Evaluation of Seismic Performance of Traditional Wooden Structure based on 3D FEM Analysis

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Summary

In this study, we evaluated the seismic performance of existing temple, which is a traditional wooden structure, based on the field survey, 3D FEM analysis of unit frame in order to estimate the restoring force of main beam called *Nuki*, and calculation of response and limit strength. In the calculation results by the existing design code in Japan, the seismic performance evaluation of the structure became a significantly lower result, and the seismic diagnosis that is likely to collapse in a large earthquake was obtained. In conducting the parameter study of 3D FEM analysis, however, the strength evaluation of *Nuki* can be obtained a higher result than the design code. If the response and limit strength is recalculated based on these analytical results, the seismic evaluation of the entire structure is considerably improved.

Keywords: traditional wooden structure; seismic evaluation; existing structure; 3D FEM analysis; field survey; calculation of response and limit strength.

1. Introduction

Fig. 1: The investigated temple

In Japan, there are many traditional wooden structures such as temples and shrines (see Fig.1). These structures depend on the regionality and the techniques of the carpenters, so there are wide variations among configuration and joint shape. Also, it's often the case that these structures were built along time ago, so detail of the joints is unclear because there are no execution drawings. In addition, the clearance gaps of the joints were often found on field investigation because of degradation. Consequently, it is very difficult to evaluate the seismic performance of existing traditional wooden structures such as temples and shrines. Therefore, we think 3D finite element method (FEM) analysis is the effective solution to evaluate the seismic performance of existing traditional wooden structures such as temples and shrines.

The purpose of this study is to evaluate the seismic performance of existing traditional wooden structure (temple, which is erected in 1673 as shown in Fig.1) based on the field survey, 3D FEM analysis and calculation of response and limit strength.

2. Evaluation of seismic performance of the existing structure

In this structure as shown in Fig.1, beams called *Nuki* and column rocking resistance become major seismic elements. However, details of the joint configurations were not confirmed because the field survey was conducted without dismantling operation and the design drawings have not been saved. Restoring force characteristics of each seismic element is determined by reference to the earthquake resistant design code in Japan based on the calculation of response and limit strength. The calculation of response and limit strength is shown in Fig.5.

3. 3D FEM analysis

The analytical model is shown in Fig.2. The analytical model is a unit planar frame. Only columns and beams called *Nuki* are modelled. Three types of models, by varying the configuration of the joint between column and *Nuki* and the material constants and the coefficient of friction, are used in analysis in order to conduct the parametric study. The details of the joint between column and *Nuki* are shown in Fig.3. The joint between column and *Nuki* is modelled to insert the *Nuki* into a hole that is processed to the column. LS-DYNA, a general-purpose FEM analysis program, is used for the analysis. The material constants of the *Japanese Zelkova* (called *Keyaki* in Japanese) wood used in the analysis are shown in Table 1. The material constants are taken from the Wood Industry Handbook in Japan. Wood material model in LS-DYNA, taking anisotropy and material non-linearity into consideration, is used as the material. In this wood material model, elastic-plastic material model is assigned for the stress-strain curve in compression, and brittle material model is assigned for the stress-strain curve in tension and shear.

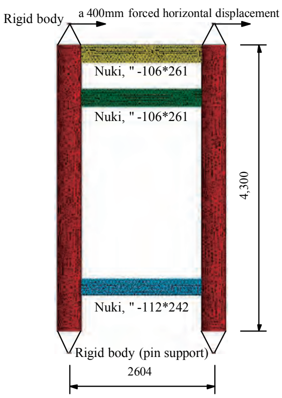

Fig.2: The analytical model

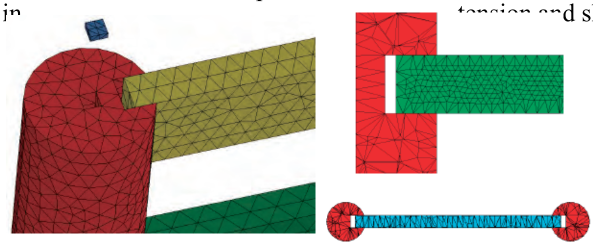

Fig.3: The details of the Nuki

Table 1: The material constants

			fiber direction (axial)	normal to fiber direction (transverse)
Young's modulus		(N/mm2)	10700	1610
shear elastic modulus		(N/mm2)	1170	500
Poisson's ratio		(-)	0.4	
maximum stress	tension	(N/mm2)	122.4	15.1
	compression	(N/mm2)	57.1	15
	shear	(N/mm2)	18.9	

Analytical results shows in Fig.4. The restoring force of *Nuki* used in the design code is also shown in Fig.15. The highest strength and stiffness are obtained from the analytical result of Model 2. On the other hand, the lower strength and stiffness are obtained from the analytical result of Model 3. Especially, initial stiffness is much lower than the other results because of the clearance gap of the joints. Model 1, which is the standard model, became the average value between the Model 2 and Model 3. When compared with the standard value of the design code, the analytical result of Model 3 showed close agreement with the standard value. This means that the evaluation of *Nuki* is significantly low in the design code.

Using the restoring force characteristics of *Nuki* as a result of the 3D FEM analysis, the response and limit strength is recalculated (see in Fig.5). The analytical result of Model 1 is used for the recalculation. The recalculation results of response and limit strength are shown in Fig.5. For Level 2 ground motion, it has become the response value of 1/18 radian for ridge direction and that of 1/21 radian for orthogonal direction, these results are considerably improved as the entire structure.

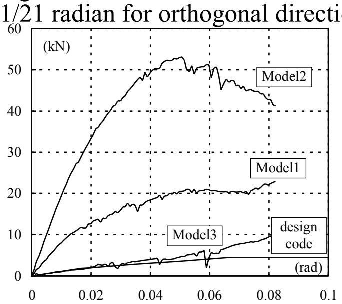

Fig14: The analytical results

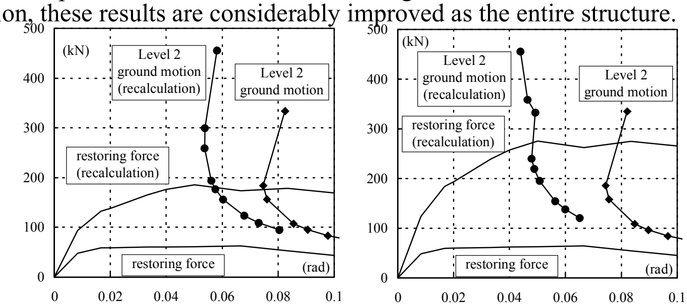

Fig5: The calculation of response and limit strength (Left: ridge direction, Right: orthogonal direction)