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DIFFERENCES IN SHEAR PERFORMANCE OF TIMBER MOMENT RESISTING JOINT DUE TO DIFFERENT JOINT TYPES

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ABSTRACT: The timber buildings with semi rigid frame structures are increasing. They have concern to the shear failure because it has large shear stress at the panel zone. The diversity of joints has led to experimental verification of the shear performance of different joints, this is not easy due to the need to conduct experiments on each joint, which increases the costs and the material size of the experiments. In this study, as a first step towards proposing a material experiment to simulate the shear performance of joints, the behavior of the tensile-bolt joint was reproduced using Finite Element Method (FEM) analysis and examined the possibility of estimating performance with minimalization like a material experiment. In addition, the material tests simulating LSB and tensile bolt joints were conducted and compared to the previous reported results of the asymmetric four point bending test. Moreover, the strain by digital image correlation (DIC) method was compared to the strain by FEM analysis. The results suggest that it is generally possible to reproduce the behavior by analysis and to estimate the joint performance. The scale down of L/2 and the material experiment show the possibility of estimating performance because the equivalent stress is almost same. In the experiments, the LSB specimens had lower shear strength and similar shear modulus values compared to the previous reported results of the asymmetric four point bending test. The tensile bolt specimens have a low shear modulus of elasticity, due to the concentration of strain near the supporting and loading points, as measured by the digital image correlation method. The comparison of results between the DIC and FEM showed generally similar strain distributions and values, indicating the possibility of reproducing experimental results in the analysis.

KEYWORDS: Shear performance, Column-beam joint, Moment resisting, FEA, Tensile bolt joint

1 – INTRODUCTION

The wooden buildings of frame structures are increasing. They have concern to shear failure because the column-beam joint has the large shear stress. There are some variations of joints, tensile bolt, drift pin and LSB (Lagscrewbolt) joints and so on. They have difference of shear transmission as shown Fig. 1. Arthur et al[1)] have compiled some reviews of moment resisting joints, although only examined each types of joint. Akiyama et al[2)] focused on the mechanism of shear force and conducted some full-scale experiments. However, the full-scale experiments need more cost and larger facility, therefore it is not easy to conduct.

Thus, if a material experiment can be proposed that simulates the shear force for each joint, the data for the structural design can easily be collected. Among material experiments, the asymmetric four-point bending test[3)-7)] is similar to the stress transfer in tensile bolt joints. However, there are no test methods which are similar to LSB and drift pin joints.

The aim is proposing the material experiments to simulate the column-beam joints. As a first step, a full-scale and minimalized scales study for application to the material tests were analyzed using FEA. The results of experiments are compared for LSB and tensile bolt joints. In addition, the results and the results of asymmetric four point bending testing [8),9)]are compared.

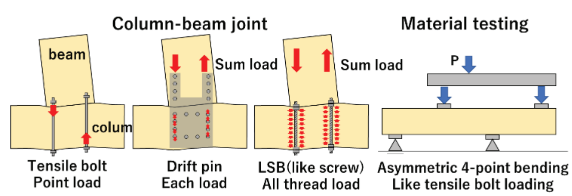

Figure 1: *Difference of joints and material testing.*

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2 – FINNITE ELEMENT ANALYSIS

2.1 MODELLS AND PARAMETERS

Figure 2 shows the analysis model. Table 1 shows the parameters of material which were based on *Scots Pine*. The parameters were referred to the references[10,11]. The parameters of tensile bolt were used from the data of structural steel in ANSYS. The calculation was used by ANSYS Workbench Student 2024 R1. The L/2 model is adjusted the length and position of cutout depends on the height. However, the tensile bolt is same dimension. The load of L/2 model is determined by the moment and height of full-scale and L/2 model. The load of material testing is determined from the area due to the neutral axis determined from vertical deformation, the stress on the top surface of the column in the analysis.

Hexahedral SOLID 186 was used for the timber and steel elements, while CONTA 174 and TARGE 170 were used for the joint elements. Timber and steel joints were friction joints with a coefficient of friction of 0.2. Beam-to-column joints were rough. At point A, a load of 20 kN was applied, calculated backwards from the maximum moment in the experiment and the length of the beam timber. Points B and C are pin-supported; points D to E are fixed and the contact between the tensile bolts and the beam and column materials is shown in Fig.2.

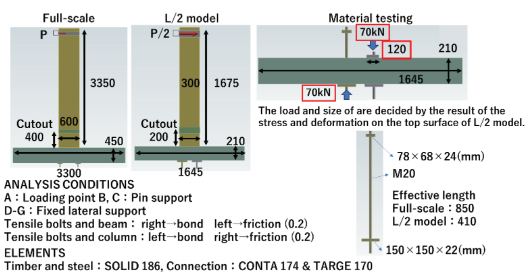

Figure 2: *Analysis model.*

Table 1: *The list of parameters (L: X, R: Y, T: Z).*

Elastic			
E_L (MPa)	10500	G_L (MPa)	525
E_R (MPa)	954.5	G_R (MPa)	30
E_T (MPa)	477.2	G_T (MPa)	525
ν_L	0.4	Bilinear curve	
ν_R	0.9	Yield strength (MPa)	6.6
ν_T	0.6	Tangent modulus (MPa)	10.5

2.2 RESULTS OF ANALYSIS

The equivalent stress of full-scale at maximum load are shown in Fig. 3. A comparison of the full-scale, L/2 model and adjusted full scale value for the same moment are shown in Fig. 4.

Figure 3 shows that, as far as deformation behavior is concerned, the tensile bolts on the tension side show the embedment behaviour and the compression side shows lifting. Increased stress were observed at the panel zone, at the tensile side steel plates of the tensile bolt and at the compression side column face. The large stress was observed at the column face on the compression side, suggesting that the embedment stress are more dominant than the shear stress. The equivalent stress of full-scale, L/2 and material testing show 4~5 MPa at the panel zone. It is considered that the panel zone will occur shear failure due to the variation of the performance, given that the stress is close to the shear strength.

A comparison of the full-scale, scale down and the adjusted value to make the same moment at full-scale are shown in Fig. 4. Here, the shear deformation of the analytical values was calculated from the length of the beam and the deformation of the loading point. Both minimalizations show behaviour similar to the full-scale results, the equivalent stress distribution at L/2 is close to the full-scale. Therefore, the possibility of estimating performance with minimalization by designing the same moment.

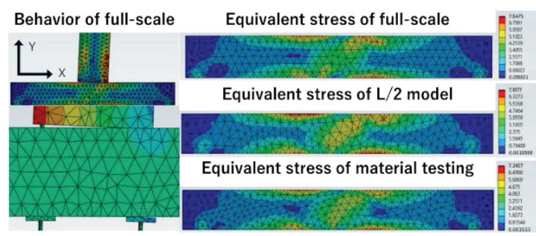

Figure 3: *Equivalent stress and deformation by FEA models.*

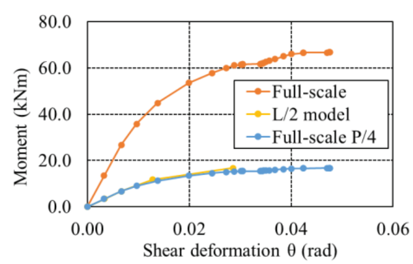

Figure 4: *Relationship between moment and shear deformation.*

3 - EXPERIMENT

3.1 SPECIMEN

Figure 5 shows the specimens. It is glulam of Sugi (Japanese Cedar). It is composed the grade E65-F255 (JAS[12]: Japanese Agricultural Standard). The range of air-dried density is 420±20kg/m^3, the moisture content is15±4.5%. The moisture content was measured at edges

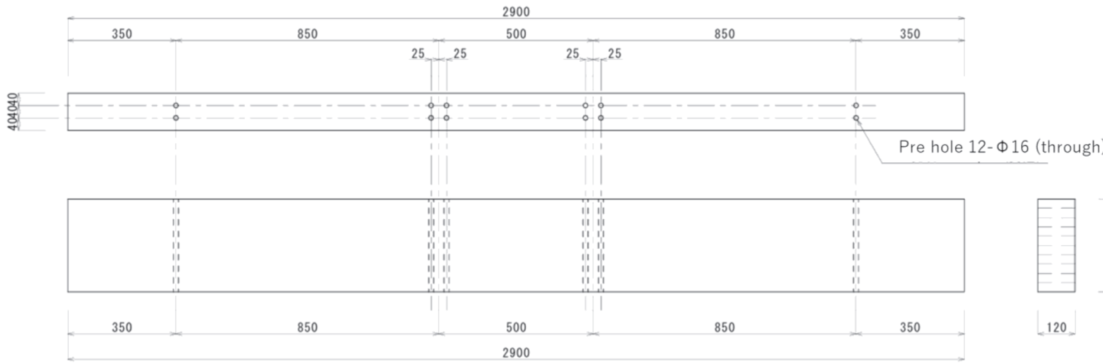

Figure 5: *Specimen.*

and center of member by a high frequency wood moisture meter (HM-520, Kett Electric Laboratory Co. Ltd.). The adhesive was used the phenol-resorcinol formaldehyde (PRF). The specimens were composed by non-finger joint lamina.

Figure 6 shows LSB used for joints at supporting and loading points. The major diameter of thread was 19 mm, the minor diameter of thread was 14.4 mm. The pitch was 8 mm, the length of insert was 300 mm. The external thread was M16 and 50 mm length on both sides.

Figure 6: *LSB.*

3.2 TESTING METHOD

Figure 7 shows the testing method of LSB specimen. The load applied by LSB inserted at supporting and loading points, as shown in Fig.8. The testing method was the asymmetric four-points bending method. The outside supporting and loading points used two LSB, and inside used four LSB.

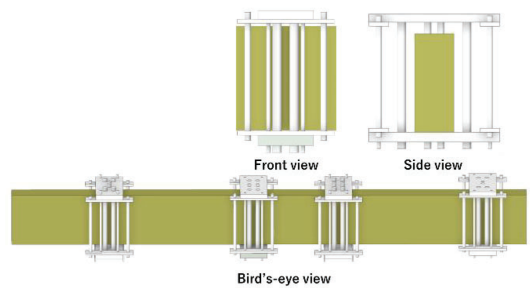

Figure 7: *Testing method of LSB specimen.*

Figure 9 shows the testing method of tensile bolt specimen. The outside supporting and loading points were same to LSB specimen. The inside were modified to tensile bolt joints.

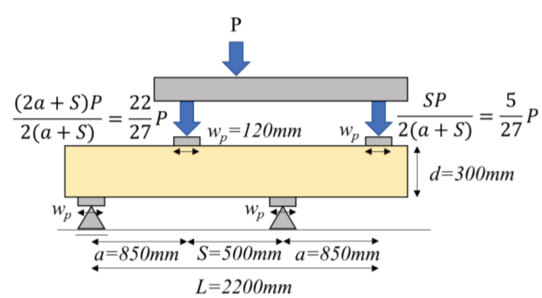

Figure 8: *Testing method of tensile bolt specimen.*

The loading speed was 1mm/min, and the load applied until the load reducing to 0.8 times to the maximum load on both testing. The deformation were measured at supporting points, loading points, shear deformation of horizontal and diagonal direction at center of specimen, and strain by digital image correlation (DIC), as shown in Fig.10.

Shear strength were calculated from the maximum load by equation 1. Shear modulus G_v, G_h, and G_d were calculated by the relationship between shear stress and shear strain at elastic range by vertical, horizontal, and diagonal deformations.

In the DIC, a random pattern was created using a matte lacquer spray and photographed with light illuminated from both sides. The random pattern was applied so that the black and white was generally 1:1, as illustrated in Fig. 11. An interval camera (Panasonic H-FS12032, maximum pixel count 4592×3448pixel) was used to capture images with a shooting interval of 1 second. The DIC analysis was calculated by GOM Correlate 2018.

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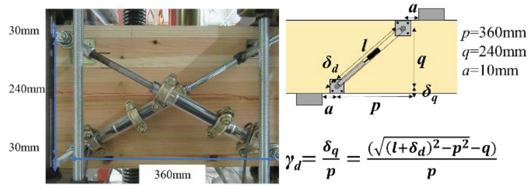

Figure 9: *Measurement method.*

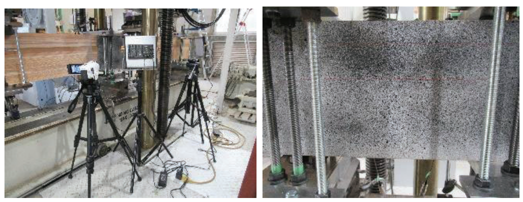

Figure 10: *Measurement by DIC.*

3.3 RESULTS AND DISCUSSIONS

Failure mode

Figure 11 and 12 show failure mode of LSB specimen and tensile bolt specimen. Shear failures were shown at red arrows. LSB specimen showed brittle shear failure at center of specimen when the load reached the maximum load. Tensile bolt specimen showed shear failure at a load equivalent to that of the LSB specimen. However, from approximately 0.5 P_{max}, the blue arrows at the inner supporting and loading points exhibited embedment. Subsequently, shear failure occurred from the embedment position and shear failure at the center of specimen.

Figure 11: *Failure of LSB specimen.*

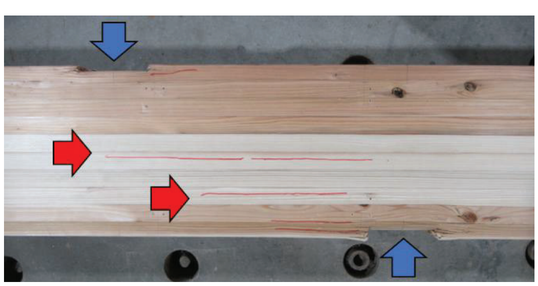

Figure 12: *Failure of LSB specimen.*

Mises strain by degital image correlation

Figure 13 shows Mises strain distribution of the LSB specimen at 0.9 P_{max} and the strain at the center of specimen at 0.1, 0.4, 0.9 P_{max}. The strain near the center of specimen was increased, providing the process of increasing strain with increasing load.

Figure 14 shows the Mises strain distribution of tensile bolt specimen at the stage when it starts to embed. In addition to the center of specimen, the strain distribution in the cross-section was checked at equal distances on both sides in order to see the strain distribution near the supporting and loading points. As indicated by the red circles, an increase in strain was observed at a distance of about 50 mm from the supporting and loading points. This suggests that the stress distribution in tensile bolt joint may differ from the shear stresses in general rectangular cross-section, due to the difference in the stress distribution caused by the embedment.

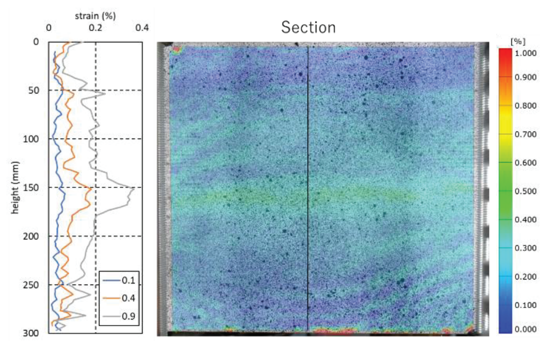

Figure 13: *Mises strain distribution of LSB specimen.*

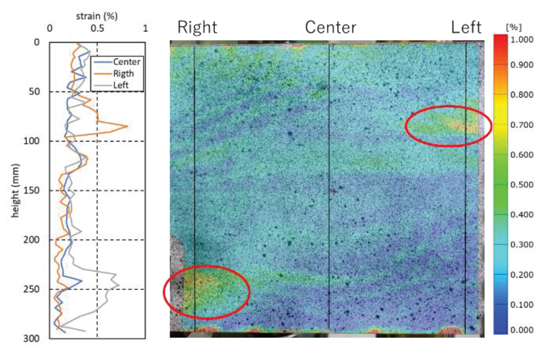

Figure 14: *Mises strain distirbution of tensile bolt specimen.*

Shear strength and shear modulus

Figure 15 shows the shear strength of the LSB specimen, tensile bolt specimen, the bending-type testing in the previous reports [8] and the off-axis method and the rocket type shear testing[9]. In the previous report, E65-F225(JAS)[12], 105mm×300mm cross-section, *Japanese Cedar* glulam was used. The specimens in this study consist of lamina of the same grade modulus of elasticity, whereas the previously reported specimens differ in that they consist of lamina of different grade. Compared to the previous report, the LSB specimens showed an average value of approximately 0.73 times higher.

Figure 16 shows the shear modulus of the LSB specimen, tensile bolt specimen and the previously reported the asymmetry four point bending test. The LSB specimens showed values comparable to those of the asymmetric four point bending test and no significant differences were found in the T-test. On the other hand, the tensile bolt specimens showed lower values than the LSB specimens, which may be due to the concentration of strain near the supporting and loading points mentioned earlier.

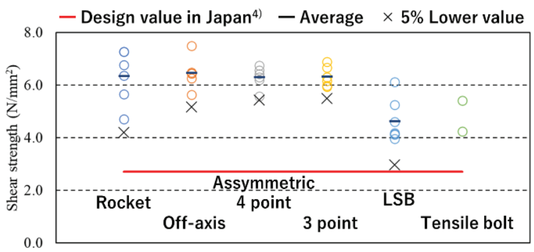

Figure 15: Shear strength.

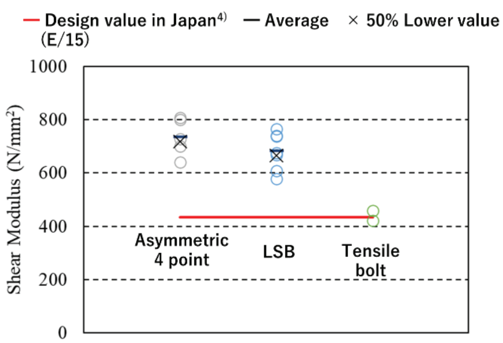

Figure 16: Shear modulus.

Compare to analysis by DIC

The results of the FEM model described in Chapter 2 and the DIC method are compared. The tensile bolt joint was simulated with eccentric loading in Chapter 2; however, the experiment was conducted to simulate its embedment by the washer because of difficultly. In this section, the loading position of the FEM model from Chapter 2 is altered to match that of the experiments in this chapter. The Mises strains in specimen cross-sections are also compared.

Figure 17 compares the distribution of Mises strain in the central part of the specimen by FEM analysis with the strain distribution by the DIC method shown in Figure 14. The DIC method includes concentric strain caused by the camera's performance in capturing the image. They make comparison difficult, however the same strain near the point of force was also observed in the FEM.

Figure 18 shows the strain distribution in the cross-section at the center, left and right in the DIC method and in the FEM. In the FEM, as in the DIC, an increase in strain was observed in the left and right cross-sections at 50-100 m above and below, and the strain values were similar values. This suggests that the FEM model in Chapter 2 was able to reproduce the strain distribution in this chapter.

In the future, we will propose a test method to simulate the eccentric loading in Chapter 2 and a method to reproduce the LSB joints in this chapter with the FEM model.

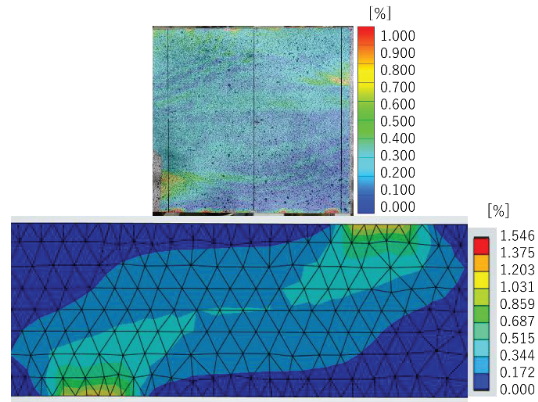

Figure 17: Mises strain distribution.

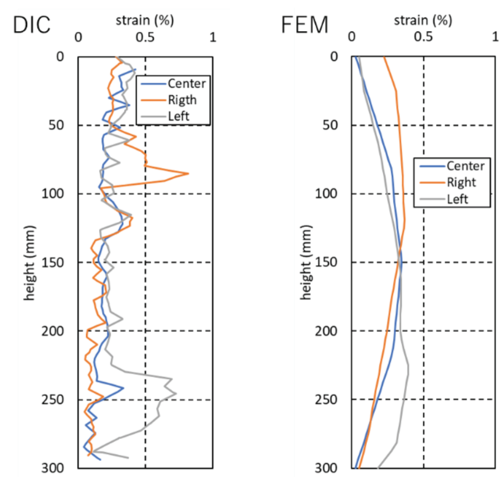

Figure 18: Comparing to Mises strain DIC and FEM at cross-section.

4 – CONCLUSION

In this study, as a first step towards proposing a material experiment to simulate the shear performance of joints, the behaviour of the tensile-bolt joint was reproduced using FEM and examined the possibility of estimating performance with minimalization like a material experiment. The results suggest that it is generally

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possible to reproduce the behaviour by analysis and to estimate the joint performance. The scale down of L/2 shows the possibility of estimating performance because the equivalent stress and deformation are almost same.
In addition, the material tests simulating LSB and tensile bolt joints were conducted. The results showed that the LSB specimens had lower shear strength and similar shear modulus values compared to the previous reported results of the asymmetric four point bending test. The tensile bolt specimens have a low shear modulus of elasticity, due to the concentration of strain near the supporting and loading points, as measured by the DIC method. The comparison of results between the DIC and FEM showed generally similar strain distributions and values, indicating the possibility of reproducing experimental results in the analysis.

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