Preliminary

Study on Bolted Cross-Lapped Joints for Wooden Portal Frame*[1]

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(Recieved May 31, 2002)

Keywords : bolt, wood, timber, joint, dowel, semi slip condition, cross-lapped joint

Introduction

Bolted Cross-Lapped Joints (BCLJ) have been used as a basic jointing method in Japan and European countries. There, however, are some problems for large scale wooden frame structures in design method. For the purpose of expanding industry of large scale wooden frame structures, it is important to develop the proper estimating methods for predicting actual performance.

So in this study we exploited a new approach which can estimate bolted joints performance, not using computer simulation, but in more practical manner.

Estimating Methods

Up to now, we have been using theory of the beam on an elastic foundation (TBEF) for estimating stiffness of timber joints. TBEF which had been applied to timber joints first by Kuenzi[1)], however, requires very complicated calculation for double sided timber-to-timber joints. Thus, in order to make main member and side member independent mechanically, we introduced 'Semi-Slip Condition' by setting a new boundary condition at the interface between side member and main member in which moment became almost zero and shear force was equal to the applied load. By setting this boundary conditions, we got relatively simple equations for estimating stiffness (K_s) as following:

$$K_s=\frac{K_{h1}\cdot K_{h2}}{K_{h1}+K_{h2}} \tag{1}$$

where, K_{hi} is defined as "Semi-Slip modulus" and derived using eq. (2).

$$K_{hi}=\frac{2\lambda_i^3(EI)_s(\sinh\lambda_i t_i\cosh\lambda_i t_i+\sin\lambda_i t_i\cos\lambda_i t_i)}{\cosh\lambda_i t_i-\sin^2\lambda_i t_i} \tag{2}$$

where,

$$\lambda_i=\sqrt[4]{\frac{k_i d}{4(EI)_s}}$$

t_i: thickness of timber-i

$(EI)_s$: bending stiffness of bolt

d: diameter of bolt

i: 1 is main member, 2 is side member

k_i: bearing constant for timber

For estimating yield load of single dowel joints with timber side member, we have been using European yield model theory (EYT)[2)] based on rigid-plastic theory. It is not consistent to use different theory for estimating stiffness and yield load. Thus, we used TBEF to estimate stress in wood and bolt. It seemed to be difficult to derive closed form solution for estimating stress of bolt. So, we used computer simulation for estimating stress in bolt for 15,000 combinations. From results of simulation, eq. (5) was derived. And in order to estimate stress of wood, eq. (6) was derived from Kuenzi's hypothesis for yield load in single bolted joints. So we defined following criteria (eq. 3, 4) for the yield condition of single bolted joints.

$$P_y=\min(P_{hy}\text{ of maim member}, P_{hy}\text{ of side member}) \tag{3}$$

$$P_{hy}=\min(P_{hw}, P_{hb}) \tag{4}$$

$$P_{hb}=\frac{k\sigma_{sy}Zd}{0.6K_h} \tag{5}$$

$$P_{hw}=\frac{K_h\sigma_y}{k} \tag{6}$$

where,

$$Z=\frac{d^3}{6}$$

σ_y: bearing yield stress of timber

σ_{sy}: yield stress of steel

We also derived a new analytical method of BCLJ for estimating load distribution of each fastener in bolted cross-lapped joints. Fig. 2 shows concept for mechanical model. In order to get equation for estimating rotational

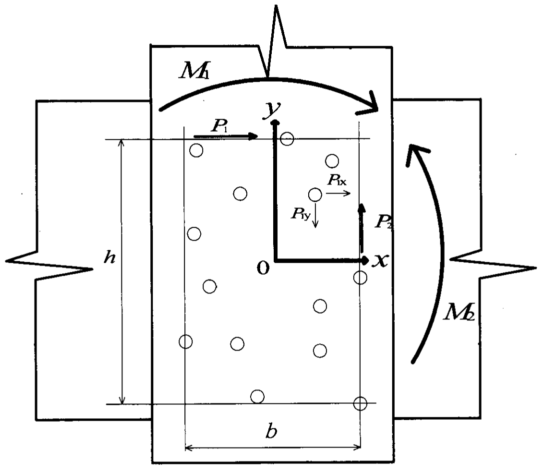

Fig. 1. Concept for mechanical model on bolted cross-lapped joint. Legend: h: distance from upper bolt to bottom bolt, b: distance from righter bolt to lefter bolt, x_i: distance from center to optional bolt in horizontal axis, y_i: distance from center to optional bolt in vertical axis.

*[1] A part of this work was presented at the 51th Annual Meeting of Japan Wood Research Society, Tokyo, April 2001.

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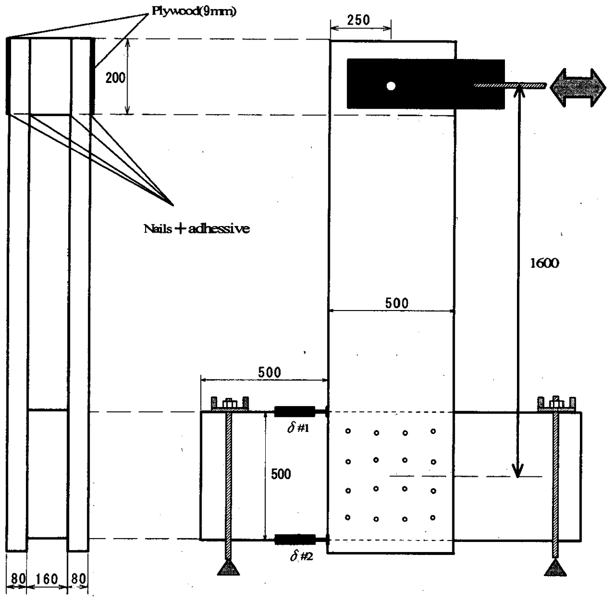

Fig. 2. Specimen for the test of bolted cross-lapped joints. Legend: Unit: mm.

stiffness and yield moment, we set following hypothesis. 1) Each member was subjected to a coupling moment M_1 and M_2. 2) The rectangular joint part (panel zone), two sets of coupling moments composed twisting moment. 3) Moment of timber is resisted by bolts with shear forces. 4) Forces could be decomposed to horizontal forces and vertical forces at panel zone. M_1 is equal to M_2. Consequently equations were derived.

Rotational stiffness (R)

$$R=\frac{\{\Sigma h^2x_i^2+b^2y_i^2\}^2}{\Sigma\frac{(h^4x_i^2+b^4y_i^2)}{K_i}} \quad (7)$$

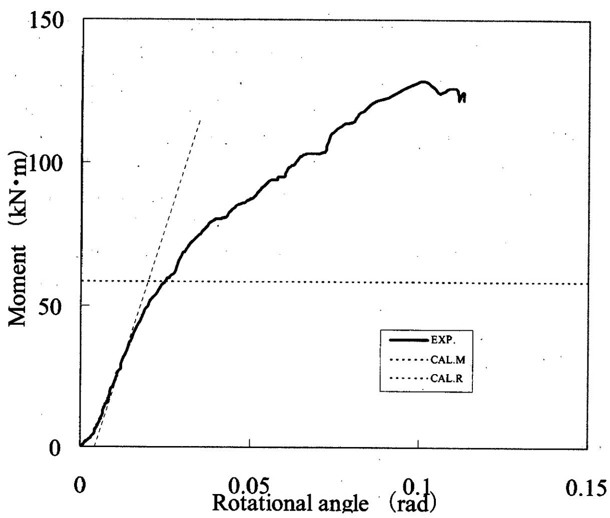

Fig. 3. Comparison between experimental result and estimating value by our proposal in bolted cross-lapped joints. Legend: EXP.: experimental result, CAL.M: yield moment by our proposal theory, CAL.R: rotational stiffness by our proposal theory.

Yield moment (M_y)

$$M_y=\frac{P_i}{\sqrt{\frac{h^4x_i^2+b^4y_i^2}{\{\Sigma(h^2x_i^2+b^2y_i^2)\}^2}}} \quad (8)$$

where, $P_i=\min(P_{yi})$

Materials and Methods

Fig. 2 shows BCLJ specimen prepared in this study. Each BCLJ specimen consists of a column (160 mm × 500 mm × 1,500 mm) and a pair of beams (80 mm × 500 mm × 2,000 mm). They were joined with bolts and formed a T-shaped assemblage. We arranged bolts allocation in rectangle or in square by changing the number of bolts from 4 to 16.

Basic conditions in this study were following: diameter of bolt was 16 mm. Length of bolt was 32 mm. Species of materials was Douglas-fir glulam, JAS grade was E105–f 300. Mean value of MC was 11%. Mean value of density was 456 kg/m^3. Thickness of main member was 160 mm. Thickness of side member was 80 mm.

Results and Discussion

Material properties for numerical calculating were adopted from the previous study[3], except for bearing properties. Bearing test of bolt was done using finished specimens.

As for the yield moment, the values by both conventional theory and our proposal were appropriate to experimental results.

While, as to rotational stiffness, estimating values by conventional theory[4] showed much higher than experimental results—about two times—in rectangular bolt-arrangement. The reason is thought that timbers at panel zone were regarded as rigid body in conventional theory. Ohashi[5] pointed out that timbers could not be assumed as rigid body in BCLJ, but condition between rigid body and soft body or elasticity. In timber-to-timber bolted joints, super imposition of forces did not work as supposed in conventional theory. While, rotational stiffness and yield moment could be predicted fairly precisely by using our proposal (in Fig. 2).

To conclude, (1) It is treacherous to use conventional theory for estimating rotational stiffness, especially when bolts arrangement was out of square. (2) Our proposal theory can predict rotational stiffness and yield moment fairly precisely even if bolts arrangement is out of square. (3) 'Semi-slip condition' makes bolts design simple. (4) From results of simulation concerning 15,000 combinations, we could derive a symbolic equation to estimate yield load based on TBEF.

Reference

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