EXPERIMENTAL STUDY ON MOMENT RESISTING JOINTS USING GROOVED STEEL PLATES FOR TIMBER RIGID FRAME STRUCTURE

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Abstract

In Japan, most of wooden houses are constructed by conventional framework construction method. They resist large earthquakes by enough quantity of bearing walls arranged in well balance on each floor. On the other hand, these walls strongly interfere with the freedom of plan. In recent years, various kinds of timber rigid frame structures have been proposed. In comparison with conventional framework construction, this type of systems allows wider openings and more flexible planning. In order to realize this system, it is very important to preserve enough strength and rigidity for moment forces in their joints. Generally speaking, special steel hardware is used to connect columns and beams tightly. However, a large number of ironware make the construction complex and the construction cost increases. Structurally, because of the extreme difference of stiffness between steel and wood, all damages are concentrating on the very local parts of wood touching with steel and they decide the performance of this system.

Yasuda and Ozawa proposed before a new type of moment resisting joint for timber rigid frame structure [1]. Columns and beams have grooves with saw-tooth shape on their contact surfaces and the rotational rigidity is obtained by engagement of the grooves. Steel bolts are utilized only for introducing pre-stress on the contact surfaces and stresses are transferred directly from wood to wood without going through ironware. A number of experiments were conducted by the authors and they showed high rigidity especially in their initial stage. However, all damages occurred in the grooves which accept forces in the orthogonal direction to the fiber and weakness of wooden material in this direction prevented further enhancement of the joint performance (Fig. A1).

On the basis of this previous research, a new improvement method for this type of joints is proposed in this research (Fig. A2). The major point is to insert steel plates between columns and beams. These plates have also grooves in both sides and the grooves on one side are orthogonal to the grooves on the other side. By connecting them via these plates, the grooves on both columns and beams are always applied stresses in the fiber direction and drastic improvement can be expected in terms of strength and rigidity. To confirm the performance of this new jointing system, bending tests using some types of specimen were conducted and the structural characteristic were examined in this paper.

Keywords: Rigid Frame Structure; Moment Resisting Joint; Saw-tooth Shape Groove Joint; Grooved Steel Plate;

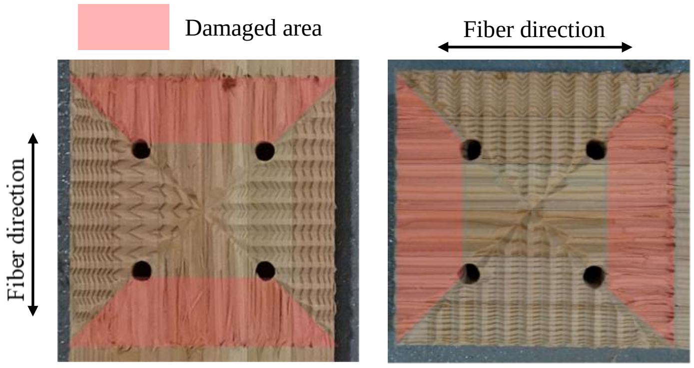


Fig. A1 - Condition of damage after experiments

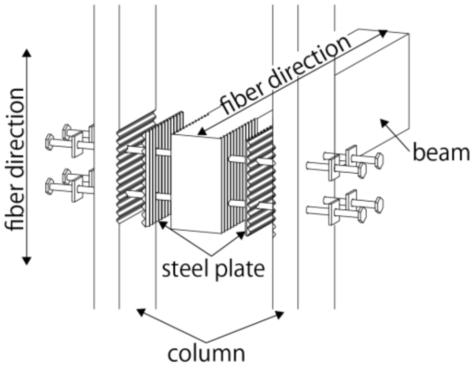
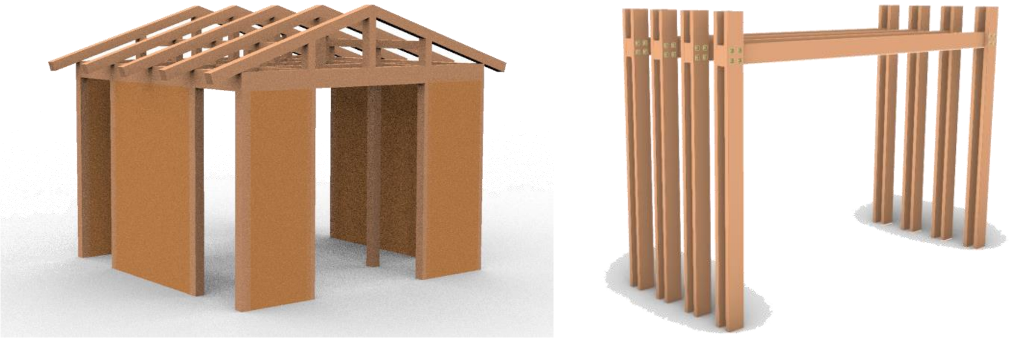


Fig. A2 - Joint with grooved steel plate

1. Introduction

In Japan, most of wooden houses are constructed by conventional framework construction method. They resist large earthquakes by enough quantity of bearing walls arranged in well balance on each floor. On the other hand, these walls may interfere with the freedom of plan. Especially in urban area in Japan, there are large number of houses with narrow frontage and it is difficult for this type of houses to secure lateral walls. If it is possible to built them by timber rigid frame structures, it allows wider openings and the freedom in layout must be drastically improved (Fig.1). To realize timber rigid frame structures, the most important point is to acquire enough rigidity for their beam-column joints. So far various types of rigid joints have been developed, and various experiments were conducted to evaluate thier structural characteristics of the joints ([2], -[3], -[4]). In most cases, special steel hardware is used to connect columns and beams tightly. However, a large number of ironware make the construction complex and construction costs increases. From the viewpoint of structual performance, due to the extreme difference of stiffness between steel and wood, all damages are concentrating on the very local area of wood touching with steel and it decides the performance of this system.



(a) Conventional Framework Construction (b) Timber Rigid Frame Structure

Fig. 1 – Comparison of construction method

2. Outlines of Saw-tooth Shape Joint

Yasuda and Ozawa proposed before a new type of moment resisting joint for timber rigid frame structures [1]. This joint connects coupled columns and a beam (Fig.2). The columns and the beams have grooves with saw-tooth shape section on their mutual contact surfaces, and the rotational stiffness is obtained by the engagement of the grooves. Steel bolts are utilized only for introducing pre-stress on the contact surfaces and timber members are tightened by minimum number of four bolts. Stresses are transferred directly from wood to wood without going through ironware. A number of experiments have been conducted by the authors and they showed high rigidity and toughness. However, all damages occurred in the grooves which accept forces in the orthogonal direction to the fiber (Fig. 3), and weakness of wooden material in this direction prevented further enhancement of the joint performance.

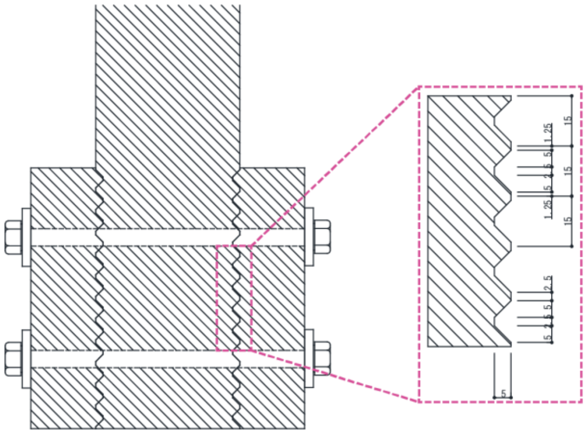


Fig.2 – Cross section of joint and detail of groove

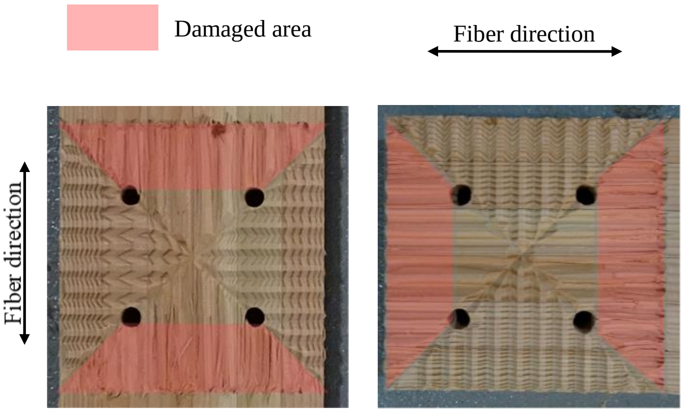
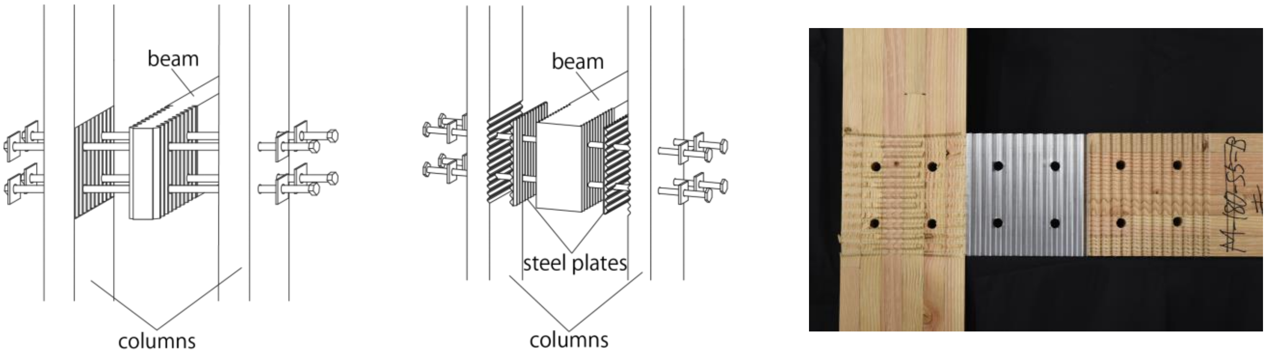


Fig.3- Condition of damage after experiments

3. Proposed Method

On the basis of the previous research, a new improvement method for this type of joints is proposed in this research (Fig.4). The major point is to insert steel plates between columns and beams. These plates have also grooves in both sides and the grooves on one side are orthogonal to the grooves on the other side. As the result, all grooves on wood always accept stresses in the fiber direction, and drastic improvement can be expected in terms of strength and rigidity.



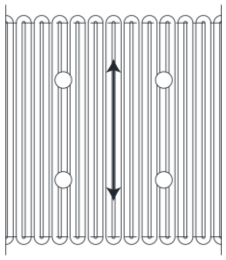
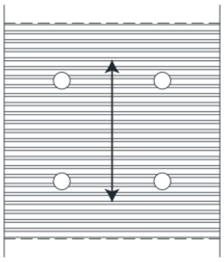
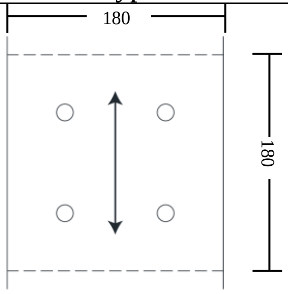
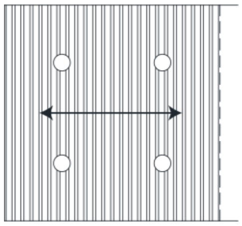
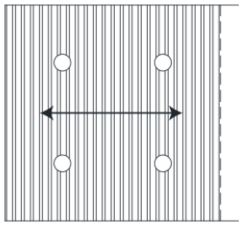
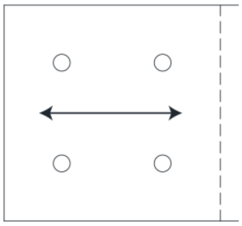
(a) Previous research (b) A new method (c) Actual joint

Fig.4 – Composition of joints

4. Bending Tests of Beam-column Joints

Specimens used in bending tests were made of Douglas-fir glulam. There are 3 types of joints in this research (Table 1). Type E is the basic model and the columns have grooves in the parallel direction to the fiber and the beams have grooves in the orthogonal direction. Type S is the new type of joints proposed in this paper. Both columns and beams have grooves in the orthogonal direction to the fiber. Type F is the model without grooves ready for comparison.

Table 1 – Each joints shape

	Type E	Type S	Type F
column			
beam			

↔ fiber direction

4.1 Methods of bending tests

Bending tests were conducted by displacement-controlling method (Fig. 5). Fig. 6 shows the cyclic loading schedule for both directions.

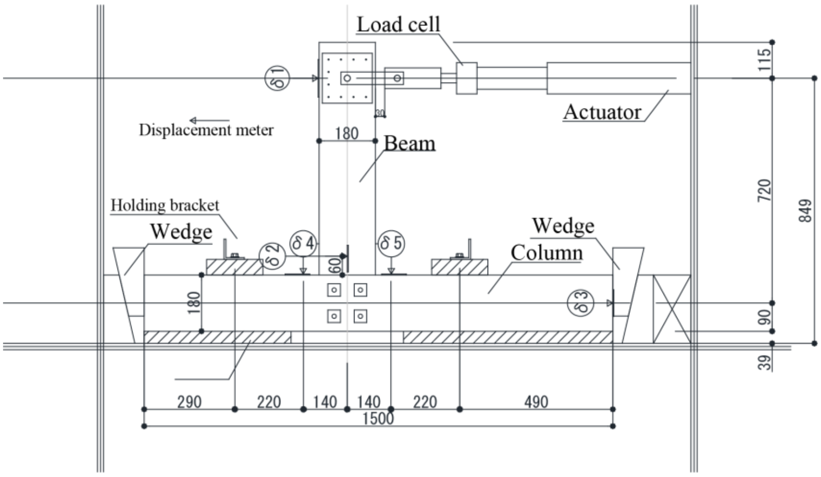


Fig.5 – Experimental device

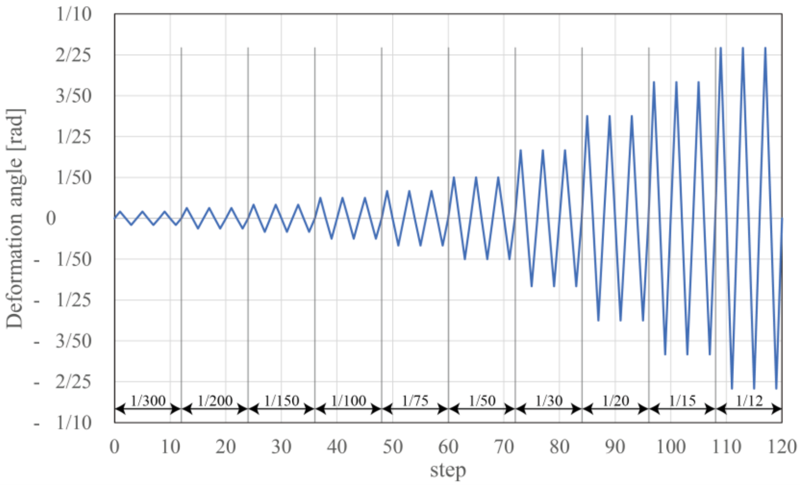


Fig.6 - Schedule of loading

After acquiring experimental data, rotational stiffness can be calculated to evaluate structural performance of this system. M and θ can be obtained by below equations (1) and (2). L_1 indicates the distance from the center of column to the loading point (in this study, L_1=720mm). L_2 is the distance between δ4 and δ5 (in this study, L_2=280mm). D_4 and D_5 are the displacements measured by displacement gauge δ4 and δ5 represented by Fig. 5 respectively.

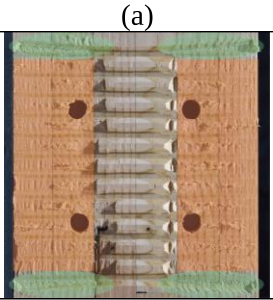
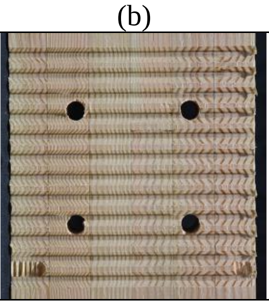
$$M = P \times L_1 \tag{1}$$

$$\theta = (D_4 - D_5) / L_2 \tag{2}$$

4.2 Results of bending tests

Table 2 shows the typical failure mode of each joint type. Red and Orange shade means that crushed damage and shear failure occurred in each area. In green shade area, it can be found that grooves on steel plates ends sank into wood.

Table 2 – Failure mode of joints

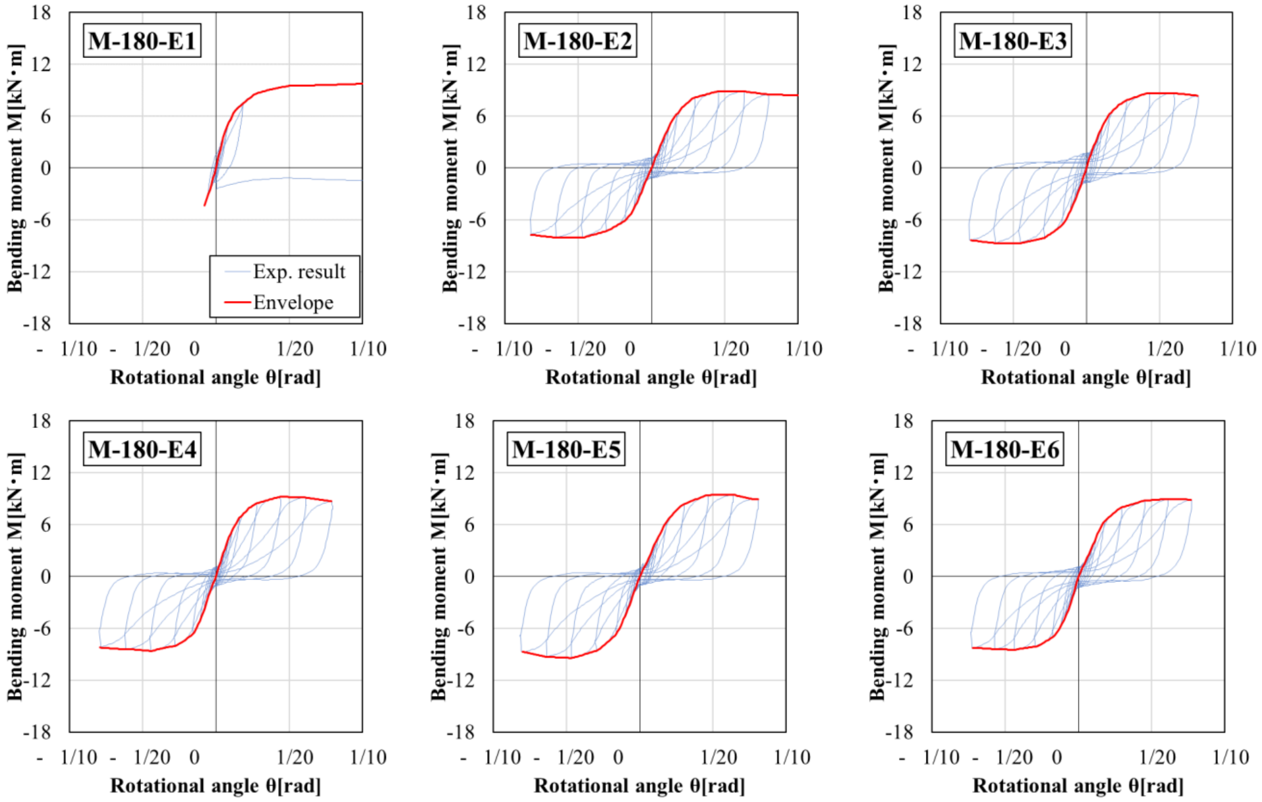
	Type E	Type S		Type F
		(a)	(b)	
column				
beam				

🟥 Crushed area 🟧 Shear failure 🟢 embedment

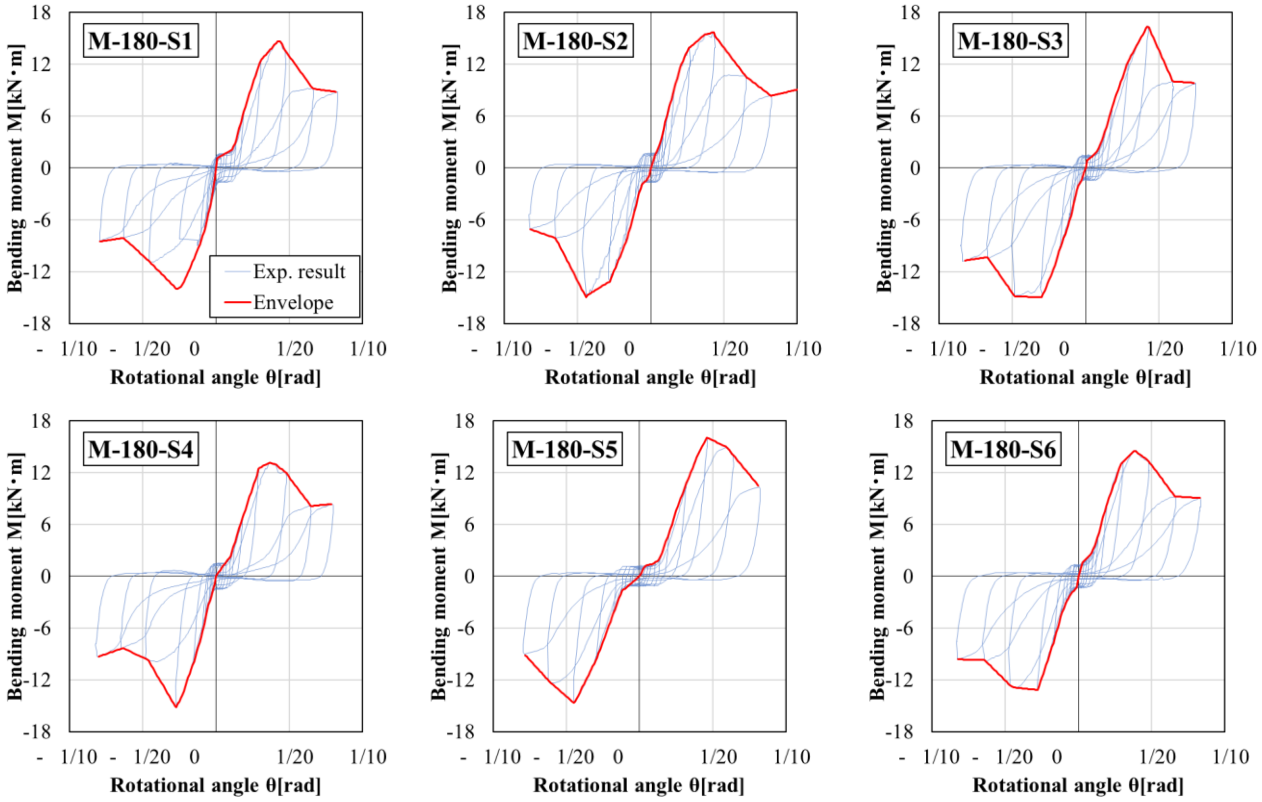
About Type E model, all damages are concentrating on the side of column. In particular, since large stresses act on the outer area of joints, the outer grooves than bolt-holes are significantly damaged. On the other hand, no large failure cannot be observed on beams' grooves.

There are two types of failure mode on specimen of type S, one is that the grooves on the column side are severely damaged (Table 2(a)), and the other is that the beams have large damages on the grooves (Table 2(b)). In this type of model, grooves are scraped off by shear force in the surface parallel to the fiber.

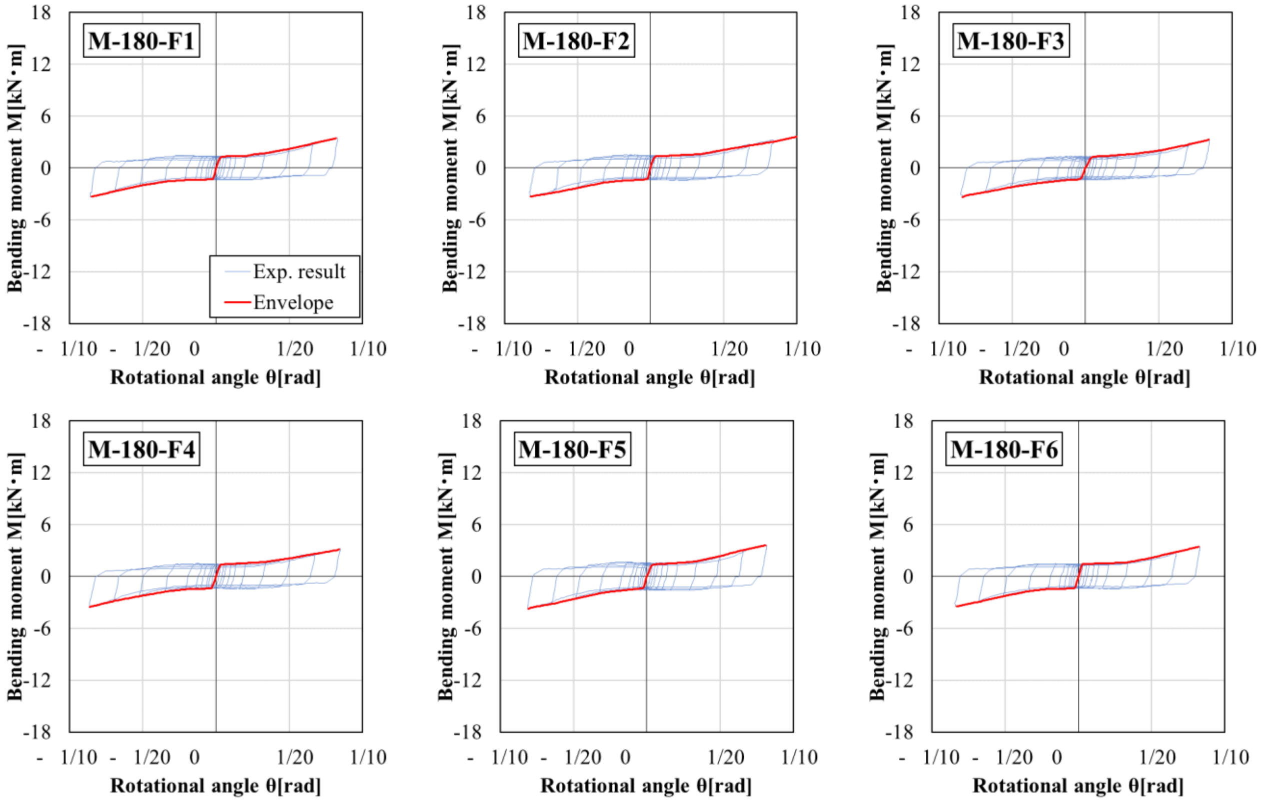
The specimens of Type F are damaged slightly on the area around the bolt-hall. It is obvious from these results that the main resistant mechanisms are the combination of the embedment of bolts and the friction on contact surfaces.



(a) Type E



(b) Type S



(c) Type F

Fig.7 - Experimental result

Fig. 7 shows the experimental results of moment-rotational angle relationship and their envelope curves.

The hysteresis loops of Type E show elastic behavior until the rotational angle reach around 1/75 rad. After that, they obtain maximum moment while losing the stiffness gradually. Then the bending strength is slowly decreasing. As a whole, it is possible to mention that very stable history is obtained even after the grooves are strongly damaged.

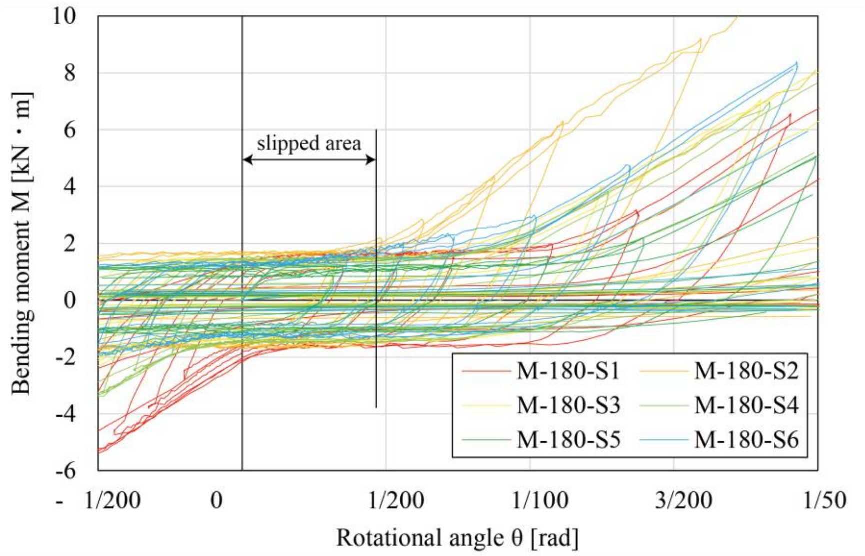


Fig. 8 – The section of the slip

Models of Type S have the range that stress is sliding in the initial stage of the bending moment-rotational angle relationships (Fig.8). After that, bending moments increase elastically up to around 1/30rad. Just after reaching bending yield strength at around 1/25 rad, it shows relatively rapid decrease until around 9 kN･m. After that it can be seen that Type S joints maintains enough strength more than 8 kN･m even in their final stage.

Type F show long range where their contact surfaces are sliding in their rotary direction after the load reaches around 1.5 kN･m. After a point of around 1/30 rad, the load increases gradually up to around 3 to 4kN･m.

4.3 Comparison between Type E and Type S

Fig. 9 shows the comparison between the average envelope curves for each type. Table 3 shows structural performances of joints evaluated from the results.

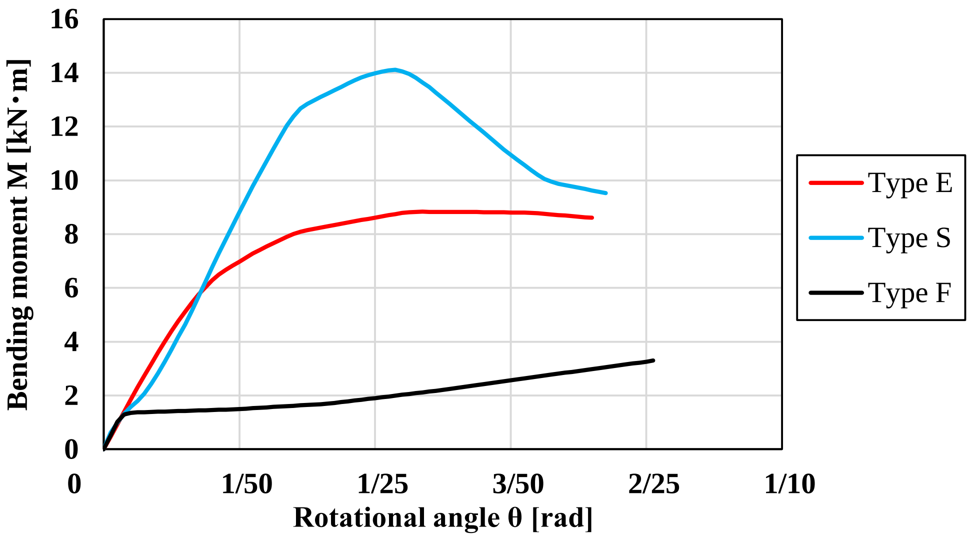


Fig.9 – Comparison of averaged envelope curve

Table 3 - Structural performance

	Yield moment	Yield rotational angle	Rotational stiffness	Maximum moment	Rotational angle of maximum moment
	M_y [kN･m]	θ_y [rad]	K [kN･m/rad]	M_{max} [kN･m]	θ_{max} [rad]
Type E	5.66	0.013	421.17	8.87	0.055
Type S	6.36	0.016	397.50	14.11	0.043
Type F				3.42	0.084

In comparison with Type E, both yield moment and maximum moment of Type S are improved. Especially, maximum moment of Type S is about 1.6 times higher than that of Type E. On the other hand, the rotational stiffness has decreased by about 5%. It is caused by the slip motion of Type S appearing in their initial stage.

5. Conclusion

In this paper, a new method of moment resisting joint for timber rigid frame structures was proposed. Bending moment tests were conducted to evaluate structural performance of this system.

There are significant differences between the structural characteristics of Type E and Type S. The maximum moment of Type S is about 1.6 times higher than Type E. On the other hand, after reaching the maximum load, the moment of Type S decrease more rapidly than that of Type E. However, it is also important feature that even after the strength deterioration, the load of Type S keeps more strength than Type E.

There was an unexpected phenomenon that stress of Type S is sliding in the initial stage. The machining errors generated during grooving is estimated as the main cause of this undesirable behavior. It is necessary to reconsider the groove shape that can absorb machining error in order to improve structural performance of this system.

6. Acknowledgements

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7. References

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