An evaluation of the dynamic properties of traditional wooden shrines located in Yurihonjo, Akita

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1. Introduction

Old traditional wooden constructions in Japan are declared as buildings of cultural interest and therefore efforts are done to preserve this kind of buildings. In this study old traditional wooden temples located in Yurihonjo city, Japan are investigated to determine their seismic characteristics and to evaluate their dynamic performance. The region is a zone of great seismic activity that can affect the integrity of the buildings. In this sense, the research is an attempt to evaluate the dynamic characteristics of these buildings by means of in-situ measurements of micro vibration. Structures correspond in general to framed wooden constructions with traditional connections between columns and beams. In general, nails are not used in these joints, and instead of them, the beam is narrowed at extreme to be inserted into a hole cut in the column. These buildings are supported by columns that rest directly on stone bases forming pinned joints. First, general evaluation to make a diagnosis of the structural condition was performed and building that presents some level of damages were chosen for this study. As an initial step to evaluate the seismic vulnerability of these historical buildings, dynamic characterization has been undertaken that is the predominant periods of vibration as well as the damping characteristics were estimated. For that purpose, measurements of the micro vibration of the building was planned and undertaken. Comparative study of the predominant periods of the structures is done by plotting these predominant periods versus building heights. Preliminary results show that wooden temples in this region have long periods in comparison to temples of other regions of Japan. In this way the present study has permitted to evaluate the structural integrity of these traditional temples which is fundamental step in the evaluation of their seismic vulnerability.

2. Target Shrines

In Yurihonjo city area there are 11 temples that are declared as local cultural heritage. For this study 9 temples were investigated to determine their dynamic characteristics. Micro vibration measurements and the correspondent analysis were performed in these selected buildings. Photographs of some of these selected structures are shown in Figure 1. The dimensions of these buildings range from approximately 5 m by 5 m for the smallest to 10 m by 10 m for the largest dimensions in plan. Structures correspond to framed wooden constructions with traditional connections between columns and beams. In general, nails are not used in these joints, and instead of them, the beam is narrowed at extreme to be inserted into a hole cut in the column. These buildings are supported by columns that rest directly on stone bases forming pinned joints.

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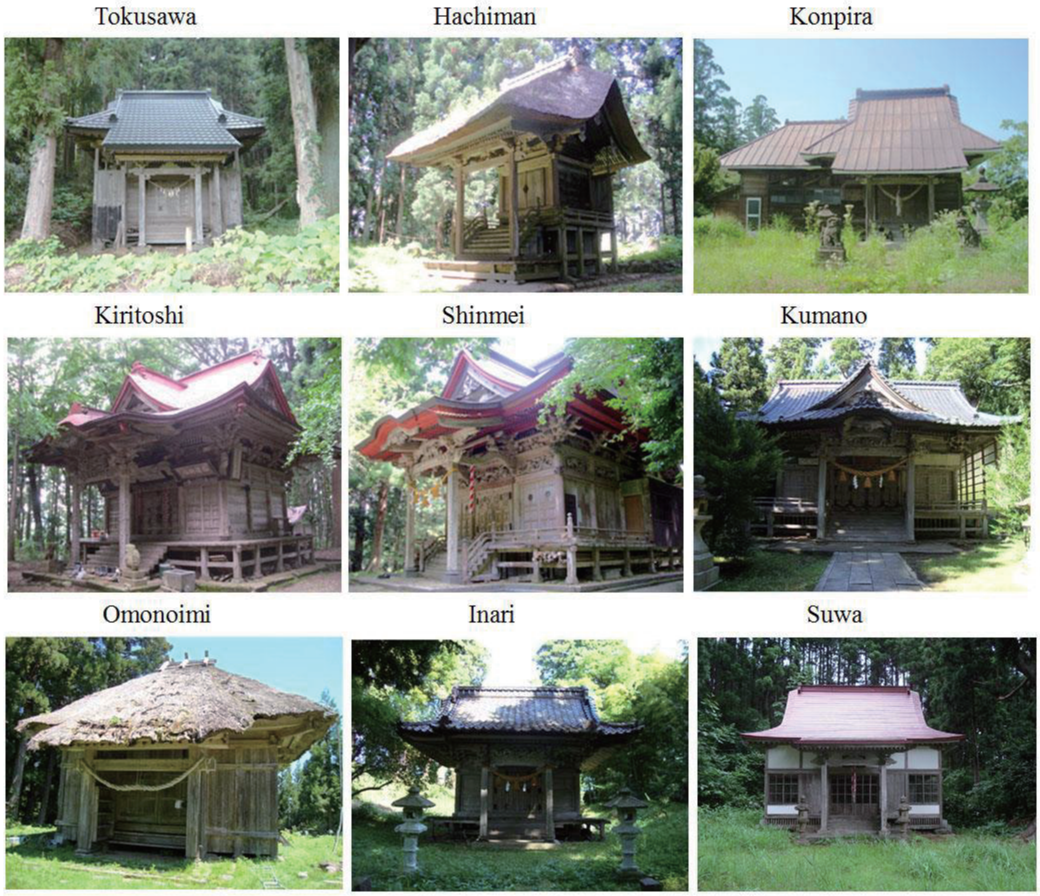

Fig. 1. Selected temples for the present study

With exception of Tokusawa temple that is located near a vegetable field, all temples are located in the upper part of hills. The structure of all temples corresponds to a traditional wooden frame. The Tokusawa, Kumano and Inari temples have tile roof, the Hachiman and Omonoimi have thatched roof, and the Konpira, Kiritoshi, Shinmei and Suwa have thin steel plates as roof.

The main damage observed in some temples was the gap between the base stone and the bottom part of the columns as can be observed in Figure 2. Apparently, this failure is due to the deformation of the girders of the bottom part of the structure. In some cases the failure is a combination of the settlement for the central part of the building with the bending of the girder. Also some elements are seriously deteriorated by the weather action. In all of the cases was observed that the maintenance of the temples are poor and administration and management offices are always closed if they exist and in other cases there are no administration offices. In general these temples are open during the corresponding local festival and during New Year Celebration, the rest of the year are closed.

Fig. 2. Details of the damages at the bottom of columns

3. Measurements Results

Micro vibrations of the selected temples were measured according to the scheme that is shown in Figure 3. One sensor was located on ground site (ch1) and four sensors were located at each corner or near the 4 corners of the building and on the upper beam of the first floor (ch3, ch4, ch5 and ch6). Measurements were performed separately for the two principal directions of the temples. To obtain the elastic viscous damping factor at the beginning of each measurement an impact force of a person was used to produce a free dumped vibration. In addition to the set of measurement for the building, the 3 components of the ground vibration were measured for each site to estimate the ground vibration characteristics by using the H/V spectrum method. In all cases the sampling frequency was 100 Hz.

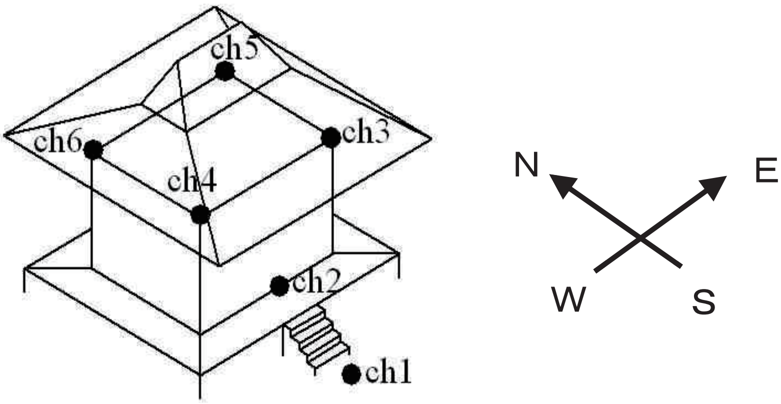

Fig. 3. General scheme for points of measurements

In Table 1 the results for selected temples are summarized. Results of predominant modes of vibration are expressed in terms of the period of vibration. In this table the calculated damping factor of the temples are also included.

Table 1. Periods of vibrations and damping factors

Temple	Height (m)	Main Direction Period (s)	Ridge Direction Period (s)	Damping Main Dir. (%)	Damping Ridge Dir. (%)
Tokusawa	5.00	0.30	0.37	4.55	4.20
Hachiman	6.30	0.34	0.31	5.55	7.42
Konpira	6.25	0.27	0.27	5.03	4.60
Shinmei	7.13	0.32	0.45	2.89	2.42
Kiritoshi	7.20	0.36	0.43	2.97	1.71
Omonoimi	4.85	0.30	0.35	2.44	2.46
Suwa	5.00	0.32	0.24	7.30	3.65
Kumano	7.08	0.50	0.64	3.70	3.06
Inari	4.37	0.32	0.43	3.92	2.49

It can be noted that the general tendency is that periods for the ridge direction are longer than those obtained for main direction. These results are compared with the general tendency curve for traditional Japanese temples reported by Uchida et al (2001). Figure 4 shows this comparison where the periods for each direction are plotted versus the height of the temple. Results for Hachiman and Konpira temples are on the curve of general tendency or a little above the curve. These both temples were recently repaired at the foundation level and therefore this effect could be reflected in the measurements results. The results for other temples lay below the curve for both directions and it indicates the weakness of the temples with long period for the corresponding height. In general these temples show unbalanced results since for main direction the results are closer to the general curve and for the ridge direction the results differ more from the curve. In this case if some reparation work is planned it is necessary to consider the reinforcement of temples in the ridge direction.

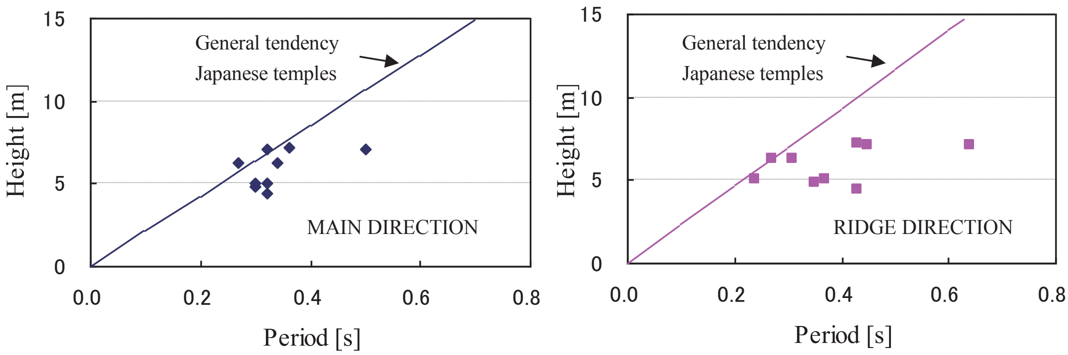

Fig. 4. Periods of vibration versus temple heights

The damping factor ranges from approximately 2% to 7%. However in previous studies of other traditional temples smaller values of the order of 2 % are reported. This fact could indicate that temples with high values of the damping factor present higher potential for energy dissipation. However, it is believed that the energy dissipation occurs due to the lack of appropriate stiffness of joints and supports and therefore could be an indicator of the vulnerability of the structure. When the damping factor is related to the period of the structure or to the height of the structure unclear relationships are obtained. Therefore, in this research the ratio of the number of spans versus the length is taken to establish a relation with the damping factor. That is the number of spans by unit length is plotted versus the value of the damping factor as is shown in Figure 5.

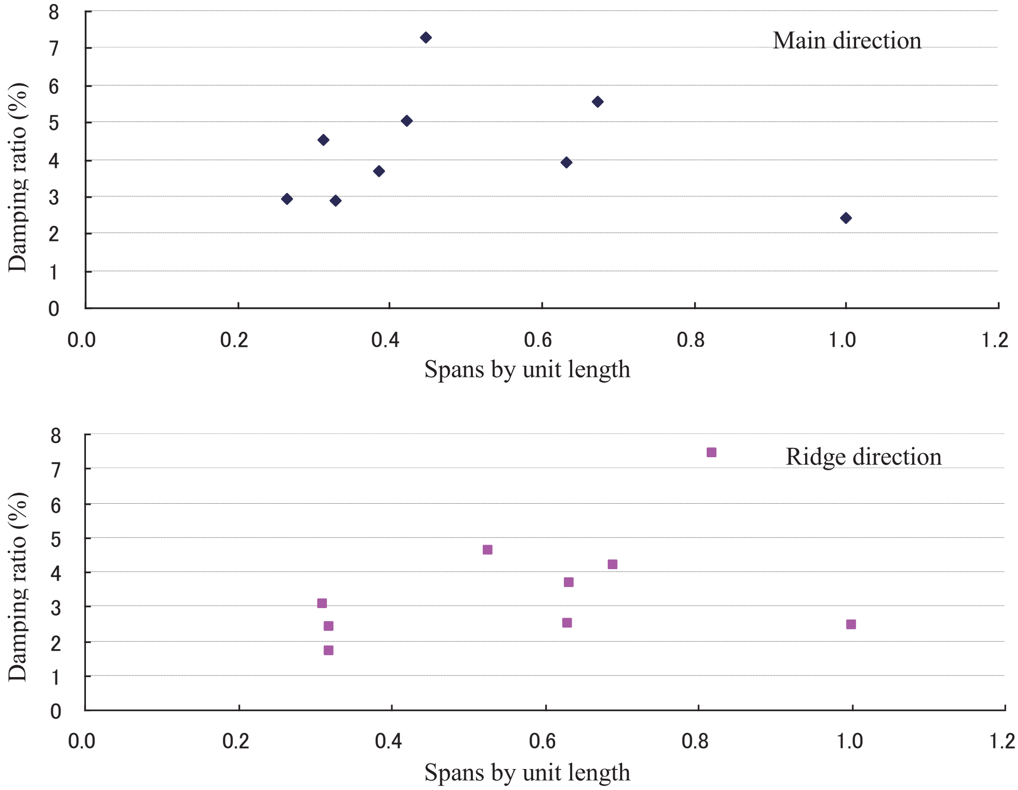

Fig. 5. Number of span by unit length versus damping factor

It can be noted that with the exception of one temple, the general tendency is to have a larger value of the damping factor when the number of span by unit length is increased. It is supposed that when the number of span by meter increases the structure presents more joints that could increase the dissipation of energy. However, the condition of the joints is an important factor as well as the distribution of joints along the height of the building which consider the presence of horizontal structural element like secondary beam.

4. Conclusions

Microtremor measurements have been successfully employed to determine the dynamic characteristics of traditional Japanese wooden temples of Yurihonjo city. The general tendency of the selected temples is that periods for the ridge direction are longer than those obtained for main direction. These results compared with the general tendency curve for traditional Japanese temples show that some temples have longer period for the corresponding height. In addition, most of the temples show unbalanced results since for main direction the results are closer to the curve than results for ridge direction. In this case if some reparation work is planned it is necessary to consider the reinforcement of the temples in the ridge direction.

The damping factor were correlated with the number of spans of the structure and general tendency of increasing damping with increasing number of spans was found. However more analysis is required since it is believed that damping is strongly dependent of the number of joints and of the conditions of these joints.

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