Seismic Performance of Japanese Traditional Timber Temple *Kencho-ji*

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Summary

This paper introduces the recent attempts to clarify the seismic behaviour of traditional timber architecture. The subject of the research is a timber temple, *Kencho-ji*, in Japan, designated as important cultural property. There are two main halls in the *Kencho-ji* temple, and one of them collapsed while the other slightly inclined by the 1923 *Kanto* Earthquake. The two main halls have similar structures, and stand next to each other. The reason for the difference in the damage is investigated through on-sight measurement, micro tremor test, earthquake monitoring, and structural analysis. As there is very few information concerning the hidden detail of the joints, the paper introduces the result of the X-ray test on the joints and structural analysis based on the result.

Keywords: timber structures, traditional joint, temple, earthquake damage simulation

1. Introduction

The *Kencho-ji* temple is located in *Kamakura*, approximately 50km south west of Tokyo. *Kamakura* was an ancient capital of Japan in 12-14th century and many Buddhist temples were built. Unfortunately due to war, fire and earthquake only a few buildings date back to this period, and *Kencho-ji* is no exception. The most recent heavy damage in was the 1923 *Kanto* earthquake. Thorough damage investigation of this earthquake has been operated in the past, and the structural characteristic of *Kencho-ji* temple was investigated. This paper introduces the recent results of the seismic performance of traditional timber architecture by taking *Kencho-ji* temple as a case study.

2. Structural Performance of Traditional Timber Structures

One of the main horizontal load resisting elements of the structure is the moment resistance of the timber frame consisting of the column and penetrating beam. It is known that the timber joints show moment resistance although it is very difficult to constitute a rigid joint. The rigidity and strength of timber joints rely on the shape and detail of the joints. Unfortunately the detail of the joint of the column and penetrating beam of the two main halls of *Kencho-ji* are hidden and there are no documents concerning the detail of the joints. Therefore the authors performed X-ray inspections to clarify the shape of the hidden detail of the joints. The result of the X-ray inspection showed that the detail and shape of the joints were different for the two main halls. It was estimated that the older and smaller building, *Butsuden*, had a shape called *Ryaku-gama* joint, which is a fairly common type of joint for column and penetrating beam, often used in the medieval period. For the newer and larger building *Hatto*, the shape of the joint was assumed to be *Sao-shachi* joint, not so commonly used.

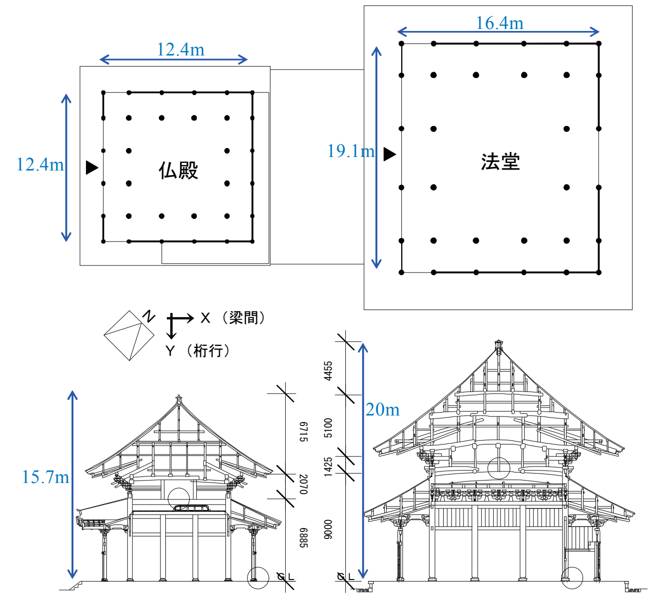

Figure1. Plan and Section of *Butsuden* (left) and *Hatto* (right) in *Kencho-ji*

Picture of *Butsuden*

Picture of *Hatto*

3. Experiment of Timber Joint

Horizontal loading test of the column and penetrating beam joint was operated based on the result of the X-ray inspection. The specimen were scaled models of the joints and the detail and shape was decided from the results of the X-ray inspection. Specimen without connecting joint was also applied in order to discuss the influence of the connecting joint. From the results of the static loading test, it was revealed that both of the joints show degradation in stiffness compared to the joint without connection, and the degradation of stiffness was approximately 50%. The *Ryaku-gama* joint showed lower stiffness compared with *Sao-shachi* joint, but the former showed bending failure at the rotation angle of 1/10rad. Whereas the latter joint did not fail even until the rotation angle reached 1/4 rad. The load displacement hysteresis curved showed pinched curve and slipping for all the joints, typical for traditional timber joints.

4. Result and Discussion

The load displacement relationship derived from the result of the experiment was modelled and static analysis was operated. From the results of the static analysis, the base shear coefficient of the two main halls were determined. The *Butsuden* showed higher base shear coefficient compared with those of the *Hatto*, whereas the damage by the 1923 *Kanto* earthquake was that the former collapsed and latter merely inclined. The contradiction in the difference of the two halls was explained based on the simulated earthquake strong motion of the 1923 *Kanto* earthquake and the difference in the vibration characteristic of the two main halls.