Three Effects of Mechanisms in Traditional Timber Structures

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Summary

The authors suggest three keywords "Diagonal Effect", "Embedment Effect" and "Frictional Effect" in order to analyse the structural system of traditional timber structures successfully. Following the keywords, refined and elegant mechanisms of traditional timber structures are revealed and their restoring force characteristics are analysed and formulated based on the Elasto-plastic Pasternak Model proposed by the authors.

Keywords: Traditional timber structure; restoring force characteristics; joint; wedge; diagonal effect; embedment; friction.

1. Introduction

There are many traditional timber structures, such as temples, shrines and town houses in Japan. They have been inherited and established by carpenters for more than thirteen centuries. Their structural systems are much different from modern structures which are usually analysed by modelling them with bar members and fixed or pin joints. Such traditional systems should be understood as integrated systems with cubic wooden blocks. Therefore, the authors suggest three keywords "**D**iagonal **E**ffect (abbreviated to **DE**)", "**E**mbedment **E**ffect (**EE**)" and "**F**rictional **E**ffect (**FE**)" in order to analyse their structural systems successfully.

Following the keywords, refined and elegant mechanisms of traditional timber structures are revealed and their restoring force characteristics are analysed and formulated based on the Elasto-plastic Pasternak Model proposed by the authors.

2. Diagonal Effect of traditional timber structures

In general, traditional wooden joints are composed of some cubic wooden blocks A, B, C etc. interlocked each other in three dimensions in Fig.1. If an external load is applied to the joint, each block contacts, embeds, slips and separates, depending on the constraint conditions and material characteristics of blocks. Now, we aim at the movement of the polygon **abcd** and the diagonal from **ac** to **a'c'** shown in the red dotted arrow. This red dotted arrow represents the major reaction against the external load and the key point of the behaviour of this joint.

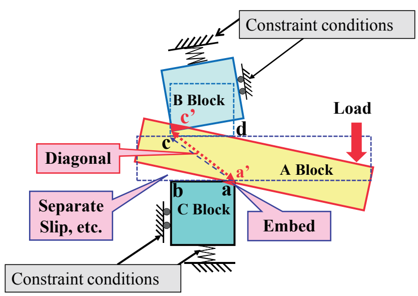

Fig.1: Basic concept of "Diagonal Effect"

Based on above discussions, we reconsider the mechanism of joints from primitive types to developed ones, and we have suggested the basic concept for the mechanisms of joints focusing on **DE** in order to approach the solution. This keyword helps us to understand the mechanisms of traditional wooden joints.

3. Embedment Effect of wood perpendicular to the grain

EE is the embedment effect which governs the compressive behaviours of wooden blocks. If one block contact to the other, partial compression or embedment occurs mostly with some increase of stiffness and strength. This stiffness increasing behaviour in partial compression is formulated by **P**asternak **M**odel (abbreviated to **PM**).

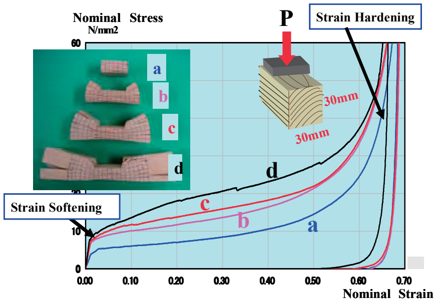

Fig.2: Stress-strain diagrams of compression of wood perpendicular to the grain

As for elasto-plastic behaviours, we made clear the softening (yielding) / hardening mechanism of embedment of wood perpendicular to the grain by partial compression tests as shown in Fig.2. The stress-stain diagram of lateral compression tests of Japanese cypress (*Chamaecyparis obtusa*) are shown in strain levels up to 0.7 (70%), where specimen **a** is a full compression specimen and **b-d** are partial ones. Based on the above results, the elasto-plastic mechanical model was developed from the elastic **PM**, and denoted "**E**lasto-plastic **P**asternak **M**odel" (abbreviated to **EPM**).

In special, the strain hardening effect of compression of wood perpendicular to the grain is the background of stable and large deformability of traditional timber structures.

4. Frictional Effect at the column bases and the joints

We consider two cases of **FE**. One is at the column bases. In traditional timber structures, columns are put on base stones without any fasteners. The column bases do not slip during moderate level of earthquakes. However, if an unexpected great earthquake happens, the columns slip at the column bases and move+ to some distances. The maximum shear forces of the structures are limited by the coefficient of friction. This effect is interpreted as a primitive kind of base isolators.

Another **FE** is found in the joints. The frictional forces take place on the contact surface of joints. Especially, in the joints with wedges, the frictional forces become large because the frictional forces are proportional to the bearing forces introduced by wedge insertion. Also the frictional forces are resources of energy consumption of earthquakes. Therefore, **FE** is very important for the evaluation of restoring force characteristics of joints.

We also pointed out that the joints with wedges behave as a frictional damper due to the frictional forces of the bearing forces and rotational embedment.

5. Conclusions

We point out that the traditional timber structural systems are much different from modern structures and should be understood as integrated systems with cubic wooden blocks. Then, we suggested three keywords "**D**iagonal **E**ffect", "**E**mbedment **E**ffect" and "**F**rictional **E**ffect" in order to analyse their structural systems successfully. As a result of some discussions following the keywords, the mechanisms of traditional timber structures are revealed and their structural systems which have been refined through long traditions and historical experiences, are proved to be elegant by modern structural technology.

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