STUDY ON STRUCTURAL BEHAVIOR OF MOMENT RESISTING JOINT BY MAKING USE OF WOOD DENSIFICATION TECHNIQUE

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Abstract

Timber rigid frame structure is a novel and attractive system. Because of unnecessity of aseismic reinforcing elements like walls and bracings, it allows wider opening and more freedom of planning than conventional framework construction that is most common in Japan. To effectively use this system, it is a critical point to develop moment resisting joints with high strength and rigidity. So far various jointing systems have been proposed and in most cases, they need large number of hardware made of steel to connect columns and beams tightly. However, the use of ironware makes the construction process complex and it causes cost increase. Moreover, because of the extreme difference of stiffness between wood and steel, stress concentrates on narrow area directly touching with steel and the very local damage determines the performance of this system.

The author have proposed a new type of moment resisting joints for timber rigid frame structures. Columns and beams have grooves with saw-tooth shape section on their contact surfaces and the rotational rigidity is obtained by the engagement of the grooves. Some steel bolts are utilized only for introducing pre-stress on the contact surfaces and internal stress is transmitted directly from wood to wood without going through ironware. Lots of experiments proved that the joints had high initial stiffness and toughness of their behavior. However, all damage occurred on the grooves receiving pressure in the orthogonal direction to the fiber and the weakness of wooden material in that direction set a limit to the performance of this system.

In this paper, by making use of wood densification technology, a new approach to improve the efficiency of this system is proposed. Wood densification is an efficient technique to enhance material properties and it has already utilized to produce not only finishing materials but also structural elements. By replacing the part of contact surface with structural panels made from densified wood, it is possible to heighten the performance of the joints. Six specimens were prepared for moment tests. In this research, laminated densified wood(KHP dehonit) were used as the panel material and CNC router cut grooves on them very precisely. Finally, they were installed on the contact surfaces by resorcinol resin adhesive. By comparing average values of the new method with the old one, maximum moment shows about 40% increase. They shows remarkable improvement of the new method. However, some types of brittle fracture, such as peeling on glued surface, split of joint panel and tensile breaking, were observed. By taking measure to prevent these brittle failure, there remains a great possibility to achieve a significant improvement.

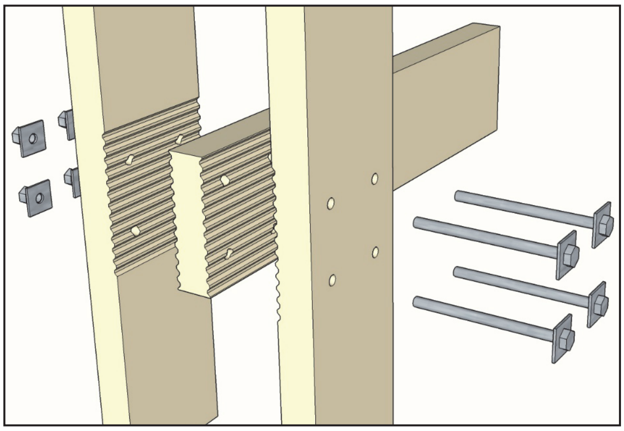
Keywords: Keywords: Timber rigid frame structure; Moment resisting joint; Wood densification

1. Introduction

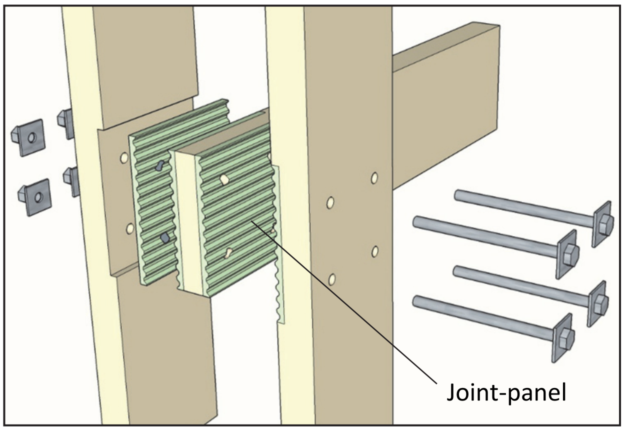
Timber rigid frame structure is a novel and attractive system. Because of unnecessity of aseismic reinforcing elements like walls and bracings, it allows wider opening and more flexible planning than conventional framework construction that is most common in Japan. To effectively use this system, it is a critical point to develop moment resisting joints with high strength and rigidity. So far various jointing systems have been proposed and in most cases, they need large number of hardware made of steel to connect columns and beams tightly. However, the use of these ironware makes the construction process complex and it causes large increase in cost. Moreover, because of the extreme difference of stiffness between wood and steel, stress concentrates on narrow area directly touching with steel and the very local damage determines the performance of this system[1].

The author have proposed a new type of moment resisting joints for timber rigid frame structures(Fig. 1(a))[2]. This is one of the developed styles of joint with serrated surface that was proposed by Idota et al[3][4] and it has been revised by the author to suit Japanese individual housing built in narrow area. Columns and beams have grooves with saw-tooth shape section on their contact surfaces and the rotational rigidity is obtained by the engagement of the grooves. Some steel bolts are utilized only for introducing pre-stress on the contact surfaces and internal stress is transmitted directly from wood to wood without going through ironware. Many results of experimental results prove that this system have high rigidity especially in the early stage of the behavior. However, all damage occurs on grooves which accepted pressure in the orthogonal direction to the fiber and the weakness of wooden material in that direction set a limit to the performance of this system.

In this paper, by making use of wood densification technology, a new approach to improve the structural performance of this system is proposed(Fig.1(b)). Wood densification is an efficient technique to enhance material properties and it has already utilized to produce not only finishing materials but also structural elements[5][6]. By replacing the part of the contact surfaces with structural joint-panels made from densified wood, it must be possible to overcome the weakness of this system.



(a)Original Model



(b)Proposed Model

Fig. 1 – Original model and newly proposed model

2. Outline of Experiments

In order to evaluate the structural performance of the newly proposed method, moment tests were conducted in the laboratory at Technical University of Dresden. Fig 2 shows the details of the specimens prepared for the tests. The columns and beams were made of Spruce laminated lumber GL24H. In this research, instead of normal densified wood, densified laminated veneer lumber(KHP dehonit) material was adopted as the material of the joint panel because of its high availability. Fig.4 shows CNC router cutting the required profile(shown in Fig.3) into the KHP plate. Finally, the completed joint panels were installed firmly on the contact surfaces by resorcinol resin adhesive(Bakelite® PF 0283 HL). After curing, coupled columns and a beam were united with 4-M12 steel bolts by applying 22kN･m torque. Totally six test-specimens(No.1-6) were ready for the tests.

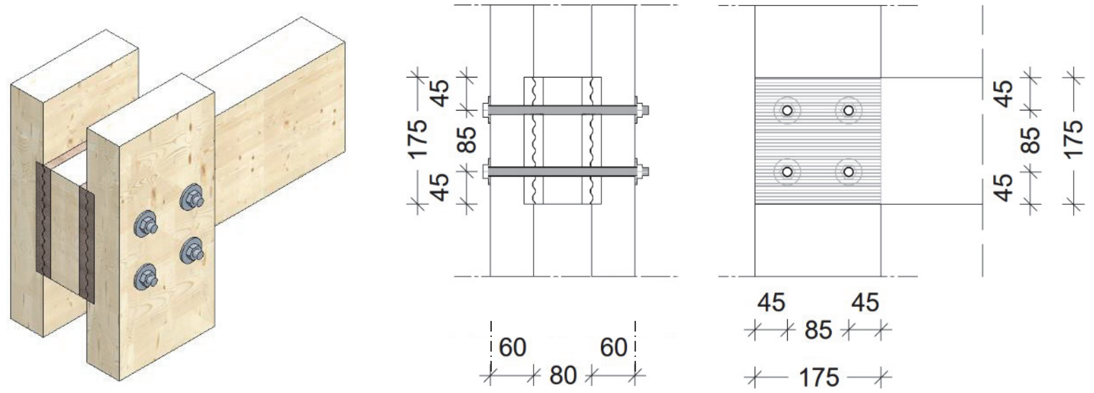


Fig. 2 – Details of specimen

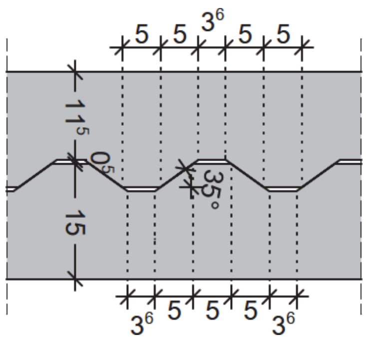


Fig. 3 – Groove profile

Fig. 4 – CNC router grooving on KHP panel

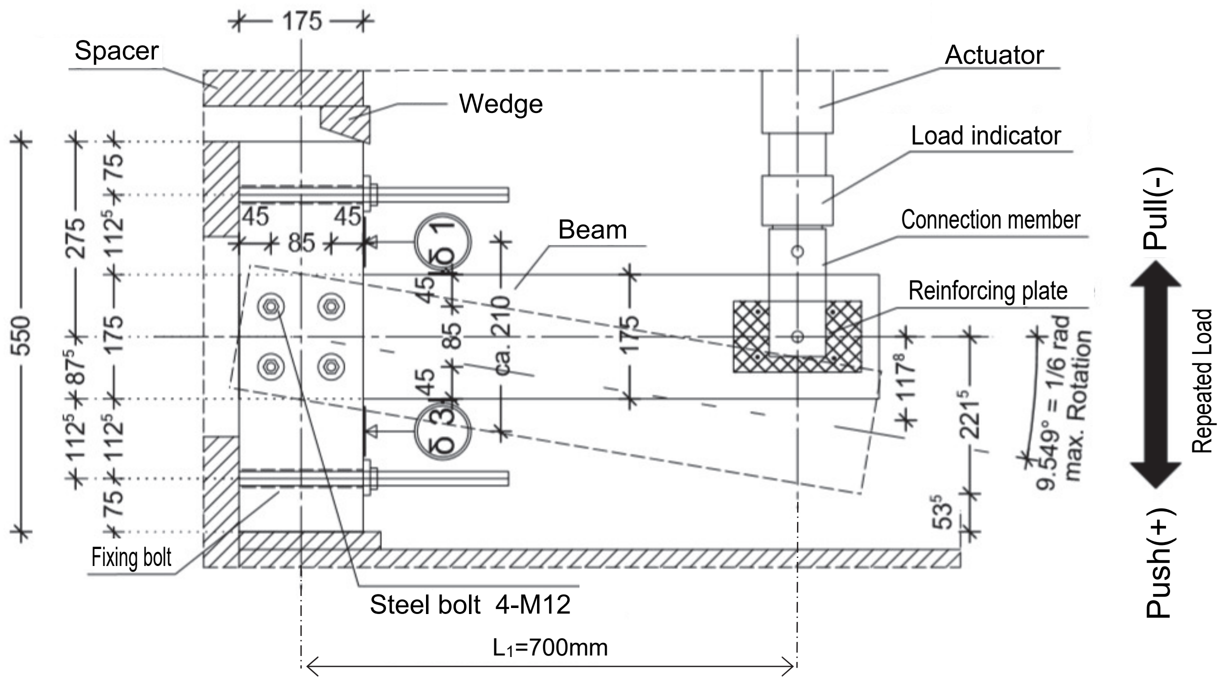


Fig. 5 – Outline of moment tests

The summery of the tests is shown in Fig.5. Each specimen was fastened tightly on test-bed by using screw steel bars. Four displacement gauges(δ_1-δ_4) were installed to measure the rotation angle of the joint part. The specimen was loaded on the positive and negative side repeatedly by hydraulic actuator operated by a servo system. In this research, pushing side was set as positive. The loading process was advanced by displacement control method on the schedule displayed by a gray line at Fig. 6.

Moment M can be calculated by the following equation.

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

where, P is the load measured by the load indicator and L_1 is the distance from the center line of the column to the loading point.

In terms of rotation angle θ, it can be obtained by

$$\theta = \frac{(\delta_1+\delta_2)/2 - (\delta_3+\delta_4)/2}{L_2} \tag{2}$$

where, δ_1 and δ_2 are the displacements measured by gauges on the tension side and δ_3 and δ_4 are the ones on the compression side. L_2 is the distance between the gauges on both sides of the joint. L_2 was set to 210mm in this research.

3. Results of experiments

3.1 Loading schedule

The red line at Fig.7 shows the actual schedule of displacement control process with the planned schedule indicated by a gray line. It can be seen that the actual schedule was deviating from the plan.

Fig. 7 shows the actual history of bending moment and the actual rotation angle. It can be seen that the moment history is asymmetric respect to the horizontal axis. This phenomenon occurred by the malfunction of pulling ability of the actuator due to any reason. Therefore it can not generate more than 12kN pulling force(equivalent to 8.4 kN･m in bending moment shown in Fig.7) though there was no problem for pushing process.

Accordingly, thereinafter, the structural performance of this system will be discussed by using only the pushing side results considered to be as reliable data.

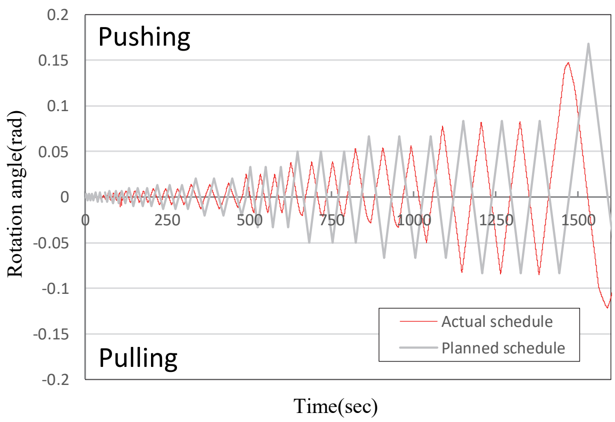


Fig. 6 – Loading schedule

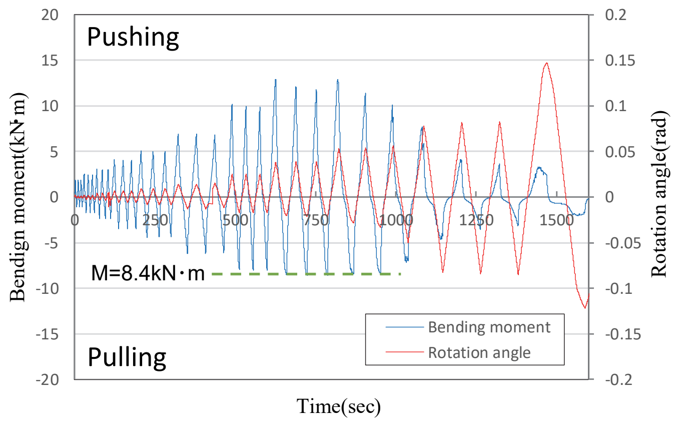


Fig. 7 – Bending moment and rotation angle

3.2 Destruction conditions

Fig.8 shows some representative results of damaged condition.

Almost all damages occurred on the joints parts of the beam. It can be divided following three types of destruction conditions.

(a)Breaking on tension side No.1, No.4

(b)Cleaving No.2, No.3, No.5

(c)Sliding along the grooves No.6

No.1 and 4 specimens suddenly fractured in a brittle way by breaking on tension side of beam after achieving maximum moment(Fig. 6(a)). Then, the adhesive surfaces between beams and joint-panels were peeled off and the panels split along the veneer layer of KHP material because the split tensile strength of this material in the orthogonal direction to the adhesive surface is not so large.

Cleaving along annual rings is the most frequent breaking condition in this research(shown in Fig.6(b)). Peeling of the adhesive surface can also be recognized at the same time. In the uppermost photo of Fig.8(b), it is possible to see that the end section of beam was split into 5 parts because of internal tensile breaking occurring around bolts area. It is also a typical type of brittle fracture.

No.6 was the only specimen enduring large moment without brittle fracture(shown in Fig.6(c)). The behavior was very stable and tough, and the only detectable damage to see was small breaks and dents on the grooves. It can be say that the destruction property of this model is the most desirable.

(a)No.1, No.4 (b)No.2, No.3, No.5 (c)No.6

Fig. 8 – Destruction conditions

3.3 Moment-rotation angle relationship

Fig.9 shows the moment-rotation angle relationship for all the 6 specimens with their envelope curves.

After achieving the maximum values, moment dropped very rapidly in all specimens except for No.6. Especially, there are very rapid loss of strength when the tensile side of beams is broken(see Fig.9(a) and (d)). On the other hand, the behavior of No.6 is very stable and the energy absorption is large enough. In order to realize stable and tough system as rigid frame structures, it is very important to secure enough section for beams in comparison with the joint strength.

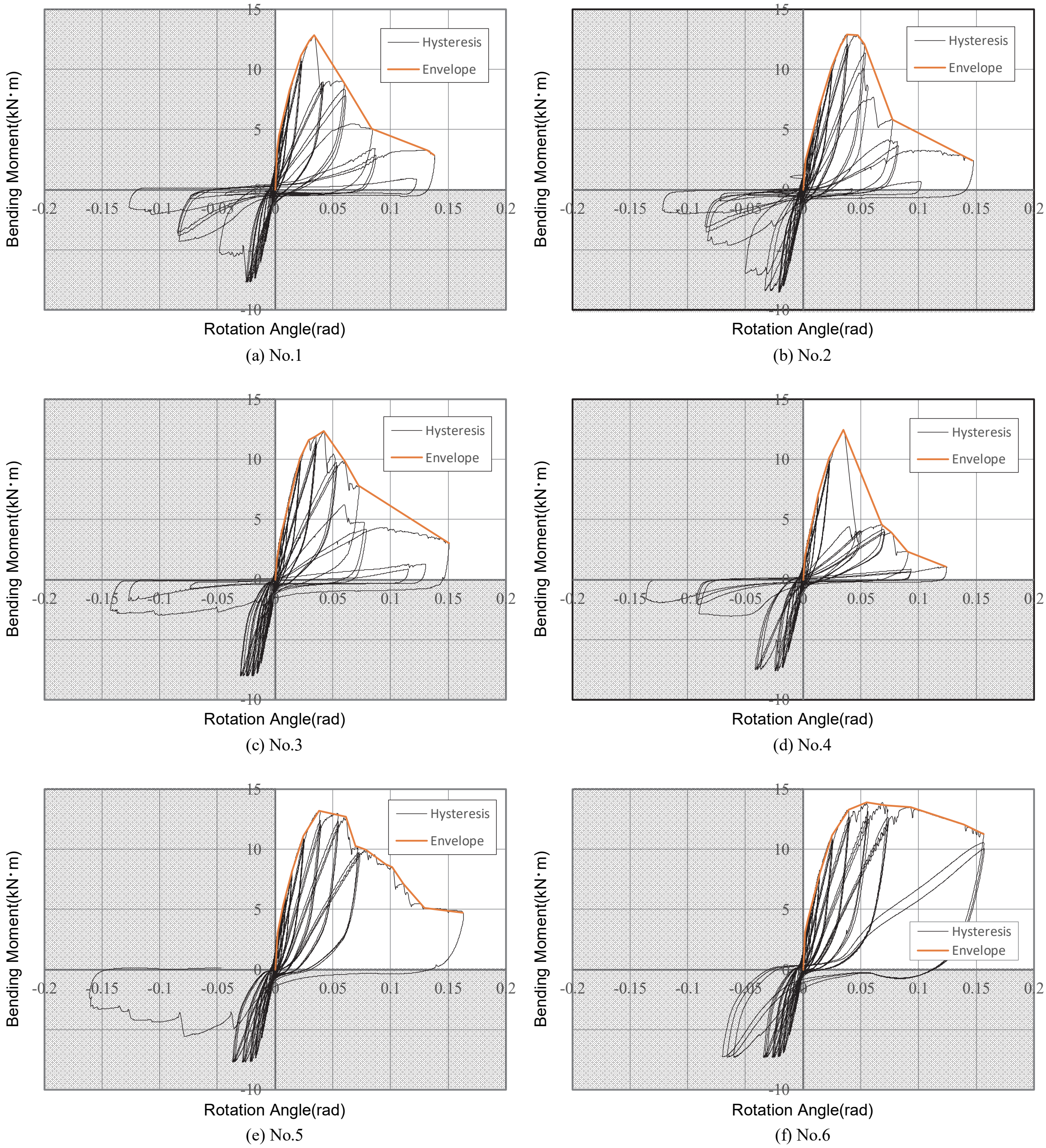


Fig. 9 – Moment-Rotation angle Relationship

4. Comparison with the original models

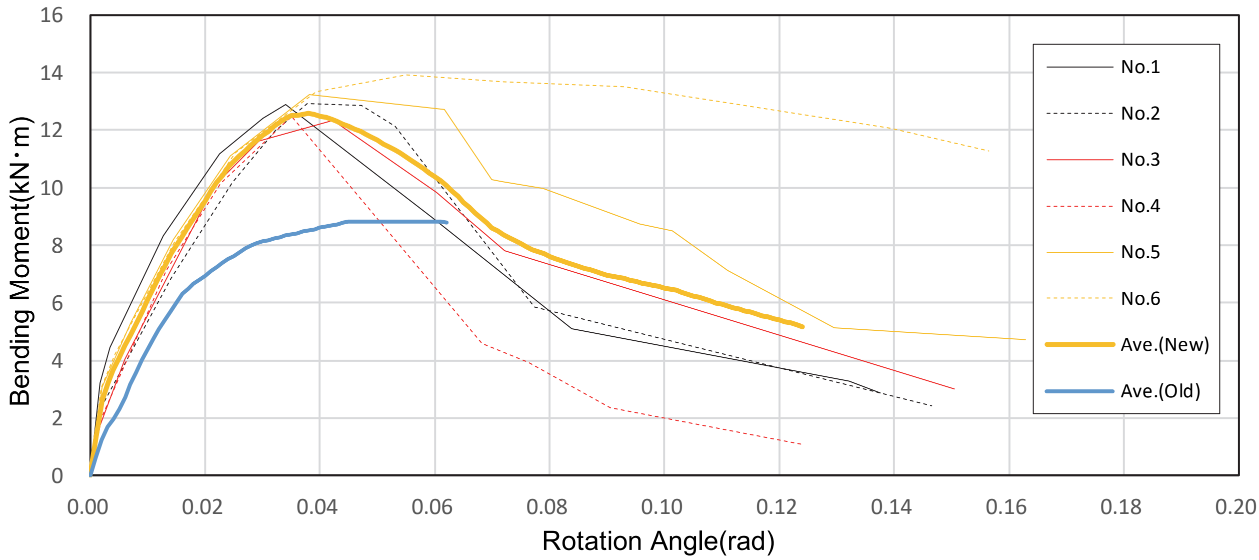


Fig. 10 – Comparison between proposed method(New) and old one(Old)

Fig.10 shows a gathering of the all envelope curves shown in the previous figure. The orange bold line indicates the averaged line of the curves and the blue line is the one of old models'. The maximum value of new one is about 1.4 times higher than the old. In addition, the new type shows very high initial stiffness without any backlash. Especially, the high performance of No.6 alone deserves special attention.

5. Conclusion

In this paper, a new method to improve moment resisting joints using groove engagement is proposed. The feature of this system is to utilize wood densification technique to enhance the structural performance of the joints.

In order to evaluate the performance and to grasp its destruction property, moment tests using six specimens were conducted. The results show some types of rupture style including brittle damage type like tensile side breaking. One specimen demonstrated very desirable performance without fragile damage and showed great potential of this improvement method. It is extremely important and not so difficult to avoid brittle fracture that results in rapid loss of moment strength by using beams with enough section property..

6. Acknowledgement

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7. References

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