The Seventeenth KKCNN Symposium on Civil Engineering
December 13-15, 2004, Thailand

Flexural Resistance of Steel to Wood Connection with Various Multiple-Bolt Configurations

*Ali Awaludin[1] and Watanachai Smittakorn[2]

Department of Civil Engineering, Chulalongkorn University, Bangkok, Thailand
ali.awaludin@ugm.ac.id, fcewsk@eng.chula.ac.th

ABSTRACT

Four multiple-bolt configurations of steel to wood connection are tested. Maximum moment resistance and moment-rotation curve of the connections are the focus of this study. Lateral resistance and elastic slip modulus in inclined angle to wood grain can be found by applying Hankinson's formula to the data from single-bolted connection test in various angles. Multiple-bolt configuration has a significant effect on the maximum moment resistance that can be achieved. By increasing the number of bolts in multiple-bolt connection, the effective distance between bolts is decreased. Consequently, fasteners become incapable to develop its full dowel bearing strength, and connection ductility is also decreased.

Keywords: Multiple-bolt configuration; Moment resistance; Connection ductility

INTRODUCTION

Moment-resisting connections are the most crucial parts in several types of wood structures, for example, arches and rigid frames. In multiple-bolt connection, the bending moment is counter balanced by the product of the lateral load in each fastener and its distance to the center of the group. In most cases, fasteners in the group resist lateral load in different angles to wood grain, upon which resistance varies greatly. Therefore, the moment capacity of connection is greatly affected by the fastener configuration. The use of steel plates as side members in timber connection is expected to improve the strength of connection. Based on Trayer's work (1932), the strength of steel to wood connection subjected to tension parallel to grain is 20% higher than that of wood to wood connection.

---

[1] Graduate student
[2] Lecturer

For a moment-resisting connection subjected to an applied bending moment M as shown in Fig.1(a), the applied bending moment will be counter balanced by the lateral resistances of fasteners. According to Ohashi *et al* (1989), lateral resistance of each fastener in joint depends on the slip modulus in the direction of this lateral resistance due to the orthotropic behavior of timber. By assuming that the rotation center coincides with the center of the fastener group, the equilibrium condition is given by Eq.(1) (Racher, 1995), where n is the number of fasteners. When the lateral load of fastener is inclined with angle θ to wood grain, Hankinson's formula as shown in Eq.(2) can be used. The maximum moment resistance of connection may be approximated by assuming that all fasteners reach their ultimate lateral load resistances (F_u) at the same time as in Eq.(3).

$$M = \sum_{i=1}^{n} F_i r_i \tag{1}$$

$$F_\theta = \frac{F_{//} F_\perp}{F_{//} \sin^m \theta + F_\perp \cos^m \theta} \tag{2}$$

$$M_u = \sum_{i=1}^{n} F_{ui} r_i \tag{3}$$

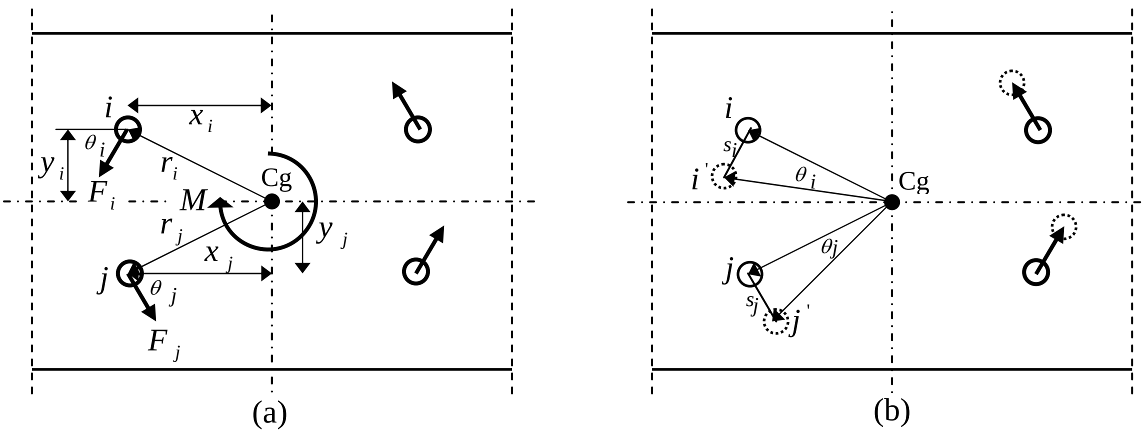

Fig. 1. (a) Acting forces at connection, (b) Joint rotation and bolt displacement

During applying bending moment, each fastener will displace to its new configuration as shown in Fig.1(b). Steel plates, as side members, are much stiffer than wood member. Deformation of steel plate is small and can be neglected. Therefore, rigid plate assumption can be applied to this case. All fasteners will displace to their new positions by the same rotation. When the most stressed fastener deforms plastically, its stiffness decreases. Since stiffer fasteners attract more loads (Blass, 1995), the rigid plate assumption gives opportunity for moment redistribution. However, the true load distribution is highly indeterminate.

The aims of this research are to investigate the moment and rotation curve of steel to wood connection subjected to bending moment, and to find out the effect of multiple-bolt configuration on moment resistance of steel to wood connection. Yield mode of wood crushing is chosen as the expected yield mode since this yield mode is quite often found in multiple-bolt connection (Taylor *et al*, 2002). Four types of multiple-bolt configurations of steel to wood connection are examined.

EXPERIMENT SET-UP

Multiple-bolt connections are tested under pure bending using the test set-up as shown in Fig.2. The test was run at a constant rate to achieve the maximum load in about 10 min. Joint rotation of connection can be measured by considering the geometry of connection as shown in Fig.3 and Eq.(4). Moment resistance at a certain joint rotation can be predicted by Eq.(5), where k is slip modulus obtained from single-bolted connection test.

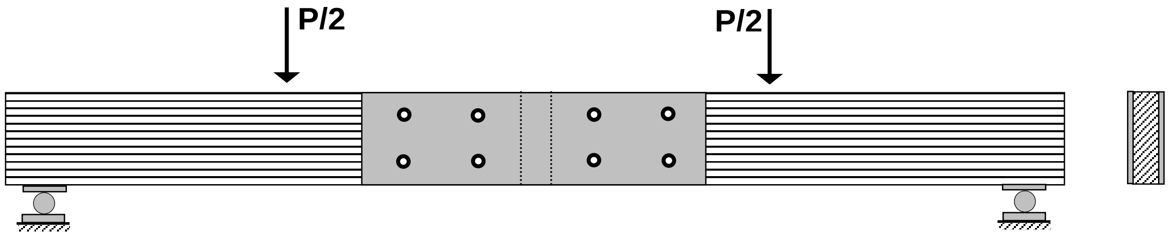

Fig. 2. Test setup of moment resisting connection

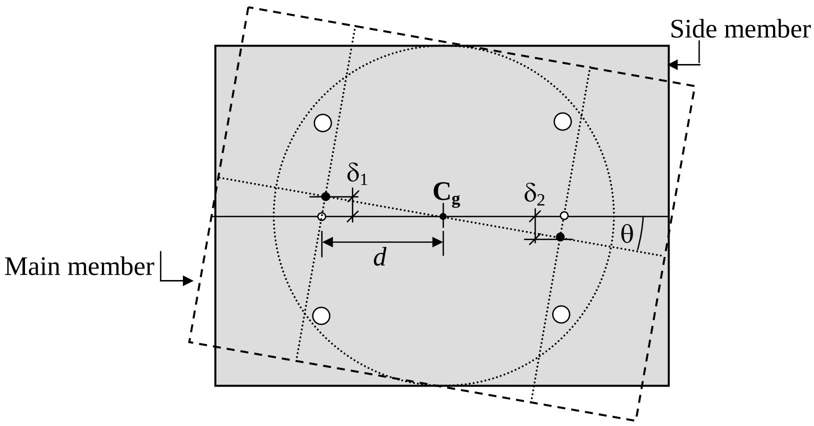

Fig. 3. Joint rotation

$$\theta \approx \frac{\delta}{d} = \frac{\delta_1 + \delta_2}{2d} \tag{4}$$

$$M = \frac{\delta}{d} \sum_{i=1}^{n} k_i r_i^2 \tag{5}$$

RESULTS AND DISCUSSION

A wood specimen (shorea obtusa) with moisture content of 14.17% and specific gravity of 0.86 is used in this research. The wood thickness is 34 mm, the steel plate thickness is 4 mm, and the bolt diameter is 12.4 mm. The bending yield stress of bolt is 606.75 N/mm^2. Test result of single bolted connections for the lateral load resistance and slip modulus in various angles to wood grain are shown in Fig.4. Hankinson's formula with m equals to 1.7 was appropriate to explain the lateral load resistance and elastic slip modulus for various loading orientations. An average value of plastic slip modulus between parallel loading and perpendicular loading to wood grain can be used to represent the plastic slip modulus for all loading orientations. The ratio of plastic slip modulus to elastic slip modulus varied from 0.07 to 0.23.

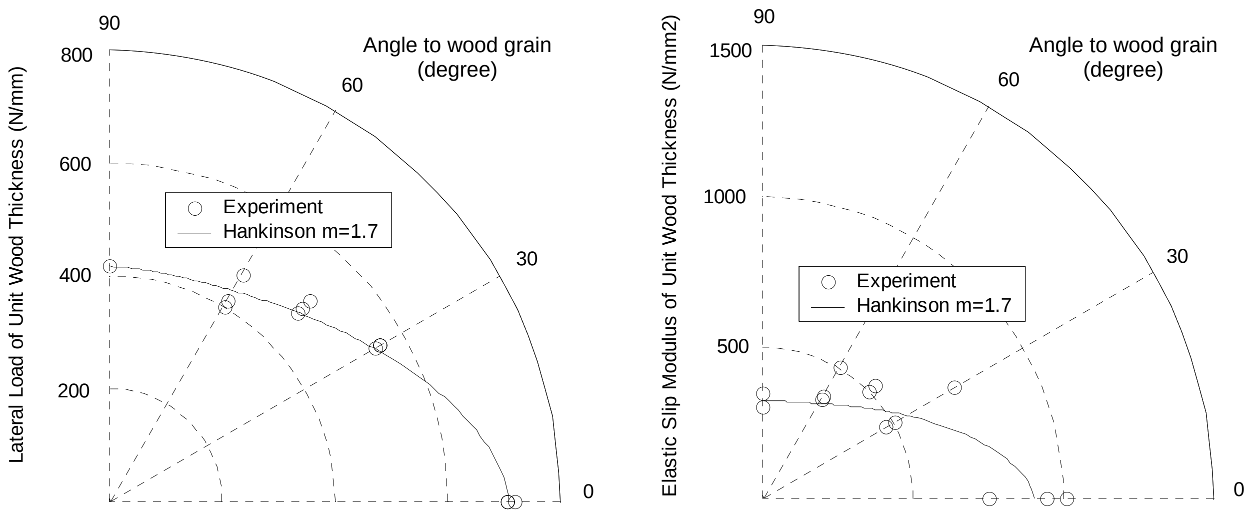

Fig. 4. Lateral load resistance and elastic slip modulus of single bolted connection

After the test for moment resistance of each connection, single bolted-connection tests for the ultimate lateral load resistance in the directions parallel and perpendicular to wood grain ($F_{u//}$ and $F_{u\perp}$) were carried out. The ultimate lateral load resistance for intermediate angle to wood grain was calculated by Hankinson's formula with the value of m equal to 1.7. The theoretical maximum moment resistance can be obtained by substituting this ultimate lateral load resistance into Eq.(3). The theoretical and experimental values of maximum moment resistances are presented in Table 1. The results show that by decreasing the effective distance among bolts due to the increment of the number of bolts or due to its multiple-bolt configuration, fasteners become incapable to develop its full dowel bearing strength. Connection of 6V gives higher ratio of moment resistance (M_{th}/M_{es} = 0.7) than that of connection 6H or 6C because its multiple-bolt configuration does not reduce the distance among bolts in row.

Table 1. Maximum moment resistance of connection

Multiple-bolt configuration	Ultimate lateral load resistance		Maximum moment resistance		
	$F_{u//}$ (kN)	$F_{u\perp}$ (kN)	Theoretical (M_{th}) (kNm)	Experiment (M_{ex}) (kNm)	M_{th}/ M_{es} (%)
4H	24.99	19.47	6.366	4.930	77
6H	24.77	16.56	8.466	3.714	44
6V	22.61	12.96	6.296	4.399	70
6C	24.66	16.48	7.005	4.105	59

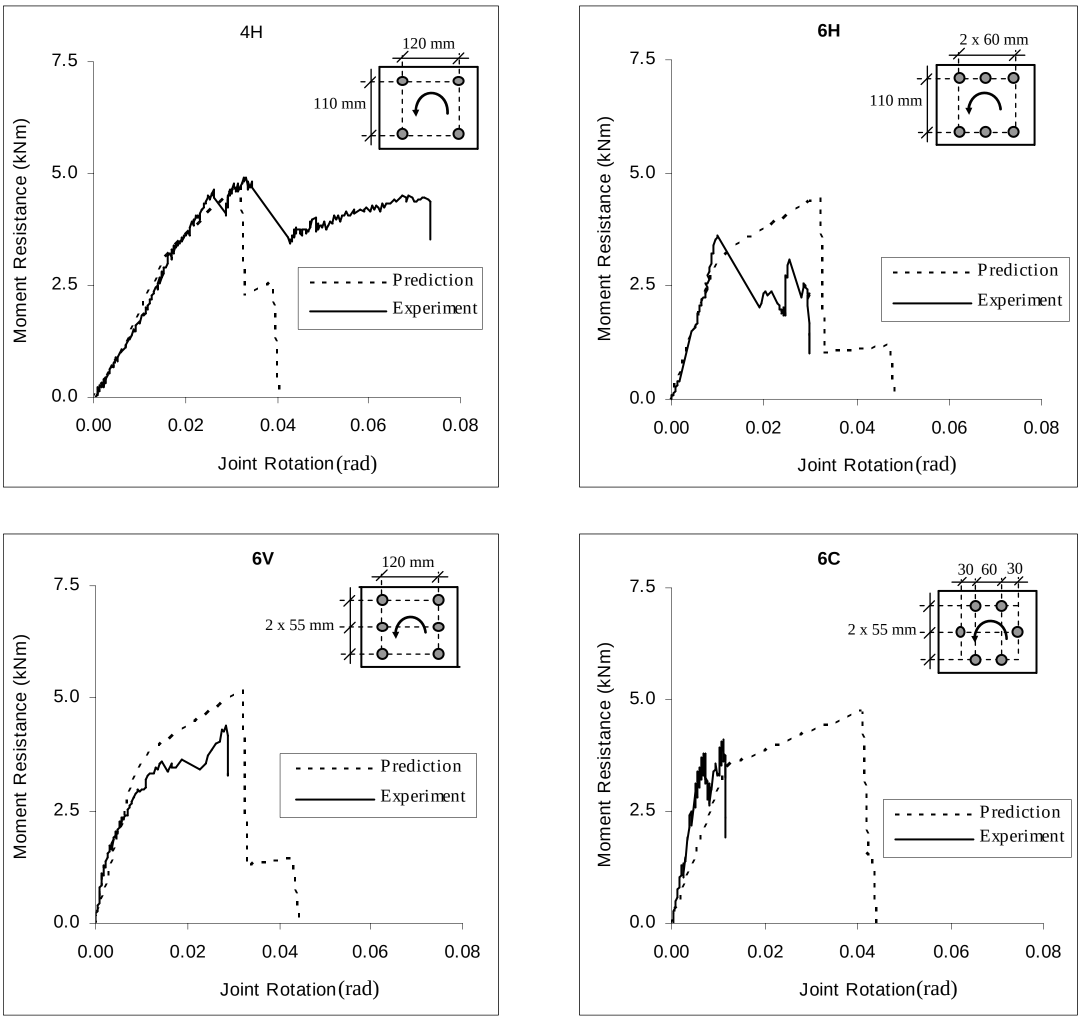

Fig. 5. M-θ curves of prediction and experiment with various multiple-bolt configurations

M-θ curve prediction can be obtained by making use of the information of fastener slip from experiment and simplified bilinear load-slip curve of single bolted-connection. The overall steps of determining the M-θ curve prediction are as follows: 1) Read displacement δ_1 and δ_2 from experiment. 2) Calculate joint rotation and slip of each fastener. 3) Define the fastener initial slip due to the different diameter of lead-hole and the diameter of bolt. 4) Find out the slip modulus of each fastener. 5) Calculate the internal moment resistance using Eq.(5). The M-θ curves of both prediction and experiment are shown in Fig.5. The M-θ curves of prediction and of experiment show a good agreement for all type multiple-bolt configurations; although for multiple-bolt configuration 6C the M-θ curve of experiment is a little stiffer. This discrepancy is due to the tightening inconsistency when bolts are embedded into connection. The connection ductility decreases when the number of fasteners increases. Multiple-bolt configuration 6V has a significant ductility compared with multiple-bolt configuration 6H and 6C. When the number of fasteners increases, the maximum moment resistance of connection tends to decrease due to insufficient distance among fasteners.

CONCLUSION

Multiple-bolt configuration has to be one of the most important considerations when designing the moment resisting connection. A significant decrease on moment resistance and ductility of connection can occur when the effective distance among fasteners of the multiple-bolt configuration reduces. Moment-rotation curve that is obtained from a simplified bilinear load-slip curve of single bolted connection test has a good agreement with the experimental result of all multiple-bolt configurations.

ACKNOWLEDGEMENT

This research was funded by AUN/SEED-Net. The authors are indebted to technician staff of Material Testing laboratory of Civil Engineering, Chulalongkorn University, for their help in preparing the test. Finally the authors would like to thank Prof. Hirai Takuro, Prof. Ekasit Limsuwan, and Dr. Anat Ruangrassamee for fruitful discussion.

REFERENCES

Blass, H. J. (1995), "Multiple fastener joints", *Proceedings of Timber Engineering STEP I*, C15/1-C15/8, Center Hount.

EUROCODE 5. (1995), Design of timber structures European pre-standard ENV 1995-1-1: general rules and rules for buildings, CEN, European Committee for Standardization, Brussels.

Ohashi, Y. and Sakamoto, I. (1989), "Study on laminated timber moment resisting joint", *Proceeding of the International Conference on Timber Engineering*, Vol. 2, 37-42.

Racher, P. (1995), "Moment resisting connection", *Proceedings of Timber Engineering STEP I*, C16/1-C16/10, Center Hount.

Taylor, R. J. and Line, P. (2002), "Is your wood connection all stressed out? – It needn't be!", *Wood Design Focus.*

Trayer, G. W. (1932), "The bearing strength of wood under bolts", *Tech. Bulletin. 332*, U.S. Dept. of Agric., Washington, D.C., Oct.