey of 426 buildings and microtremor measurements on the ground in a more widespread area. As a result, we found evidence of early Showa period billboard architecture. We subsequently measured the dimensions of the billboard architecture and surveyed the materials of the walls, roofs, windows, *etc.* Furthermore, we constructed a standard billboard architectural model and conducted eigenvalue analysis to evaluate their respective vibrational properties, such as the natural frequency and vibrational mode. Lastly, sensitivity analyses were conducted on the floor rigidity or materials of the walls.

Keywords: Eigenvalue analysis, Sensitivity analysis, Natural frequency, Vibrational mode, Mortar wall, Eccentricity, Exhaustive survey.

1 INTRODUCTION

The seismic retrofitting of old buildings is critical in earthquake-prone countries. There are areas in Tokyo, Japan with Densely Built-up Wooden House Areas. Construction in this region requires the incorporation of seismic resistance and/or fireproof properties into all of the buildings in the area (Bureau of Urban Development Tokyo Metropolitan Government 2012). Thus, studies related to ensuring the soundness and stability of the city and its buildings are necessary, not only for disaster prevention, but also for urban planning and community revitalization.

In a previous study, we targeted Ota City, Tokyo, aiming to renovate buildings in the area. In the initial stage of the study, we conducted an exhaustive survey of 383 buildings and roads in the northwest area of Chuo-3, Ota City (Takiyama 2015). We considered the structural classification, number of stories, building use, fencing, underfloor ventilation opening, base, walls, roof shape, materials, distance between buildings, distance from the frontal road, etc. Next, we conducted ground microtremor measurements at several locations within the area of study.

In this research, which is a continuation of the aforementioned study, we conducted another exhaustive survey in the southern area of Chuo-3, Ota City. We found evidence of early Showa period billboard architecture. Thus, we aimed to gain an understanding of the vibrational properties of the billboard architectures, measure their dimensions, and survey the materials of the walls, roofs, windows, etc. Lastly, we constructed the corresponding analysis models and conducted eigenvalue and sensitivity analyses.

2 EARLY SHOWA PERIOD BILLBOARD ARCHITECTURE

2.1 Exhaustive Survey of 809 Buildings in Chuo-3, Ota City

With the exception of the northeastern area, we investigated 809 buildings and roads throughout Chuo-3 between July 6 and July 13, 2014 for the first exhaustive survey, the results of which were presented in the aforementioned previous paper. The second survey was conducted on June 25 and 26, 2016. Comprehensive results of our exhaustive survey are shown in Figure 1 to 4.

There are early Showa period billboard buildings along the traditional shopping street, as indicated by the yellow line in Figure 1, with an anterior view shown in Figure 2. Billboard buildings are a type of residential housing with an integrated store (Fujimori 1975). They are wooden residences with a mortar wall or sheet copper located only at the front of the building.

We classified the statistical data for the structures as shown in Figure 3. Out of all of the buildings, 222 were wooden structures, 63 were reinforced concrete structures, and 77 were steel structures (see Figure 3(a)); out of all of the billboard buildings, seven were wooden structures, three were RC structures, and four were steel structures (see Figure 3(b)).

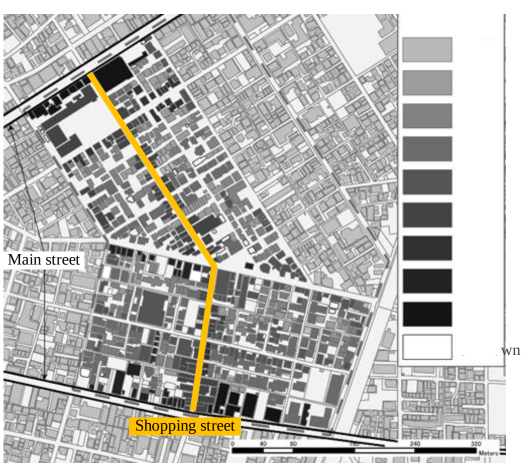


Figure 1. Distance from house to frontal road.

Figure 2. Billboard building anterior view.

The measurement results of the distances from the billboard buildings to the nearest road or building are shown in Figure 4. Nearly 80% of the buildings are located 1 m or less from the frontal road. The contour of the distance from the frontal road is shown in Figure 1. In the area divided into geographic sections, we found that the buildings were densely packed.

2.2 Early Showa Period Billboard Architecture

Early Showa period billboard architectures may have two problems. The first problem centers on the assumption that the stiffness of the billboard wall is higher than that of the remaining wooden frames. Thus, the eccentricity of the entire building may be greater than that of a typical wooden structure because of maldistribution of the earthquake-resistant elements. Secondly, it is feared that there are fewer earthquake-resistant columns and walls on the ground floor behind the billboard wall because the ground floor is a store. Considering these potential problems, we conducted eigenvalue analyses to evaluate the vibrational properties of billboard architecture. Next, we measured the dimensions of a few billboard buildings to construct an analysis model.

Front and side elevation views of House A are presented in Figure 5. The billboard wall is 250 mm thick. We were unable to obtain actual measurement values of windows because of narrow pitch with the adjacent building.

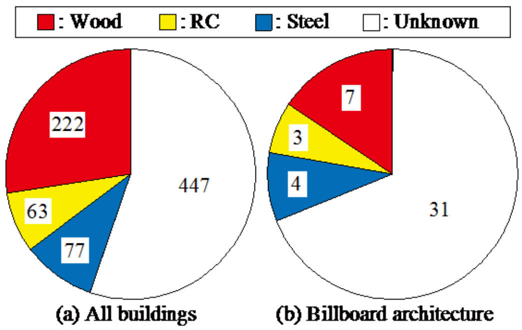


Figure 3. Structure type.

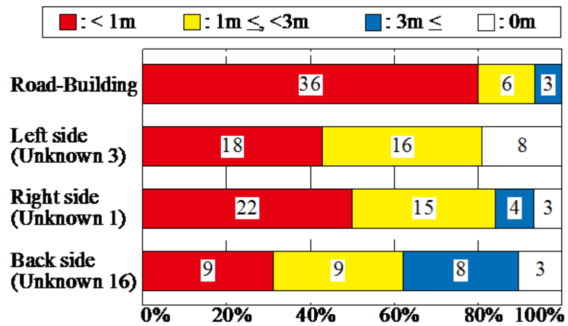
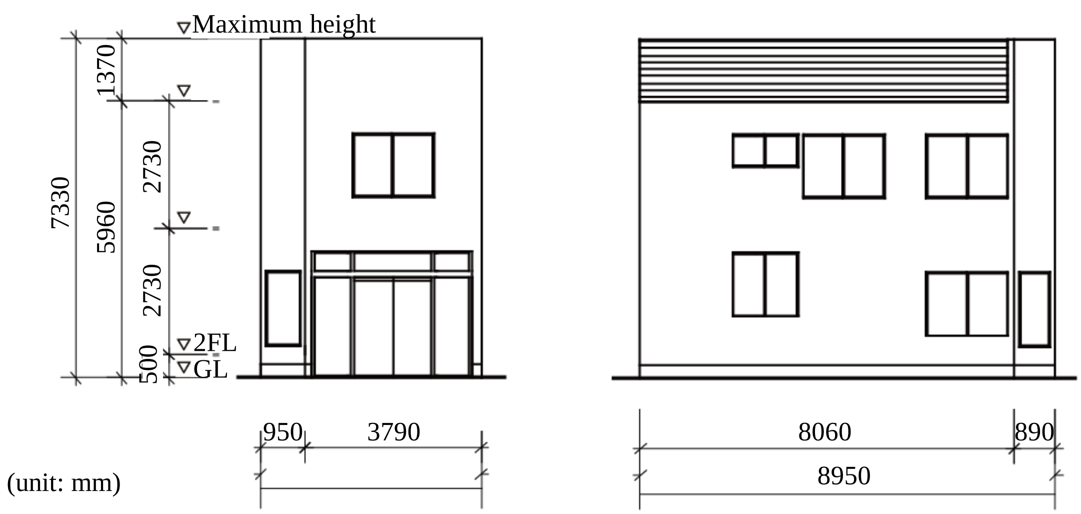


Figure 4. Distance to billboard building from nearest road or building.



(a) Front elevation (b) Side elevation

Figure 5. Measurements of House A.

3 EIGENVALUE ANALYSIS OF BILLBOARD ARCHITECTURE

3.1 Analysis Model

The analysis model was constructed based on the results of Section 2.2. The dimensions of the columns and beams were 105 × 105 mm and 105 × 210 mm, respectively; both structure types were made with laminated timber of red pine. The joints were connected via V-shaped hardware. The assumption of dead load is shown in Table 1 (Japan 2008). The billboard was made of mortar, which has a dead load per unit area of 20 kN/m^3 (Architectural 2014). Therefore, the total weight of House A was 299.3 kN; the total weight was distributed between the elements of each floor, i.e., 74.9 kN for the 1st floor, 122.2 kN for the 2nd floor, and 102.2 kN for the roof.

The analysis model of House A is shown in Figure 6. We arbitrarily assumed the positions of the columns, beams, outer walls, inner walls, and billboard. The columns have been labeled from 1 to 20. The analytical direction is parallel to the billboard. The vertical planes have been constructed according to the analytical direction and labeled as “a” to “f” in Figure 6.

The shear force of the wall performed brace substitution with a truss spring. The truss spring operates only under tension force. The outer wall consists of lath mortar and plaster board, with the wall magnification being 2.43; the inner wall is plaster board with a wall magnification of 0.96; billboard has been designed as added mortar to the outer wall. The horizontal plane is substituted as a brace, and there is a truss spring-like vertical plane. The floor plane consists of 24-mm-thick structural plywood, and the roof plane is 9 mm thick.

Table 1. Assumption of dead load.

Part	**Classification**	**Load per unit area (N/m^2)**	
Roof	Tile-roofing (non-roofing earth)	per roof surface	640
Purlin	Less than 2 m of purlin’s span		50
Ceiling	Plywood	per ceiling surface	150
Floor	More than 8 m of span	per floor surface	250
Wall	Framework of wall	per wall surface	150
	Lath mortar		100
	Plaster board		100

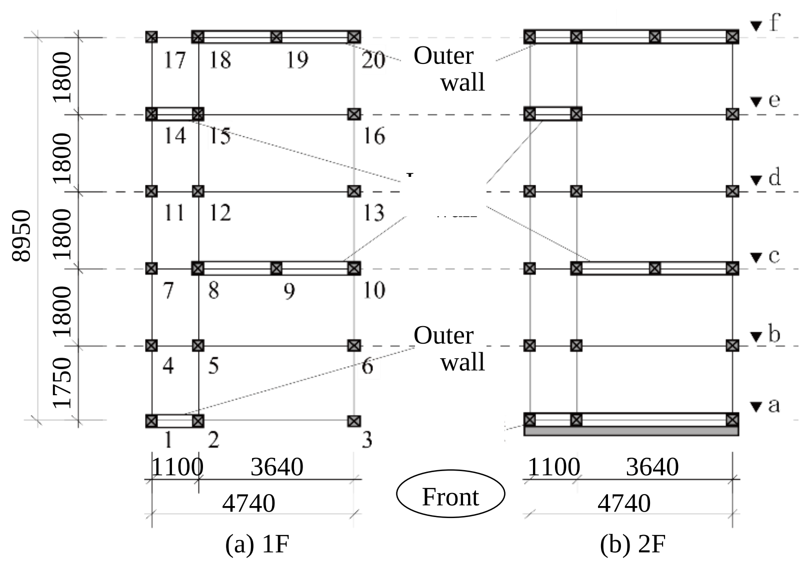


Figure 6. Analysis model of House A.

3.2 Results of Eigenvalue and Sensitivity Analyses

Eigenvalue analysis and sensitivity analysis was conducted from above structural model by using SNAP ver. 7 as elasto-plastic analysis software for three-dimensional frames of arbitrary shape.

The natural frequencies and vibrational mode shapes are illustrated in Figure 7(a). The first natural frequency was similar to the peak frequency band. With the first natural frequency, Column 3 of the first story yielded the maximum story deformation angle. In Column 3, with the first natural frequency, the story deformation angle of the first story significantly differed from that of the second story. This was due to the large opening in the first story and thick billboard wall of the second story.

In the case of repairing the span of billboard to outer wall, as shown in Figure 7(b), the first natural frequency was found to be higher than that shown in Figure 7(a); this is because of a reduction in weight and eccentricity. The mode shapes of Planes a and f appeared to be considerably distorted. In Column 3, the amplitude in the vertical direction was smaller than that shown in Figure 7(a).

Regarding closing the front opening of the first story by using a billboard wall, as shown in Figure 7(c), the first natural frequency was higher than that shown in Figure 7(a). The amplitudes of Planes b and e were high and seemed to be largely concentrated about the center. The amplitudes of wooden structures were higher than those of billboard.

Regarding increasing second floor rigidity, as shown in Figure 7(d), the first natural frequency was marginally higher than that shown in Figure 7(a). There were no planes with high amplitudes. Moreover, the vertical amplitude of Column 3 was marginally less than that shown in Figure 7(a).

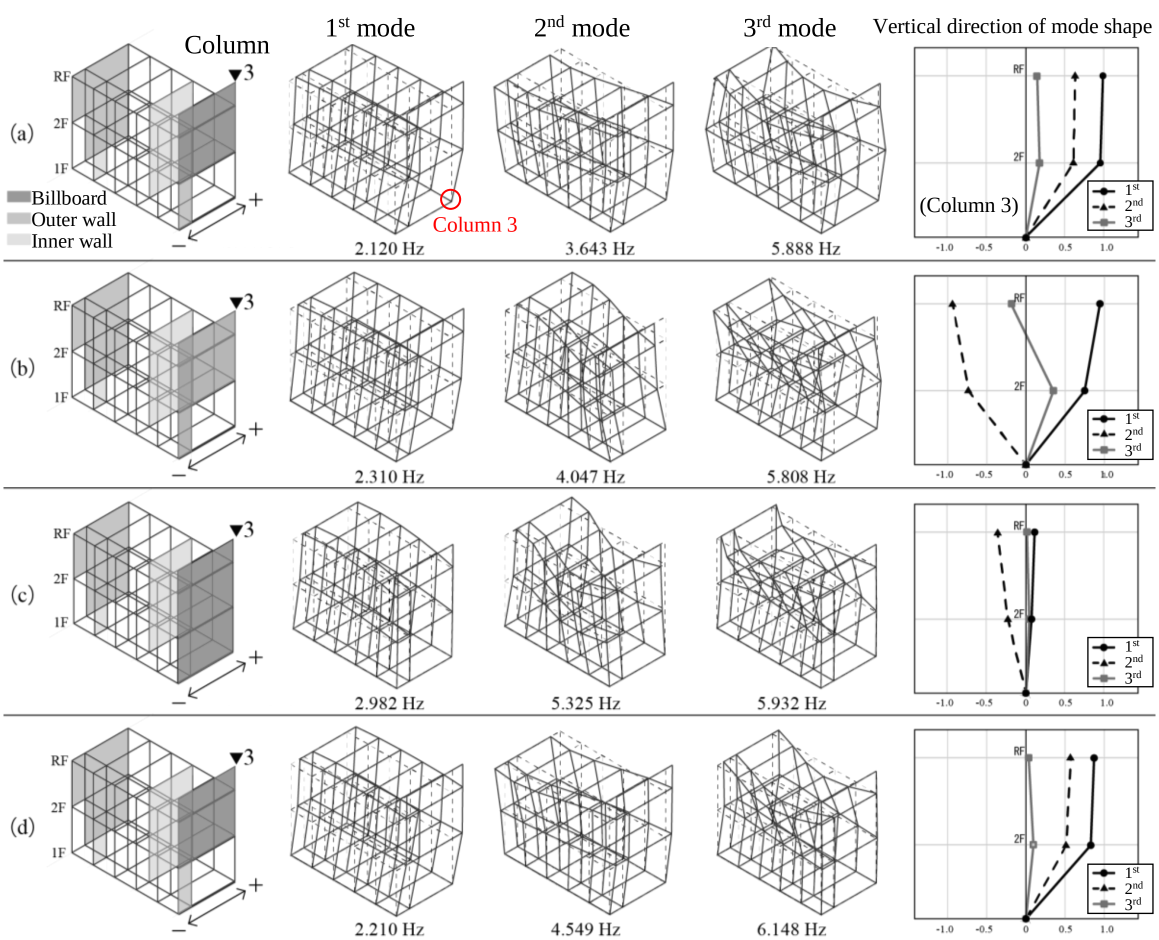


Figure 7. Sensitivity analysis results: natural frequency and mode shape.

4 CONCLUSIONS

In this study, we conducted an exhaustive survey in the southern area of Chuo-3, Ota City. We then investigated a sample of early Showa period billboard architecture, measuring the dimensions and surveying the materials of the walls, roofs, windows, *etc*. Lastly, we constructed an analysis model and conducted eigenvalue and sensitivity analyses to evaluate the vibrational properties of billboard architecture. Major findings from this study are summarized as follows:

(i) 809 buildings were investigated and roads throughout the entire area with the exception of the northeastern area of Chuo-3. There were early Showa period billboard buildings along the local traditional shopping street. Nearly 80% of all billboard buildings were located 1 m or less from the frontal road.

(ii) An analysis model was constructed as based on measurements of the dimensions of a few billboard buildings. Eigenvalue and sensitivity analyses were conducted on the structural model to evaluate the vibrational properties of billboard architecture.

(iii) For House A, with the first natural frequency, the first story exhibited the maximum story deformation angle along the frontal plane of the billboard. Additionally, the story deformation angle of the first story significantly differed from that of the second story. This is because there are fewer earthquake-resistant elements built into the first story and because the second story has a thick billboard wall. The amplitude differed between wooden structures and the billboard. This is because the eccentricity of the entire building may be larger than that of the typical wooden structure.

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