Nondestructive Inspection for Structural Safety of Historical Buddhist Temple "Zenkoh-ji" San-mon

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INTRODUCTION

The main purpose of this study is to inspect the structural safety of historical wood buildings. In Japan, there are many historical wood buildings which have been preserved as cultural properties. For proper management of these buildings, internal state of structural members must be evaluated exactly. This study shows the nondestructive inspection which was performed at the entrance gate of "Zenkoh-ji" in Nagano, which is one of the famous Buddhist temples in Japan.

HISTORY OF REPAIRS

It is known that the entrance gate "San-mon" of Zenkoh-ji started to build in 1744 and was completed in 1750. Zenkoh-ji has received a specification of Japanese important cultural property in May 1965. Repair of the roof which remained in record till today has been performed at intervals of about 40 years, and 5 times (presumption 6 times) were counted. The repair in 1924 was large-scale especially. The form of the roof till then called "Tochi-buki" changed into the form called "Hiwada-buki". Furthermore, it has reinforced by the adding element called "Hanegi" and "Hohzue" to the roof. Then, at the time of the Matsushiro earthquake intermittently caused from 1965 to 1970, temporary reinforcement was given to the pillar of a lower layer, and complete repair of the roof was performed from 1972 to 1973. Repair of stone steps, building blocks, and etc. was performed in 1983, then it has continued until now. However, deformation of the building has come to be conspicuous in recent years due to the inclination of a pillar and eaves hang. Ignited by Hiwada-buki having reached its life, when it has passed 30 years since the last roof repair, the investigation of structure (creation of a present condition figure, a check of element modification and a breakage situation, a power-proof examination, structural analysis) was performed from 2001 to 2002. Then, it was decided upon master plans, such as a repair object at the time of being this construction, and structure reinforcement. Based on this repair plan, half-demolition repair was started in October 2002 and will be completed in December 2007.

San-mon of Zenkoh-ji, before and under repairing.

METHOD

The materials for investigation were "Marubashira", columns of the first floor, and "Noboribari", ascent beams of the roof. These materials were Keyaki (Zelkova serrata) and Japanese red pine (Pinus densiflora) which were felled more than 260 years ago. Stress wave velocity was measured by using Hungarian "FAKOPP" stress wave timer. The stress wave is induced by a hammer impact. The read out of the machine is the transit time, which travels through in the radial or longitudinal direction of materials. The stress wave velocity and the elastic modulus of individual wood materials were evaluated. The elastic modulus was estimated by the stress wave velocity with supposing wood density.

Stress wave measurement for nondestructive inspection.

RESULTS AND DISCUSSION

As an example of the measurement results, the stress wave velocity in the radial direction of the column of the first floor is shown in Fig. 1. About the column of the first floor "Marubashira" (Keyaki) shown in Fig. 2, the velocity was measured in two radial directions (NE-SW and NW-SE directions) perpendicular to each other, at the height for every 0.3 m. The velocities in NE-SW direction showed 1500 m/s order, and were judged to be in general appropriate. As an index of the measurement result, the equivalent elastic modulus in radial direction (ER) by setting the density to 500 kg/m^3 was attached to the horizontal axis in Fig. 4. From this, when the stress wave velocity is about 1500 m/s, the general value on ER of Keyaki is acquired. It seemed that NE-SW direction showed the appropriate results according to Fig. 4. On the other hand, the stress wave velocities in NW-SE direction showed notably small values above 2.6 m height.

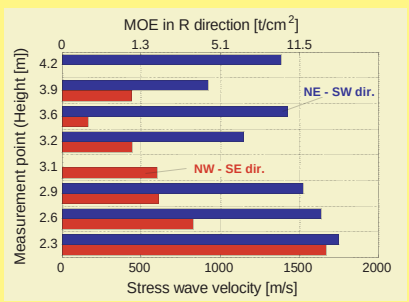

Fig. 1. Stress wave velocity.

Fig. 2. Marubashira.

When the wave velocity is small, the existence of an internal defect other than a fall of elastic moduluscan be considered. From this examination, the existence of the internal defect (for example, big crack) was guessed in the direction orthogonal oriented to the NW-SE direction, in the case of this column.

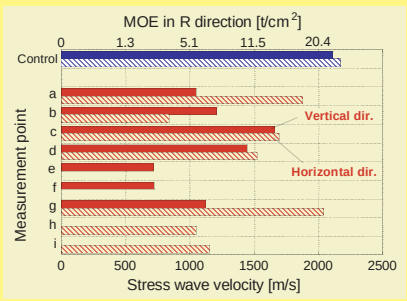

Fig. 3. Stress wave velocity.

The stress wave velocity in the longitudinal direction of an ascent beam "Noboribari" (Japanese red pine) was 4625±343m/s (equivalent elastic modulus 110±17t/cm^2), and was judged to be appropriate value. The stress wave velocity in the radial direction of the material is shown in Fig. 6. The wave velocity shows small value in some measurement points. Velocity of the vertical direction shows small value especially near the front (measurement points "e", "f", and "g"). That is, in this measurement area, existence of internal defects, such as a crack, was able to be considered horizontally. This has supported judgment by viewing as shown in Fig. 5. On the other hand, the control material (neighbouring ascent beam) which is completely satisfactory according to viewing showed about 2000m/s in wave velocity, and was judged to be normal.

Fig. 4. Noboribari.