Evaluation of Mechanical Behavior on Traditional Timber Interlock Joint and Its Structural Applications

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Japanese traditional timber structures mainly consist of interlock joints and therefore have lasted against earthquakes. This is because resistance of the interlock joint depends on compression perpendicular to the wood grain and friction between wood members, which are able to show large ductile deformation different from other wooden characteristics. However detailed study has not been performed about mechanical behavior of the joint. In this study, Nuki joint as a representative of traditional joints was investigated especially being focused on the initial stiffness. The re-evaluation on the mechanical behavior of the joint and structural elements was carried out depending on the latest knowledge and technology, and its practical application to the modern building was considered by giving improvement on the joint. There have been a lot of remained uncertain factors on the evaluation of interlock joints. Therefore, quantitative approach was performed step by step in each level of structural components, which are material, joint and structural element, fundamentally by depending on mechanical models and experiment, aiming to contribute to the improvement of accuracy of design method.

Firstly, in terms of material properties, embedment and friction characteristics were studied. Especially the influence of supporting condition on the apparent elastic modulus of partial compression was focused. A finite element method was used in order to investigate the difference of surface deformation between the models with different additional length and boundary conditions. Those tendency obtained by the model was verified by the accurate experimental result in which the influence of friction was removed. Finally factors of surface deformation were proposed on the equations for structural designing [1]. Moreover, basic material properties such as elastic modulus and strength on compression perpendicular to the grain, and coefficient of friction were analyzed depending on the experiment, and their influence on the embedment property was quantitatively verified. As a result, the problem of double standard in terms of usage of material properties was solved on current design formulas.

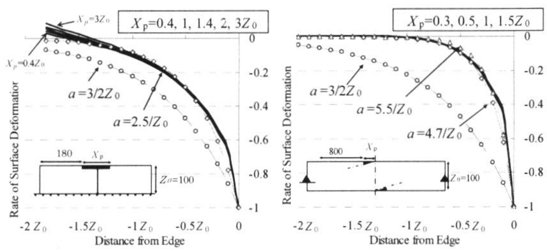

Figure 1. FE result of surface deformation at additional part in different support condition.

Then structural behavior in the joint level was studied focusing on Nuki joint in which embedment and friction are the fundamental resisting factors. In particular, the influence on the stiffness by wedge insertion and generation of gap were studied, which have been neglected in practical design though high improvement with wedges or reduction by gaps on the stiffness are observed in actual experiments. Those influences were analyzed in detail depending on mechanical model and mechanical properties proposed in previous investigation. Consequently simple equations were introduced which are able to estimate the rotational behavior of Nuki joint to the extent of plastic range, and those estimated curves showed satisfactory agreement with experimental results [2].

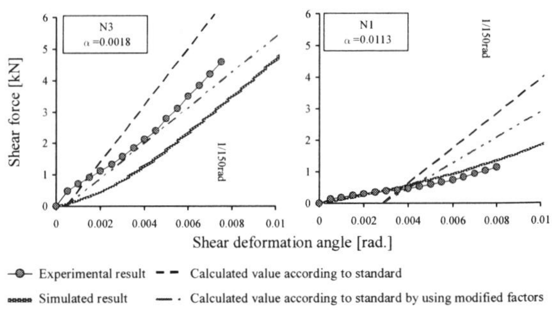

Figure 2. Example of simulated and experimental results on shearing of lattice shear wall.

As a next step, the aforementioned results were applied on the analysis of structural element, i.e. the lattice shear wall. The lattice shear wall is consist of many number of half-lap joints, which mechanism of resistance is almost as same as Nuki joint, and is regarded as one of the important structural element to reinforce traditional buildings such as Machiya residential house by virtue of its ductile load carrying capacity. The simulating analysis on the initial stiffness was performed by taking the variation of gap generation between each individual joint into account. At the same time, the long term evaluation on the behavior of shear wall was carried out by periodically applying load on the same specimen over one year. As a consequence, the result of simulated agreed very well with that of experimental, and the influence of clearance of the joint on shear-resistance-factor was quantitatively clarified [3].

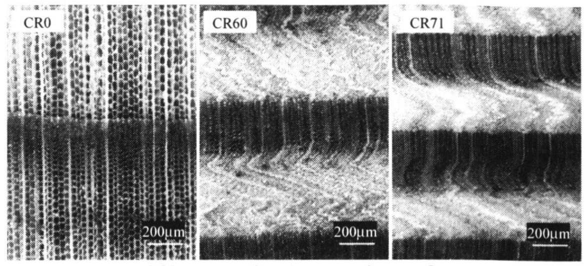

Figure 3. Difference in the section of compressed wood in accordance with compression ratio.

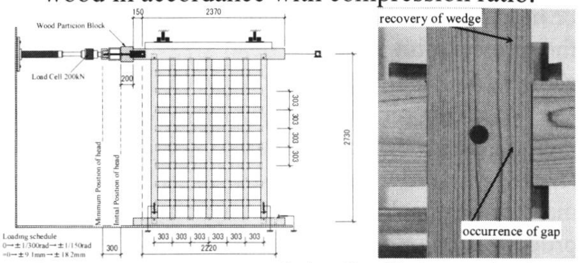

Figure 4. Test setup and detail of joint on lattice shear wall with compressed wooden wedges.

By taking above results into consideration, an application of compressed wooden fasteners into the traditional joint was investigated. Compressed wood is manufactured by compressing softwood in radial direction with moderate heat and high pressure, which is thought to be suitable for the use in traditional construction. Moreover since compressed wood spring back gradually when being subjected cyclic humidity change, it is expected to work to compensate for the gap generation so that the initial stiffness of the joint is sustainable. In order to verify those characteristics more clearly, stress relaxation test was carried out. Consequently it was found out that compressed wood can work in terms of not only recovering its dimension but also maintaining compressive stress between timber bodies when compression ratio is high. Besides, fundamental mechanical properties of compressed wood were investigated with focusing its use as structural elements. In result, calculation formulas which include only compression ratio and original mechanical properties were introduced [4] which is expected to contribute to the optimal design of compressed wood as fasteners.

Based on the results in previous section, the effect of compressed wooden fasters was studied in the case they were used in traditional structural elements such as Nuki joint or lattice shear wall. As a result of long term experiment on structural behavior, the sustainable capacity on stiffness was verified [5]. This means that mechanical behavior of traditional joint became more independent from duration of time and accumulation of damages.

Through the above-mentioned findings, the reliability on the design of traditional structures which consist of interlock joints became more improved, which is expected to lead to the better recognition on traditional techniques and the promotion of timber structure in long-life buildings.

References

[1] A. Kitamori, T. Mori, Y. Kataoka, K. Komatsu, "Effect of Additional Length on Partial Compression Perpendicular to the Grain of Wood -Difference among the supporting conditions", *Journal of Structural and Construction Engineering, Transactions of AIJ*, in press.

[2] A. Kitamori, Y. Kato, Y. Kataoka, K. Komatsu, "Proposal of Mechanical Model for Beam- Column 'Nuki' Joint in Traditional Timber Structures" *Mokuzai Gakkaishi*, vol. 49, no. 3, pp. 179-186, 2003.

[3] A. Kitamori, K. Jung, M. Minami, K. Komatsu, "Evaluation on Stiffness of Lattice Sehar Wall -Influence of gap and its verification by long term test-" *Journal of Structural Engineering*, vol. 55B, pp. 109-116, 2009.

[4] A. Kitamori, K. Jung, T. Mori, K. Komatsu, "The Evaluation on Mechanical Properties of Compressed Wood in accordance with the Compression Rate", *Proceedings of the IAWPS2008*, Vol.1(CD), 2008.

[5] A. Kitamori, K. Jung, M. Minami, K. Komatsu, "Improvement of Shear Resistance on Traditional Lattice Shear Wall", *Proceedings of the 10th world conference on timber engineering*, Vol.1(CD), 2008.