DYNAMIC CHARACTERISTICS OF A HISTORICAL MASONRY BUILDING LOCATED IN AKITA

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ABSTRACT

The seismic vulnerability of a historical masonry building located in rural area of Akita is investigated in this research. The study of these types of buildings is essential due to that there are not specific regulations for masonry buildings and that only few researches have been performed in the field of masonry constructions. As an initial step to estimate the seismic vulnerability of these historical constructions evaluation of dynamic characteristics of the target building has been undertaken. For this purpose, microtremor measurements in the building were carried out. To calibrate the analytical FEM model, mechanical parameters of masonry brick units were estimated by a series of laboratory test on some stock brick units available near the building under study. Good agreement between modes of vibrations estimated from microtremor measurements and from FEM model was obtained.

1. INTRODUCTION

Many brick masonry buildings were built during the Meiji period in Japan (by the end of the 19^{th} century), becoming a common technology of construction. During the great Kanto earthquake, which occurred in the year 1923, many brick masonry buildings collapsed dramatically, mainly due to the lack of appropriate reinforcement. Due to that poor seismic performance, this type of construction was abandoned and was replaced by reinforced concrete technology. Therefore, only few masonry constructions remain at present, and have became historical constructions.

Some of these buildings are located at the north east part of Japan, specifically in Akita prefecture, and most of them have been declared local cultural heritages. One of them is located at Ani village, which was constructed in 1879 to serve as residence for a German engineer that worked in a local mining company. In recent years, many regions, cities or towns in Japan have been very active in showing their own particularities; especially in historical and local culture aspects and some masonry buildings are being included in their local activity programs. However, it is necessary to consider the restoration and conservation of these buildings.

For this purpose, the assessment of seismic behavior and its vulnerability as well, are needed. The study of these types of buildings in Japan is essential due to that there are not specific regulations for masonry buildings and that only few researches have been performed in this field.

Under this context, the seismic vulnerability of the target building is assessed in this research. As an initial step to evaluate the seismic vulnerability of these historical buildings, the dynamic characteristics of the target building have been undertaken. For this purpose, microtremor measurements in the building were carried out in this research. For the analytical modeling, mechanical parameters of masonry brick units were estimated by a series of laboratory test on some brick units available in stock near the building under study.

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The calibration of the mechanical parameters of masonry brick walls in the analytical modeling was performed based on the results obtained from microtremor measurements. The dynamic characteristics obtained from the analytical modeling of target structure shows intricate modes of vibration, which reflect the multiple predominant peaks observed in the transfer functions of microtremor measurements. The multiple predominant frequencies obtained for a certain frequency range are consequence of the effect of mass distribution in brick walls. The procedure has permitted the identification of the probable mode of failure of the concerned structure.

2. BUILDING CHARACTERISTICS

The building object of the present study is located at Ani village in Akita prefecture and it was constructed during the 12th year of the Meiji period (year 1879). It was constructed to host Adolf Mecker, a German engineer that came to Japan to work in the mines at Akita region. As can be observed in Figure 1, the main structure is formed by the masonry walls and complemented with wooden elements that form a kind of fence around the building. The architectural style corresponds to Gothic Renaissance with some arches at doors and at windows. The masonry units were fabricated with clay of the zone and burned in a factory constructed for that specific purpose. The design and the direction of the construction of the house were done by Mr. Mecker himself.

Figure 1. Target building (Ani Ijinkan)

After finishing his employment contract, Mr. Mecker returned to his country and the house was used first as a government office, and then as social club for the mining workers.

The building under study, have suffered the action of some earthquakes, and the most recent was the Moriyoshiyama earthquake in the year 1982. This earthquake was a near source earthquake and destroyed partially the building. The prefecture government reconstructed the building replacing the triangular gabble wall of the second story by light material instead of clay brick masonry. Then, only the first floor walls remain with the former clay brick jointed with cement mortar.

The building was designated as prefecture cultural heritage in the year 1956, and was recognized as Japanese national cultural heritage in the year 1990.

3. MICROTREMOR MEASUREMENTS

Figure 2 shows the plan distribution of the building, where the sensors were located in the following arrange for one set of measurement: one sensor at the first floor (1) and six sensors at the second floor level (from 2 to 7).

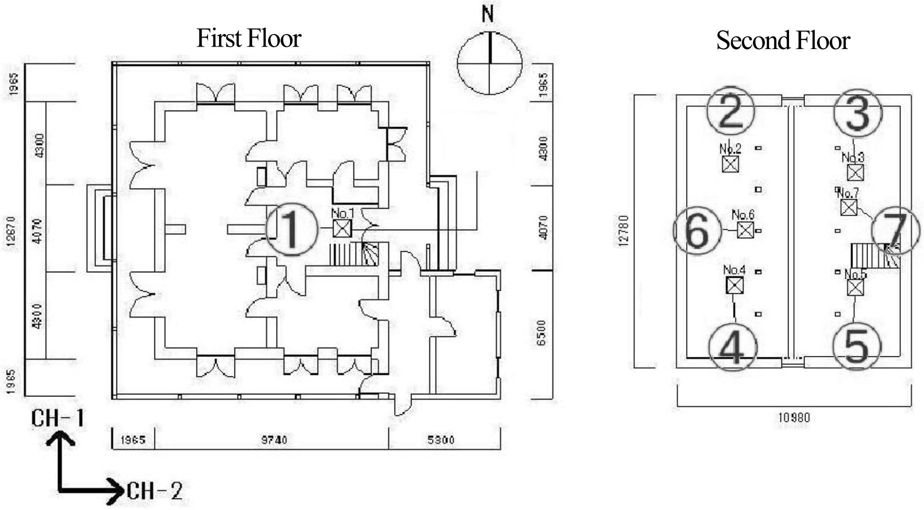

Figure 2. Locations of microtremor measurements

Three sensors for microtremor measurements along principal directions (east-west (EW), north-south (NS) and up-down (UD)) were set at each location. The micro vibrations were measured simultaneously during 500 seconds with sampling frequency of 100Hz. Then, transfer functions using selected stationary portions of these records were calculated, and the values at predominant frequencies were picked up to estimate the dynamic characteristics of the structure. The results of transfer function for horizontal components are shown in Figure 3 and 4. The Fourier spectrum calculated at each measured point of the structure was divided by the Fourier spectrum obtained at the first floor level, to obtain only the vibration characteristics of the building. The several peaks displayed in transfer functions would indicate intricate modes of vibration in such a way that is difficult to interpret the vibration characteristics of the building. These intricate modes of vibrations can be explained by the mass concentration in walls instead of the slab.

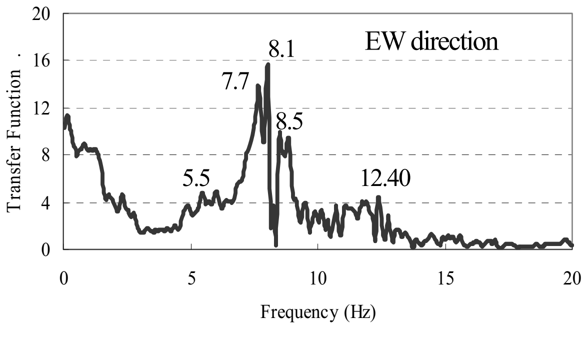

Figure 3. Transfer function for EW direction

However, based on microtremor measurements results verified by analytical modeling, it was possible to identify the predominant mode of vibration of the building that corresponds to the horizontal normal mode of vibration of the whole structure. The values of 7.7 Hz and 7.0 Hz around one of the predominant peaks in the EW direction and in the NS direction were identified (Fig. 3 and 4). The other peaks can be explained as higher modes of vibration that would correspond to the vibration of walls. Also, a small peak around 5.5 Hz was detected (Fig. 3), which could correspond to the vibration of the chimneys of the building.

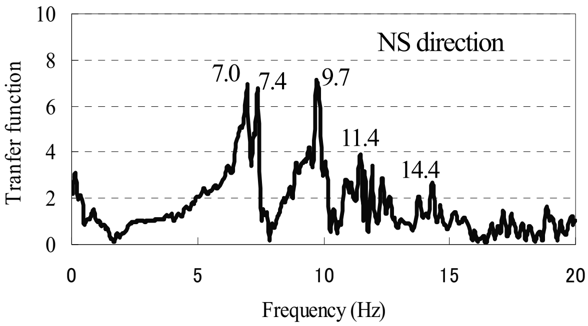

Figure 4. Transfer function for NS direction

To verify the predominant mode of vibration, portions of microtremor records for all locations were filtered for 7.7 Hz. As shown in Figure 5, the signals filtered for 7.7 Hz in the EW direction show that all the movements at all locations are in phase. Therefore, the value of 7.7 Hz corresponds to the horizontal normal mode of vibration.

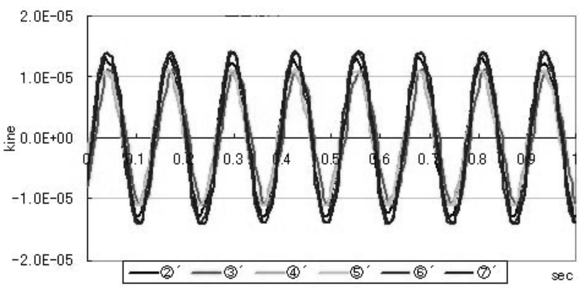

Figure 5. Signals filtered at 7.7 Hz (1st mode in EW direction)

4. BRICK MASONRY TEST

Brick units taken from a stock of the target building were tested to determine their physical and mechanical properties. It was difficult to distinguish the brick units of the stock used during former construction works from those used for repairing works. Independently of this condition, units of good appearance were selected for laboratory tests (Fig. 6).

Figure 6. Masonry brick unit and compression test

Compression tests were performed to obtain the values of strength and Young modulus. However, high values of these mechanical properties were obtained, which could be due to the size of test pieces. Apparently, the height of specimens was not enough to avoid the confinement effect produced by the constraint of lateral sides of brick units. Therefore, this constraint could be one of the factors of apparently high values for elastic properties. Then, slender specimens and the inclusion of joint mortar as well, would be necessary for appropriate characterization of masonry walls. As reference, the values of water suction ratio, density, compression strength and modulus of elasticity obtained from brick units are shown in Table 1.

Table 1: Physical and mechanical properties obtained from brick units

Suction ratio (%)	Density (gr/cm^3)	Compression strength (N/mm^2)	Young Modulus (N/mm^2)
24	1.64	12	1.06×10^4

5. FEM ANALYSIS

In order to compare the results obtained from microtremor measurements with some analytical procedure, a finite element model considering the brick masonry walls, the second floor wooden slab and the wooden roof was performed. The wall thickness is 80 cm, which was modeled as solid element instead of shell element. This criteria was adopted with the intention of obtain the influence of wall mass in the modes of vibration. Here, a matrix of masonry brick units and mortar with homogenous properties was assumed.

An inverse analysis considering that the dynamic characteristics from the analytical FEM model must be equal to those obtained from micro vibration measurements was carried out. The model was performed according to available plans and direct measurements of the building. The complete model is displayed in Figure 7.

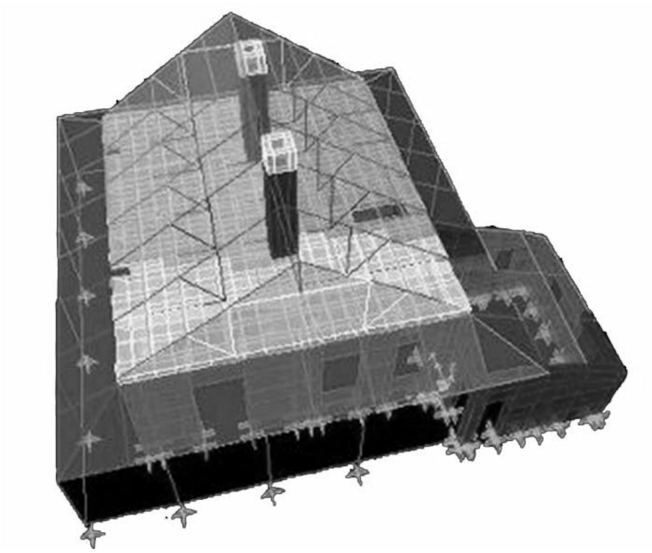

Figure 7. FEM model of Ani Ijinkan building

Tables 2 shows the comparison of the predominant frequencies for the 12 modes of vibration obtained from microtremor measurements and the results obtained from 3D analytical FEM model (EW and NS directions). A good agreement between both results of modes of vibration was obtained.

Table 2: Comparison of predominant frequencies obtained by microtremor and analysis (Hz)

Mode	Microtremor	FEM
1 st (NS normal mode)	7.0	7.2
2 nd (EW normal mode)	7.7	7.8
3 rd (Torsional mode)	9.7	9.6
4 th	Predominant peaks from 11.4 Hz to 14.4 Hz	12.0
5 th		12.6
6 th		12.8
7 th		13.2
8 th		13.3
9 th		13.5
10 th		13.6
11 th		13.7
12 th		14.1

6. CONCLUSIONS

Several predominant frequencies in the transfer functions of micro vibration measurements were obtained. According to these results, intricate modes of vibration in target building are assumed.

Mechanical and physical properties of brick units were evaluated from laboratory test. High values of these mechanical properties were obtained. Therefore, appropriate values were estimated from inverse analysis by comparing values of modes of vibration from analytical FEM model and from transfer functions of microtremor measurements.

The FEM model was performed based on the properties of masonry brick walls considered as solid elements, due to the masonry brick walls concentrate structure mass mainly, and therefore they have a great influence in the modes of vibration.

The results showed that there is a good agreement between the observed frequencies from microtremor measurements and those obtained from analytical 3D FEM model in the range of 7.0 Hz to 14.4 Hz.

Microtremor measurements combined with FEM analysis have provided valuable basis for assessing the dynamic characteristics of heritage masonry structures.

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