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MEASUREMENT OF AXIAL FORCE OF SCREWS FOR SPLIT REINFORCEMENT AT TIMBER-STEEL-TIMBER DOWEL JOINT

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ABSTRACT: In this study, joint shear test of timber-steel-timber dowel joint was performed by changing the cross-sectional dimensions of the member, the position and the number of the self-tapping screws for reinforcement. The axial force of the screw was measured using a strain gauge which is placed in the centre of the screw, and the influence of the position and the number of the screws in lateral tensile force was confirmed.

Ultimate displacement became higher by using screws for reinforcement. In Pre-Divided (PD) test specimens, the ultimate displacement was equivalent to that of SR specimen by using two screws per shear plane. It was confirmed that the measured axial force in PD test specimen corresponds to the load axial force after the split occurs. When using two screws, closer screw to the dowel mainly resist to lateral tensile force. The ratio of lateral tensile force changes as the displacement progresses. Total lateral tensile load exceeded 30% of joint shear load in PD specimens.

KEYWORDS: Split reinforcement, Dowel joint, Axial force

1 INTRODUCTION

Timber-steel-timber dowel joint is generally used in large scale timber structures. Ductile behaviour can be ensured by bending deformation of a dowel and embedment at timber member under lateral loading. On the other hand, depending on the conditions of the joint, timber member easily splits due to the lateral tensile stress caused by the dowel, and sufficient ductility cannot be obtained. To prevent splitting failure, it is effective method to insert full-threaded self-tapping screws near the dowel.

Schmid [1] and Bejtka [2] proposed the theoretical models to calculate the force generated in the reinforcing screw. It is proposed that reinforcement elements should be designed to resist 30% of the load transferred by each dowel-type fastener and shear plane [3]. But it is still uncertain how much axial force occurs to reinforcement screws.

Wolfthaler et al. [4] tried to measure the axial force generated in the screw for splitting reinforcement by implementing a strain gauge in the screw. As a result, depending on the conditions, an axial force larger than 30% is generated, and it is pointed out that the load on the screw located at the end of the multiple dowel joint was particularly large. However, the measured axial force is not the same as the transverse tensile force generated at the joint because it is considered that not only the screw but also the wood transfers the lateral tensile force. Furthermore, the effects of the cross-sectional dimensions of the member and the driving position of the screw are also unknown.

In this study, joint shear test of timber-steel-timber dowel joint was performed by changing the cross-sectional dimensions of the member, the position and the number of the self-tapping screws for reinforcement. The axial force of the screw was measured using a strain gauge which is placed in the centre of the screw, and the influence of the position and the number of the screws in lateral tensile force was confirmed.

2 MATERIALS AND METHODS

2.1 Materials

Sugi glulam of strength grade E65-F255 [5] was used for side member. The dimensions of the specimen were 582 mm in length and 105 mm in width, and the thickness t was 45, 75, and 105 mm on each side. A steel plate with thickness of 9mm was used for central member. A steel dowel was used to connect timber and steel plates and the diameter was 16mm. Full-thread screws (pane-lead X, Synegic co. ltd.) were used for split reinforcement. A picture of the screw is shown in Figure 1. A strain gauge (BTM-6C, Tokyo Measuring Instruments Lab.) was implemented in the centre of the screw to obtain the axial force during the joint shear test. The relationship between strain and axial force in each screw was obtained in advance.

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2.2 Test setup

The list of test conditions is shown in Table 1. The first number in each type name indicates the thickness of one side of the specimen. Three thicknesses of 45mm, 75mm, and 105mm were selected. The following symbols represent the reinforcement conditions. Test setup of each reinforcement condition is shown in Figure 2. There were three types of test specimens. Non-reinforced test specimens (hereinafter referred to as NR) has no reinforcement screws and only timber resists to lateral tensile forces. Screw reinforcement test specimens (hereinafter referred to as SR) has one or two reinforcement screws around dowel joint part. At pre-divided test specimens (hereinafter referred to as PD), the glulam was divided into two in the width direction at the center of the dowel, and they were connected by screws so that the lateral tensile stress generated by the dowel during the test is transferred only by the screw. One or two screws were inserted on each side, which is the same as that of SR specimens. The position of the screw is shown in Figure 3. The screws were placed symmetrically on each member. At the test specimen with one screw, self-tapping screw was driven into the position A in the figure. Distances between dowel centre and the position A was 3*d* (*d*: diameter of the dowel). This value was determined to avoid touching the dowel to the screw during the test. Distances between shear plane and the position A was 1.5*d*. At the test specimens with two screws, self-tapping screws were driven into the positions of AB, AC, and AD, respectively. Distances between dowel centre and the position B was 5*d* and two screws are located parallel to the grain. Distances between shear plane and the position B was 3*d* and two screws are located perpendicular to the grain. Position D was located on the unloaded side and the distance was 1*d* to get as close as possible to the dowel.

The upper part of the specimen was fixed to a steel plate with a thickness of 12 mm using a bolt with a diameter of 24 mm A steel plate with a thickness of 9 mm was connected to the lower part of the specimen by a dowel with a diameter of 16 mm. Therefore, there is a total gap of about 3 mm in the lower part of the specimen. Arrangement of the dowel was determined based on the standard of Architectural Institute of Japan [6].

The relative displacement between the main material and the side material was measured with a displacement transducer SDP-

Table 1: *Test series*

Type	Thickness (mm)	Pre-division of member	Screw pos. (see Fig. 2)	*n*
45-NR	45	No	-	9
45-SR-A			A	4
45-SR-AB			AB	7
45-PD-A		Yes	A	6
45-PD-AB			AB	6
45-PD-AD			AD	7
75-NR	75	No	-	9
75-SR-A			A	6
75-SR-AC			AC	6
75-PD-A		Yes	A	6
75-PD-AC			AC	6
75-PD-AD			AD	5
105-NR	105	No	-	9
105-SR-A			A	6
105-SR-AC			AC	5
105-PD-A		Yes	A	6
105-PD-AC			AC	6
105-PD-AD			AD	6

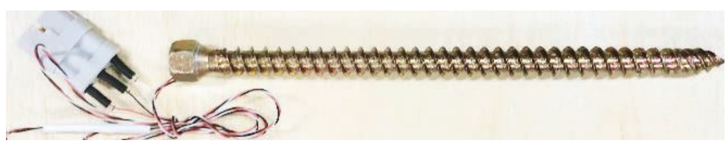
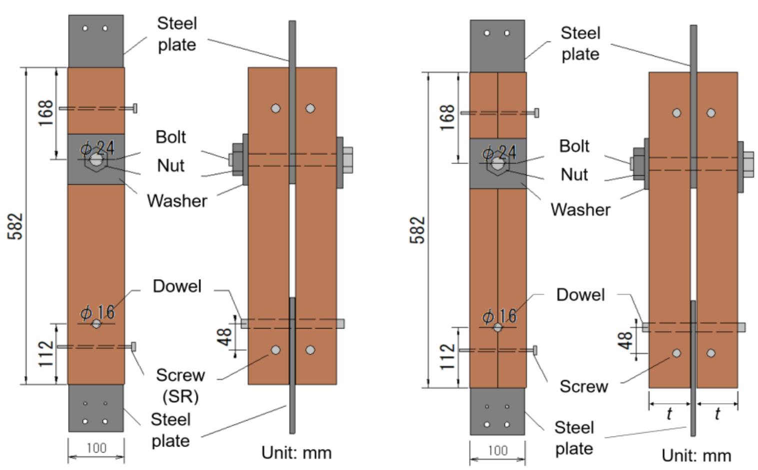


Figure 1: *Self tapping screw with strain gauge*



(a) NR and SR specimens ***(b) PD specimens***

Figure 2: *Test setup (an example of SR specimen)*

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100C (Tokyo Measuring Instruments Lab.). The axial force was obtained from the strain measured during the joint shear test. In the test, a monotonous load was applied in the tensile direction, and the test was stopped when the load dropped to 80% or less of the maximum load after the maximum load was applied, or when the displacement reached 30 mm.

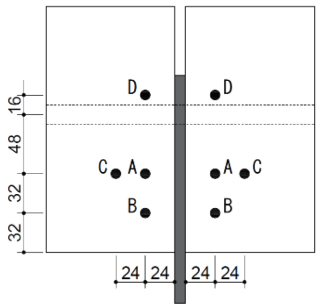
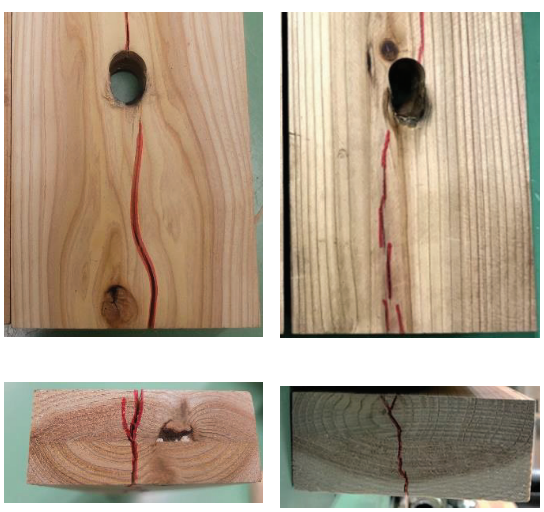


Figure 3: *Position of reinforcement screws*

3 RESULTS AND DISCUSSION

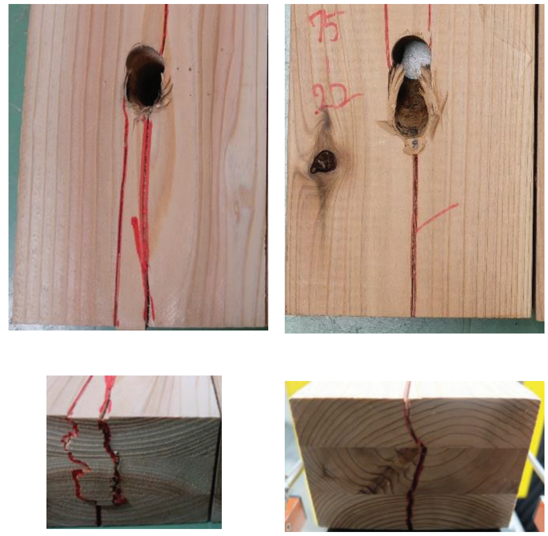
3.1 Failure pattern

Figures 4-5 show examples of failure patterns of NR and SR specimen after the test. In the NR specimen, failure due to row shear and splitting was observed. In the SR specimens reinforced with a single screw, the rate of failure due to splitting and row shear decreased, and the shear displacement of the joints until failure increased. In the SR specimen using two screws, no shear failure or splitting failure occurred in the wood even when the displacement exceeded 30 mm.



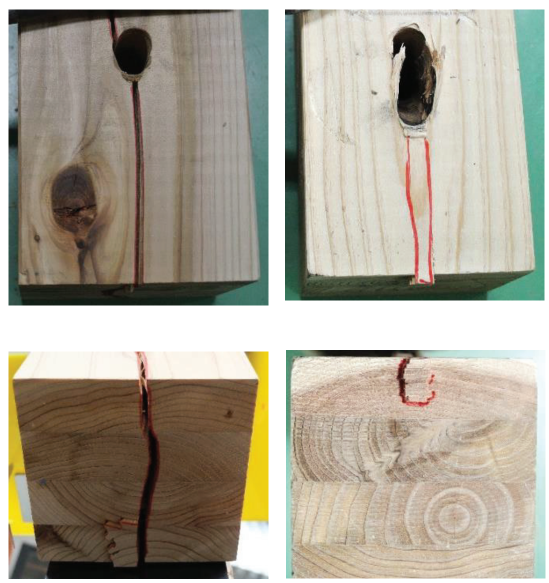
45-NR *45-SR-A*

Figure 4: *Failure of specimens with the thickness of 45mm*



75-NR *75-SR-A*

Figure 5: *Failure of specimens with the thickness of 75mm*



105-NR *105-SR-A*

Figure 6: *Failure of specimens with the thickness of 105mm*

3.2 Ultimate displacement

Figure 7 shows a comparison of the ultimate displacements under each condition. By screw reinforcement, the average value of ultimate displacement increased by 37 to 60% in the SR test specimen with a thickness of 45 mm, 188 to 190% in the test with a

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thickness of 75 mm, and 98 to 112% in the test with a thickness of 105 mm compared to NR test specimens. At thicknesses of 75 mm and 105 mm, the ultimate displacement was 30 mm or more. Most of the specimens were not failed and the loading was stopped.

In PD test specimens, the ultimate displacement was not improved by one screw in the test specimens with thickness of 75 mm and 105 mm. The deformation performance equivalent to that of SR specimen was obtained by using two screws.

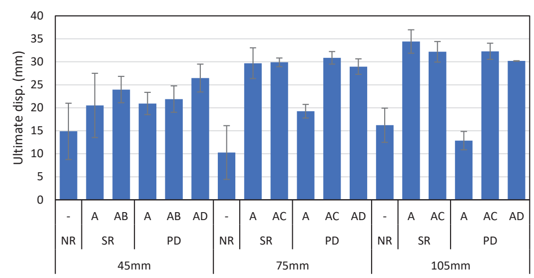

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Figure 7: *Comparison of ultimate displacement*

3.3 Axial forces measured by screws

As an example of the measurement result of the axial force acting on the screw, the result of the matching test specimen of 45-SR-A and 45-PD-A is shown in Figure 8. PD specimens showed slightly lower load-bearing capacity than SR specimens. At the moment of cracking, the shear load decreased slightly, while the axial force on the screw increased immediately. Similar behaviour was also reported by Wolfthaler et al [3]. In 45-SR-A test specimen, it was confirmed that the axial force increased with the occurrence of splitting.

On the other hand, in 45-PD-A test specimen, the axial force increased immediately after the load was applied. Since the axial force is almost the same after the split occurs in the main materials on both sides, it can be said that the measured axial force in PD test specimen corresponds to the load axial force after the split occurs.

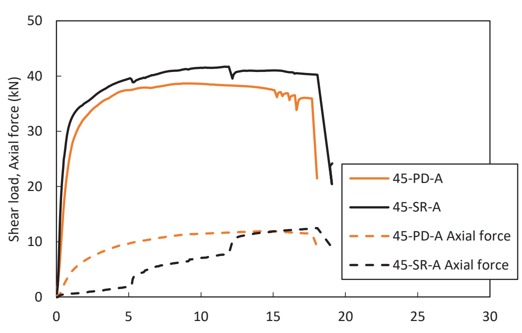

Figure 8: *Load-displacement relationship of 45-SR-A and 45-PD-A*

Ratio of average total axial force of screw on each type to shear force is shown in Figure 9. Axial loads decrease at 45-SR-A and PD-A specimens with all thickness. In these specimens, the number of screws was not enough and withdrawal of screw was observed. At PD specimens with two screws, total axial force finally reached around 30~40% of joint shear load in PD specimens. On the other hand, final axial load was about 10% at SR specimens with two reinforcement screws. This tendency was similar between specimens with different thickness.

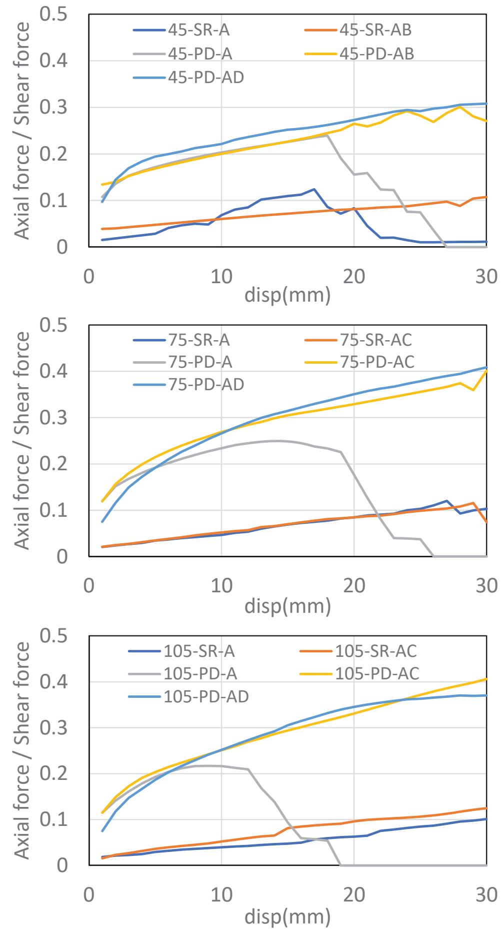

Figure 9: *Ratio of average total axial force of screw on each type to shear force*

Ratio of axial force of screw at each position to shear force is shown in Figure 10. In the reinforced type with one screw, both the shear load and the axial force decreased in the 75mm and 105mm thickness series. This is because the strength of the reinforcing screw was insufficient, and the screw was pulled out, leading to destruction. In the reinforcement type with two screws, no fracture accompanied by a decrease in axial force was observed. In the test type with a thickness of 45 mm, when the driving position was AB, the axial force of B was slightly higher at the initial stage of deformation, but as the deformation progressed, the screw of A showed higher axial force. Ultimately, the A screw bears a lateral tensile force that is 1.5 times greater than that of the B screw. On the other hand, when the driving position is AD, most of the lateral tensile force was borne by screw A at the initial stage of deformation, but in the end, screw D also borne nearly half of the lateral tensile force.

In the test type with a thickness of 105 mm, when the driving position is AC, although the axial force of screw A, which is closer to the sheared surface, showed a slightly higher axial force, there is a difference from screw C and the axial force tends to increase as deformation progresses. It was mostly the same.

A common point in all measurement results is that the load ratio and distribution of the axial force are nonlinear, and it is difficult to determine a single value with a simple dynamic model. It suggests the need for a model that considers the nonlinear behaviour of wood due to Dowel's local bearing pressure and changes in stress distribution.

Fig. 5 shows the ratio of axial force of screw at each position to shear force in PD test specimens. It was confirmed that the screw position A mainly bears the axial force. The axial force at position C was slightly smaller than the axial force at position A, and a screw at position D initially showed a negative axial force in 105-PD-AD specimen.

Total axial force finally reached about 30-40% of the shear force in PD specimens. Axial force of 30% of shear force was sufficient to ensure the deformation performance of the joint even if the contribution of tensile stress perpendicular to the grain was ignored.

4 CONCLUSION

- Ultimate displacement became higher by using screws for reinforcement. In Pre-Divided (PD) test specimens, the ultimate displacement was equivalent to that of SR specimen by using two screws per shear plane.

- It was confirmed that the measured axial force in PD test specimen corresponds to the load axial force after the split occurs.

- When using two screws, the closer screw to dowel mainly resist to lateral tensile force. The ratio of lateral tensile force burden changes as the displacement progresses.

- Total lateral tensile load exceeded 30% of joint shear load in PD specimens.

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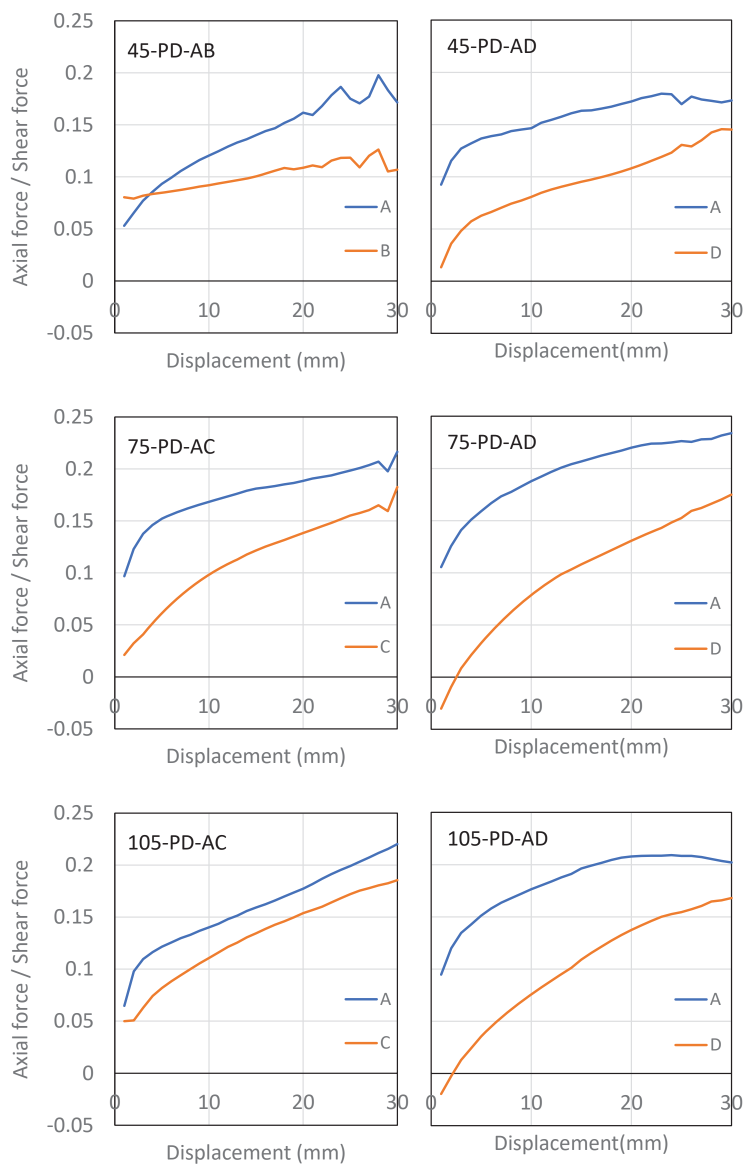

Figure 10: *Ratio of axial force of screw at each position to shear force*

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