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EFFECT OF THREAD SHAPE ON WITHDRAWAL PERFORMANCE OF LAGSCREWBOLT INSERTED INTO PERPENDICULAR TO GRAIN

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ABSTRACT: In order to verify the effect of thread shape on the withdrawal performances of Lagscrewbolt (LSB) inserted into perpendicular to the grain, it was conducted withdrawal tests using LSBs with different thread diameter and pitch. The withdrawal capacity and initial stiffness were higher for larger thread diameters or smaller thread pitches, and increased almost proportionally to the insertion length. Compression area and shear area were adapted as the evaluation methods used for screwed fastener, and it was evaluated the withdrawal capacity and initial stiffness per each area. The 5%-tile compression strength, which is the withdrawal yield load divided by the compression area, was almost equal to the criterion strength, and it is considered that the first yielding on withdrawal behavior is due to the yielding caused by the compression of the timber dovetailing the screw threads. The shear strength, which is the withdrawal capacity divided by the shear area, becomes lower as the thread pitch increases, and it is considered that the shear strength also changes because the shear performance when loaded radially varies with the height of the shear area of timber dovetailing with the screw threads.

KEYWORDS: Lagscrewbolt, thread diameter, thread pitch, withdrawal capacity, beam-column joint

1 – INTRODUCTION

Lagscrewbolt (LSB) is a screwed fastener that transfer forces through its withdrawal resistance. It is used in beam-column joints and column base joints in timber semi-rigid frame structure mainly using glulam. Design rules of the withdrawal performances such as the withdrawal capacity and initial stiffness are provided by some design guidelines, e.g. [1,2]. These design rules were theorized based on the Volkersen model [3-5]. The effect of the thread shape of LSB on the withdrawal performances had not sufficiently verified, therefore the model and guidelines present estimated equations calculated from experimental results. However, it has been reported that the volkersen model tends to underestimate withdrawal performances for larger insertion length in some withdrawal tests of LSB under various conditions [6-9]. In order to simplify and streamlining the design rules, the method that can estimate the withdrawal performances from parameters such as thread shape and wood species is needed.

The withdrawal performances of LSBs inserted into parallel to the grain was studied using finite element analysis [10-12]. In these references, only one type of thread shape was used, the effects of thread diameter and pitch are not taken into account. Therefore, the withdrawal model [13] was proposed to calculate the withdrawal capacity of LSB inserted into parallel to the grain using the thread diameter and pitch and the shear strength of timber applying the withdrawal model of tapping insert [14] and the references [10-12]. However, although LSBs are inserted into perpendicular to the grain of the column timbers in the column-beam joints, there is a lack of studies on their withdrawal performances. The withdrawal behavior of LSB inserted into perpendicular to the grain has been reported to exhibit deformation behavior with toughness caused by a combination of bending and compression deformation of timber [3,5,15].

In this study, it was conducted withdrawal tests of LSBs inserted into perpendicular to the grain of glulam by varying the thread diameter and pitch, and insertion length in order to verify the effects of thread shape and insertion conditions on the withdrawal performances of LSBs inserted into perpendicular to the grain.

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2 – MATERIALS AND METHODS

Fig. 1 shows the experimental jig and the glulam setup. Table 1 shows the list of specimens. The glulams standardized in Japan Agricultural Standard (JAS 1152) made of Japanese ceder (*Cryptomeria japonica*, Jc) class E65-F255 and Scots pine : European Red pine in Japanese (*Pinus sylvestris*, Sp) class E95-F315 were used. Four heights of glulams (120, 180, 240, 300mm) were used, and LSBs were penetrated the glulams, so that the height of the glulams and effective insertion length (L) were the same. The reaction force was restrained by the bolts and steel plate or channel on each side. The length of glulam and the position of support steel plates or channels were adjusted assuming that the stress would spread at 45°. In the tests with insertion length of L120, nine different thread shapes (three thread diameters (D): 21, 23, 25mm, three thread pitch (P): 6, 8, 10mm) were used. In the tests with insertion length of L180-300, four different thread shapes (two thread diameters (D): 21, 25mm, two thread pitch (P): 6, 10mm) were used. The number of specimens was 3-6 of each condition.

The lead holes diameters of LSBs were 2mm smaller than thread diameters, and the LSBs were inserted into the glulams with a wrench. The loading method was monotonic tension using the material testing machine at loading speed of 1mm/min. Four displacement transducer were installed in the glulams, and the relative displacement measured between the tranceducer and fixture fixing the LSBs was used as the withdrawal displacement.

Table 1: Test conditions and number of specimens

wood species (w.s.)	thread shape		insertion length L [mm]			
	diameter D [mm]	pitch P [mm]	120	180	240	300
Japanese cedar (Jc)	21	6	6	6	5	3
		8	6	-	-	-
		10	6	6	6	4
	23	6	6	-	-	-
		8	6	-	-	-
		10	6	-	-	-
	25	6	6	5	6	4
		8	6	-	-	-
		10	6	6	6	4
Scots pine (Sp)	21	6	6	6	6	4
		8	6	-	-	-
		10	6	6	6	4
	23	6	6	-	-	-
		8	6	-	-	-
		10	6	-	-	-
	25	6	6	6	6	4
		8	6	-	-	-
		10	6	6	6	4

3 – RESULTS AND DISSCUSSIONS

3.1 FAILURE MODE

The failure mode of almost specimens was withdrawal failure accompanied by rising up of the surface fibers, shown in Fig. 3. Although there was no clear trend in the extant of rising up of the fibers, some specimens of Jc-D25-P6 series showed cracking across the entire surface lamina, as shown in Fig.4.

Fig. 5 and 6 show the cross-sectional views of TR and LR plane of the glulam where LSB was inserted. In TR plane, the timber dovetailing the screw threads was subjected to compression and the fibers shifted in the shear plane, resulting in rolling-shear-like deformations. In LR plane, in addition to compression, the fibers bent and cracked in tension. There was no difference in these failure modes depending on the thread shapes.

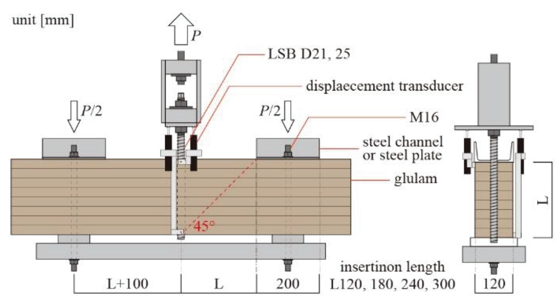

Figure 1. Loading configuration and specimen

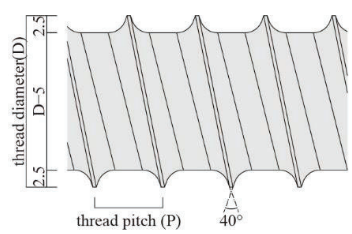

Figure 2. Thread shape of LSB

Figure 3. Withdrawal failure with rising up of the surface fibers

Figure 4. Cracking of surface lamina

Figure 5. Section of TR face

Figure 6. Section of LR face

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3.2 LOAD-DISPLACEMENT RELATION

Fig. 7-9 show typical load-displacement relationships. In almost all specimens, the stiffness decreased once at about 0.3 times the maximum withdrawal capacity (P_{max}), and then the load increased to P_{max} with a gradual decrease in stiffness, followed by a gradual decrease in load up to $0.8P_{max}$. In subsequent evaluations, the initial slope of the visual inspection was used as the withdrawal initial stiffness (K: stiffness) in order to correctly evaluate the initial stiffness. It was confirmed that the larger the thread diameter or the smaller the thread pitch, the higher the capacity and stiffness. Similarly, it was also confirmed that the longer the insertion length, the higher the capacity and stiffness. The amount of withdrawal displacement at P_{max} was about half of the thread pitch, regardless of thread diameter, insertion length, or wood species.

3.3 WITHDRAWAL PERFORMANCE

Figs. 10, 11 show P_{max}, withdrawal yield capacity (P_y), and K in the L120 series. For most of the series, P_{max}, P_y, and K are higher with larger thread diameters and smaller thread pitches, but P_{max} was not so high for Jc-D25-P6 series, and the difference in K by thread diameter was slightly smaller. Figs. 12, 13 show the relationships between P_{max}, P_y, K and insertion length for each thread shapes in the L180-300 series. The longer the insertion length, the higher the withdrawal capacity and stiffness, with a gradually decreasing increase in Japanese cedar. In Scots pine, only the increase in K at D25 gradually decreases, but P_{max}, P_y, and K at D21 increase proportionally up to L300.

The glulams used for L120 and L180-300 series were manufactured in different lots, and there were significant differences in their densities. Fig. 14 shows the relationship between P_{max} and oven-dry density for each insertion length. The density of Japanese cedar shows higher values for L180, 240 compared to L120, which may be one of the reasons for the higher increase in P_{max} from L120 to L240. Therefore, it is likely that P_{max} and P_y increase proportionally in Japanese cedar, as well as in Scots pine, up to L300.

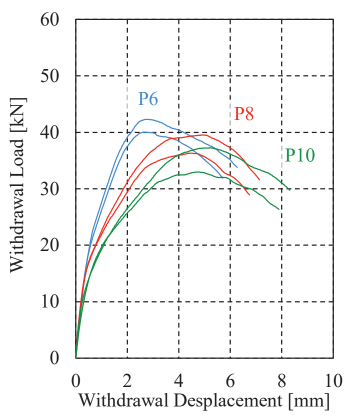

Figure 7. Load-displacement relationship compared with each P (Sp-L120-P10)

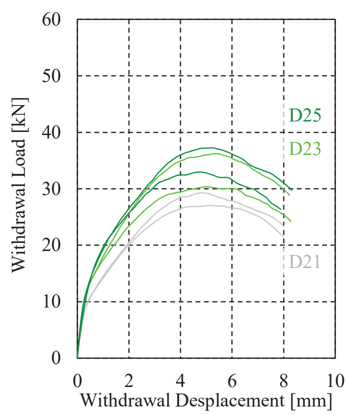

Figure 8. Load-displacement relationship compared with each D (Sp-L120-D25)

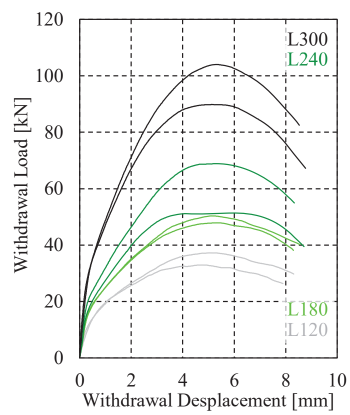

Figure 9. Load-displacement relationship compared with each L (Sp-D25-P10)

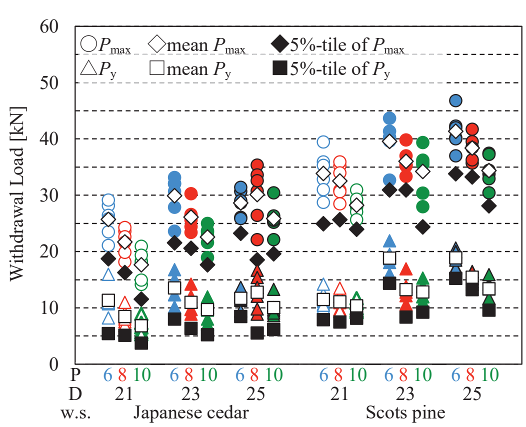

Figure 10. P_{max} and P_y compared with each thread shape

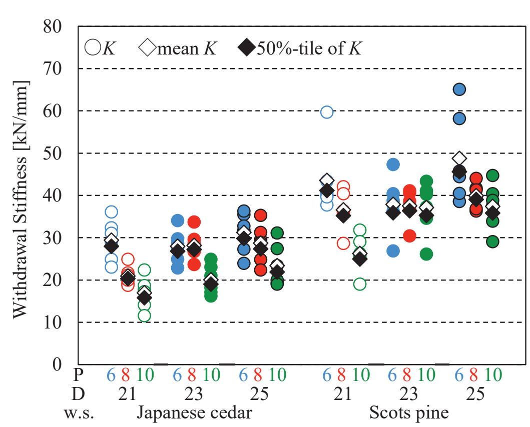

Figure 11. K compared with each thread shape

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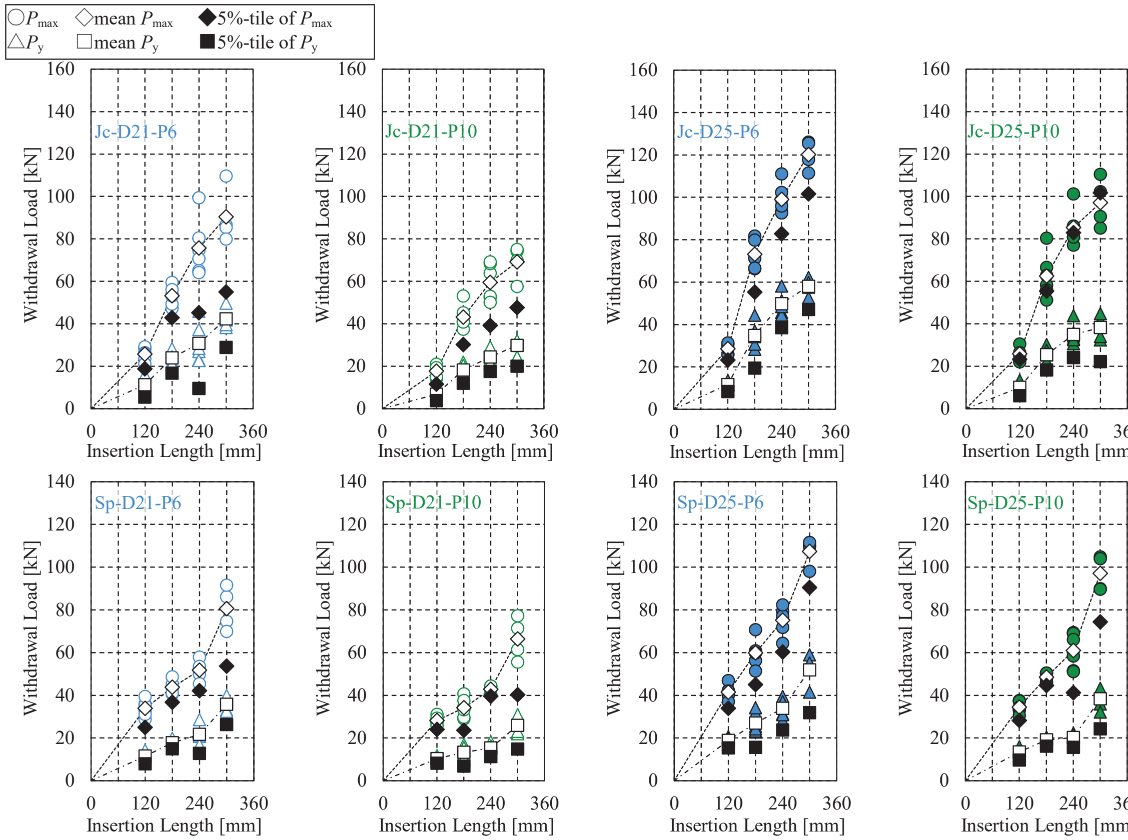


Figure 12. Withdrawal capacity-Insertion length relationships

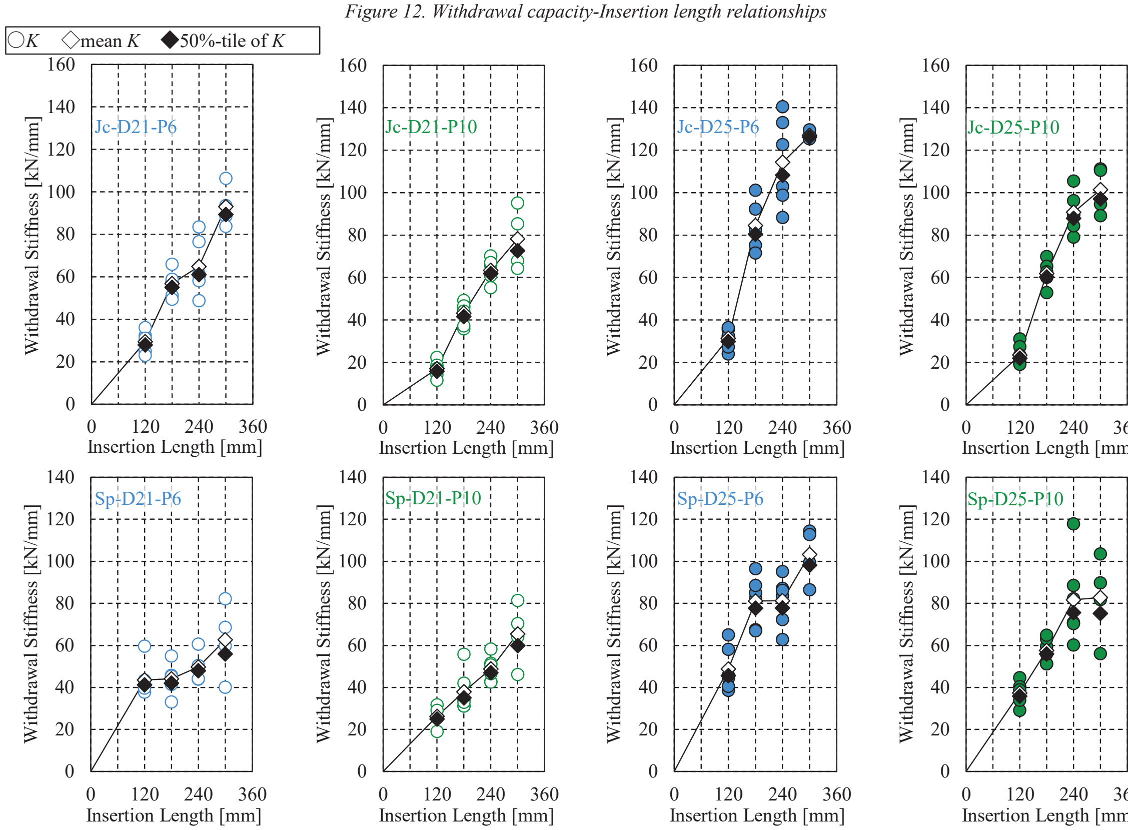


Figure 13. Withdrawal stiffness-Insertion length relationships

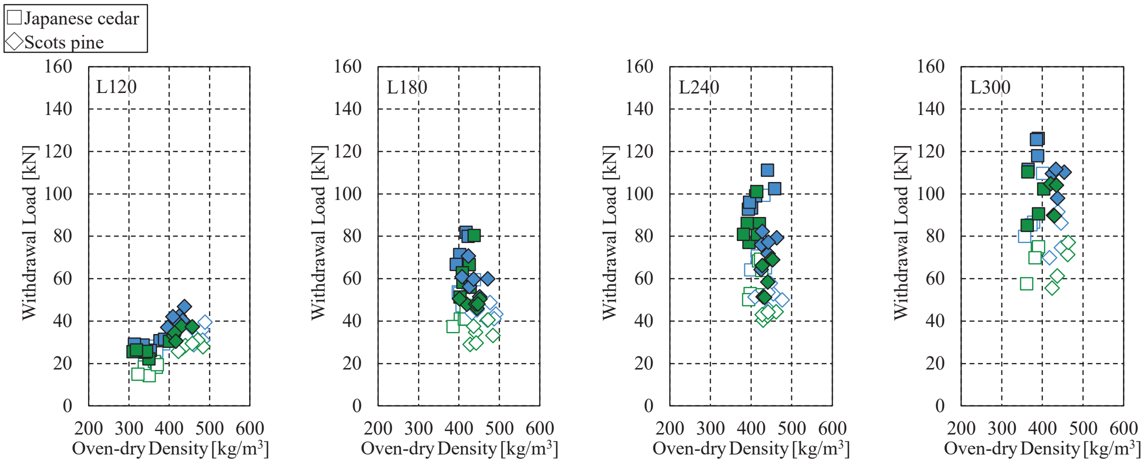


Figure 14. Withdrawal capacity-Insertion length relationships

3.4 EFFECT OF THREAD SHAPE

In order to examine the effect of thread shape, the compressive area (A_c) and shear area (A_s) used in estimating the bearing capacity of screwed fastener [13,14] were used to evaluate the strength and stiffness. The calculation methods for A_c and A_s are shown in Figs. 15, 16 and (1)-(4):

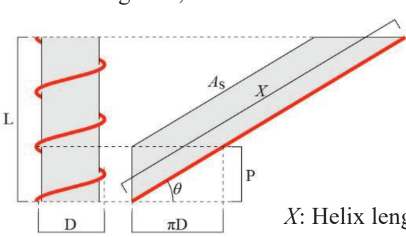
$$\theta = \tan^{-1} (P / \pi D) \quad (1)$$

$$X = D / \sin\theta \quad (2)$$

$$A_s = \pi D (D - P / 2) \quad (3)$$

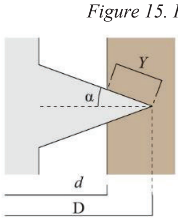
$$A_c = XY = L (D - d) / (2 \sin\theta \cos\alpha) \quad (4)$$

It has been reported that when a screwed fastener inserted into perpendicular to the grain is withdrawal from timber, it yields due to the screw thread penetration into timber [15]. Therefore, the compression strength calculated by dividing P_y by A_c is shown in Figs. 17, 18. Similarly, the compression stiffness calculated by dividing K by A_c is shown in Figs. 19, 20. These were almost the same for Jc-L120 and Sp-L180-300 regardless of thread shape, with 5%-tile of approximately 5 N/mm^2, which is almost the same as the reference strengths (Jc: 4.8 N/mm^2, Sp: 5.1 N/mm^2) [16]. The values of Jc-L180-300 and Sp-L120 were generally higher than the reference strengths. However, the higher density of the glulams, especially for Japanese cedar series, may be the reason for this. The compression stiffness was almost constant for each species in L120, but tended to be higher with larger thread diameter and pitch in L180-300.



X: Helix length [mm]

Figure 15. Helix length and shear area



Y: Dovetailing width [mm]
d: Lead hole diameter [mm]
α: Screw thread digree [°]

Figure 16. Dovetailing width for compression area

The withdrawal failure of LSB inserted into parallel to the grain has been reported to result from shear failure of timber [4,10-12,14]. While the withdrawal failure of LSB inserted into perpendicular to the grain is regarded as a combination of bending deformation of the fibers dovetailing with the screw threads and tensile crack of timber near the screw threads [5]. The thread pitch changes the number of screw threads that dovetailing timber per insertion length, and it has been reported that the height of the shear plane of the dovetailing timber (shear height), and that the greater the shear height, the lower the shear strength in transverse fiber shear behavior [17,18]. This is because the shear strength per shear area is calculated to be low because tensile crack occurs regardless of shear height, and the larger the thread pitch, the smaller the tensile area (=compression area). Therefore, we calculated pseudo shear strength by dividing P_{max} by A_s, as in the previous method [13], to examine the effect of shear height and other factors on shear strength. Figs. 21, 22 show the shear strength. The shear strength tended to be lower under conditions of larger thread pitch, i.e., larger shear height, as in [17,18]. The difference in shear strength by the thread diameter was slightly observed for Jc-D21-P6 at L180-300, but otherwise the shear strength values were similar for each species and thread pitch.

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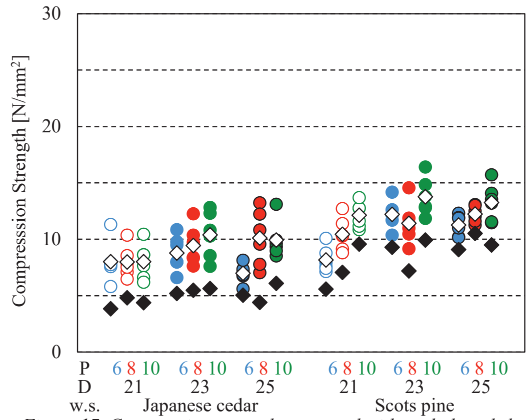

Figure 17. Compression strength compared with each thread shape

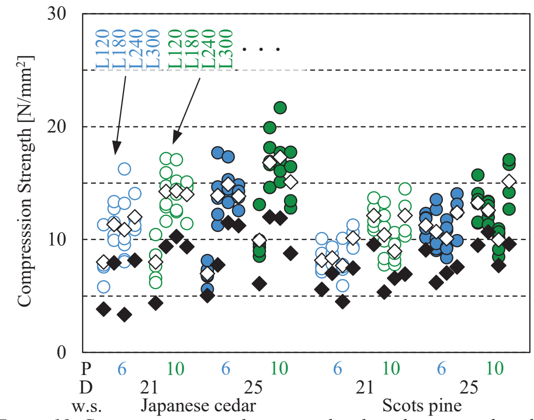

Figure 18. Compression strength compared with each insertion length

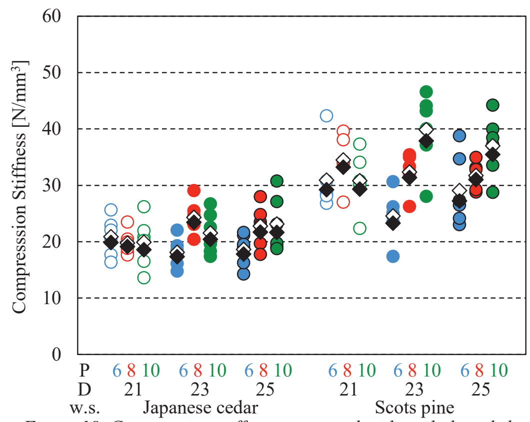

Figure 19. Compression stiffness compared with each thread shape

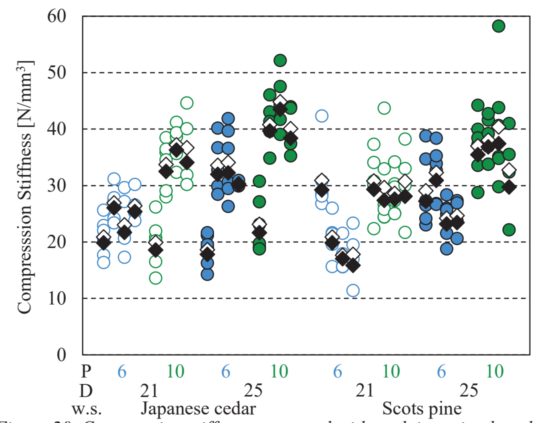

Figure 20. Compression stiffness compared with each insertion length

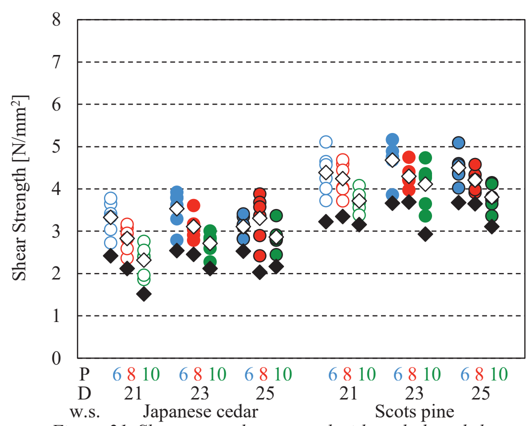

Figure 21. Shear strength compared with each thread shape

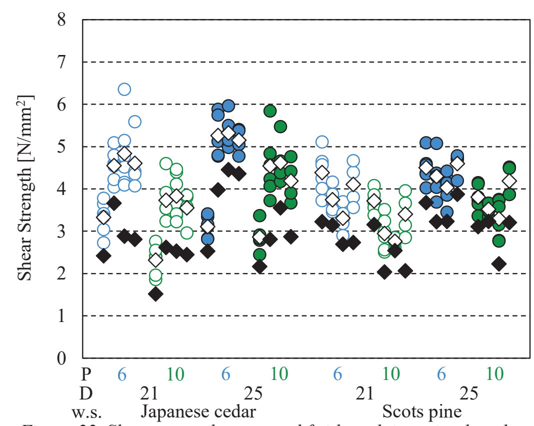

Figure 22. Shear strength compared fwith each insertion length

From these considerations, it was considered that the withdrawal failure of LSB inserted into perpendicular to the grain is caused by a combination of yielding due to transverse compression of timber dovetailing the screw threads and failure due to transverse shear with bending and tension. The shape of timber dovetailing the screw threads differs depending on the thread shape of the LSB, and by examining the difference in transverse shear strength due to the shear height, it was considered that a withdrawal model for LSB inserted into perpendicular to the grain can be proposed.

4 – CONCLUSIONS

Withdrawal tests of LSBs inserted into perpendicular to the grain with different thread shapes to investigate the

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effect of thread diameters, pitches and insertion length on withdrawal performance were conducted.

Compression area and shear area were applied to the withdrawal capacity and stiffness obtained from the tests as the evaluation method used for screwed fasteners, and the withdrawal capacity and stiffness per each area were calculated and evaluated.

1. The larger the thread diameter or the smaller the thread pitch, the higher the values of withdrawal capacity and stiffness. The larger the insertion length, the higher the values of capacity and stiffness. The trend of deformation depends on the thread pitches regardless of the thread diameter or insertion depth, and the maximum withdrawal capacity was reached when the withdrawal deformation reached about half of the thread pitch.

2. The compressive strength and stiffness, calculated by dividing the withdrawal yield capacity and stiffness by the compression area, were almost constant regardless of the thread shape and the insertion length. The 5%-fractile of the compression strength almost coincides with the reference strength, and we believe that the initial yielding at withdrawal behavior is due to the yielding caused by compression of timber dovetailing the screw threads.

3. The shear strength, calculated by dividing the maximum withdrawal capacity by the shear area, was lower the larger the thread pitch, and the shear strength at withdrawal behavior also changes because the transverse shear performance of the fiber varies depending on the shear height of timber dovetailing the screw threads.

We would like to consider the relationship between transverse shear performance and shear height, and the behavior of tension, and to a withdrawal model of LSB inserted into perpendicular to the grain.

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