WOOD RESEARCH
62 (3): 2017
417-426

STRENGTH PERFORMANCE EVALUATION OF MOMENT RESISTANCE FOR CYLINDRICAL-LVL COLUMN USING GFRP REINFORCED WOODEN PIN

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(Received June 2016)

ABSTRACT

In this study, Moment resistance performance of column-beam joints using cylindrical laminated veneer lumber (LVL) column and glulam beam were evaluated. Two types of jointing methods - Type-A, in which the beam is put on the end side of column and Type-B, in which the beam is inserted into column - were applied.

As a result of Type A, Moment resistance of the cylindrical-LVL column jointed with drift pins was shown to be 67 % higher than that of the larch log column jointed with drift pins. The larch log column jointed with GFRP Plate reinforced wooden pins was shown to be 14 % higher than that jointed with drift pins. In Type-B joint, the rotational stiffness of two specimens were 139.4 kN•m/rad. (Non-reinforced specimen) and 272.2 kN•m/rad. (reinforced specimen), respectively, and reinforced specimen was 95 % higher than Non-reinforced specimen. Based on this result it was assured that glass fiber reinforcement is able to reinforce the column.

KEYWORDS: Cylindrical-LVL, glass fiber reinforcement, reinforced wooden pin, moment resistance performance, LVL joint.

INTRODUCTION

Cylindrical-LVL column fabricated by spiral winding of a small width veneer is a technology that can transform small diameter softwood log into hollow-type large dimension timber. In Japan, the strength performance according to laminating direction at fabrication of cylindrical-LVL column since the late 1990 has been studied (Hata et al. 1998). The manufacturing conditions of cylindrical-LVL column and mechanical properties (Yamauchi et al. 1998), and the improved productivity of cylindrical-LVL have also been studied as research on continuous manufacturing method of cylindrical-LVL column and the mechanical properties of individual members was carried out (Inaba et al. 2003). Based on these studies, cylindrical-LVL is being used as column members of wooden structure and urban structures, but for structural use of cylindrical-LVL column improvement of mechanical properties by reinforcement of the hollow side of cylindrical-LVL is required, and an evaluation of strength performance of column-beam joint for application to a rahmen structure is also necessary.

In this study, cylindrical-LVL column was laminated together with a glass fiber cloth. GFRP, which was first mass-produced by the Owens-Corning company in the USA in 1939 and is in wide use to this day, has a relatively low specific gravity compared to iron material. Therefore, its increased weight as structural member itself is slight, and it offers several economic advantages compared to fiber-reinforced plastic. Today, GFRP material is being applied in most glulam, and high reinforcing effects are anticipated if this material is utilized for partly reinforced cylindrical-LVL columns by enlarging its scope.

On the other hand, the metal connection plate itself has a super high stiffness compared to wood column and beam at wooden construction, and also as the exposure persists, it is corroded by outdoor air, causing negative effect on wood and reducing aesthetics at the same time.

Accordingly, a cylindrical-LVL column partly reinforced with glass fiber cloth at the joint was fabricated in this study, and performance of this joint was compared with that of larch log column. Also, a study was conducted to improve joint performance of cylindrical-LVL column through application to an effective wooden fastener.

MATERIAL AND METHODS

Material

The veneer used for this study was 2.4 mm thick radiata pine (*Pinus radiatia* D.Don), and was saw cut to a width of 100 mm in a perpendicular-to-the-grain direction. Roll-type veneer sewed with polyester thread in order to prevent cutting was prepared. Reinforced material was the glass fiber cloth of 0.5 mm thickness and 100 mm width, which was aligned in a plain woven shape with 5 mm wide glass fiber bundle (Fig.1). The resorcinol resin was used at a ratio of 100 (resin) to 15 (hardener) in order to fabricate a cylindrical-LVL column.

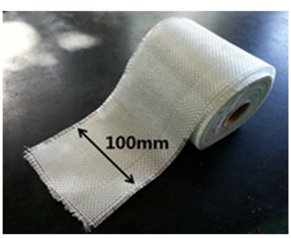

Fig. 1: Shape of glass fiber cloth.

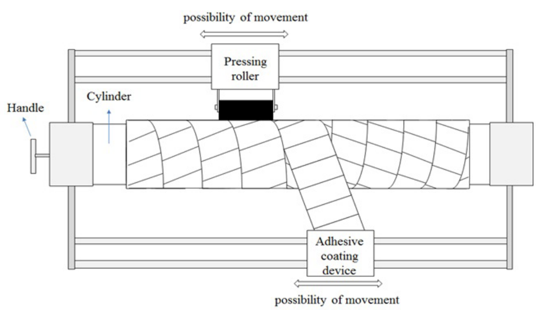

Fig. 2: Schematic diagram of spiral-winder.

United glue spreading and pressing type cylindrical laminated veneer lumber manufacturing machine

Cylindrical-LVL manufacturing machine consisted of a cylinder with diameter 165 mm (main body), veneer supplying and glue spreading part and pressing roll, as shown in Fig. 2. For the manufacture of LVL the cylinder rotates, and at this time the veneer supplying and glue spreading part performs the winding of the veneer, and at the same time pressing roll presses the veneer, following the above part. It is possible to manufacture up to 2000 mm length of cylindrical-LVL column, and the veneer laminating direction can be changed by manipulating the handle.

Manufacture of cylindrical-LVL column

As shown in Fig. 2, veneer roll was spirally laminated at an inclination of 10° to the cylinder axis. At this time, veneers were interlocked through every layer, and except for the last layer, adhesive was spread at both sides of the veneer (Berard et al. 2011). The composed cylindrical-LVL column was 20 layers. When the last veneer was laminated, the prepared column was regularly pressed (0.1 MPa) with rubber bands, and was hardened at room temperature for 24 hours or more (Hata et al. 2001). The method of manufacturing GFRP-reinforced cylindrical-LVL column is the same as the method for cylindrical -LVL column, but as shown in Fig. 3, the glass fiber cloth were 3 ply interlocked between both layers 10 and 11 and layers 18 and 19. Consequently, the outer diameters of the finished cylindrical-LVL column and GFRP-reinforced cylindrical-LVL column were 285 mm and 287 mm, respectively. For the purpose of comparing the performance with these laminated columns, larch (*Larix kaempferi* Carr.) log with diameter 250 mm was used. All columns were cut to a length of 800 mm and then tested.

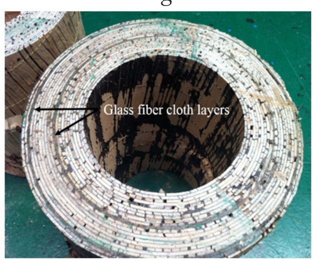

Fig. 3: Shape of cylindrical-LVL.

Manufacture of beam member

7 ply lamina with width 130 mm, thickness 25 mm, length 700 mm were laminated to width 130 mm, thickness 175 mm, length 700 mm with resorcinol resin.

Manufacture of GFRP-reinforced wooden pin

For jointing of column member and beam members, 2 types of pin, specifically carbon steel S45C drift pin of diameter 16 mm, length 130 mm and GFRP-reinforced wooden pin were used. The GFRP-reinforced wooden pin consisted of Korean ash (*Fraxinus rhynchophylla* Hance), and was processed to pin-shaped wood with length 130 mm, outer diameter 20 mm, inner diameter 12 mm, and then rod-shaped GFRP spread with epoxy adhesive was inserted.

Manufacture of moment resistance specimens of column-beam joint

The two joint types of moment resistance specimen were made as shown in Fig. 4. Type-A joint was a bridle joint which was hollow-cut as much as the height and width of beam and the beam was put on at the end side of the column. Type-B joint was a tenon joint which passes through a hole of area which was same with the end area of beam was processed on the column (Tab. 1). Larch log, cylindrical-LVL and GFRP-reinforced cylindrical-LVL were used as columns for Type-A joint, and 6 types of specimens of Type-A1~A6 were fabricated using drift pins and GFRP-reinforced wooden pins, respectively. Cylindrical-LVL and GFRP-reinforced cylindrical-LVL were used as columns for Type-B joint, and 2 types of specimens of Type-B_1~B_2 were fabricated using GFRP-reinforced wooden pins. The glulam was used as a beam, and the moment resistance specimens were fabricated in the following combination conditions.

For jointing column and beam, a 15 mm hole which was same with the diameter of drift pins was processed and pin inserted, and after the hole 22 mm in diameter, GFRP-reinforced wooden pins were spread with resin and inserted. So the number of jointing pins used was 4 at both sides of the column, and 8 pins in total were inserted.

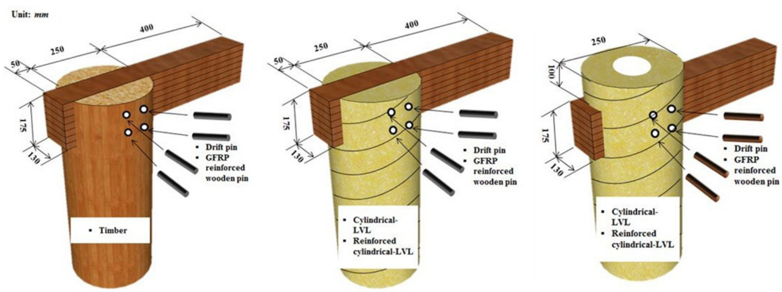

Fig. 4: Shape of moment resistance test specimens.

Tab. 1: Combination condition of test specimens.

Type of specimens	Column	Fastener	Beam
Type-A_1	Larch log	Drift pin	Larch glulam
Type-A_2	Larch log	Reinforced wooden pin	
Type-A_3	Cylindrical-LVL	Drift pin	
Type-A_4	Cylindrical-LVL	Reinforced wooden pin	
Type-A_5	Reinforced cylindrical-LVL	Drift pin	
Type-A_6	Reinforced cylindrical-LVL	Reinforced wooden pin	
Type-B_1	Cylindrical-LVL	Reinforced wooden pin	
Type-B_2	Reinforced cylindrical-LVL	Reinforced wooden pin	

Bending test of fastener

3-point bending test was executed with a universal testing machine (Instron-4482). The test followed the standard procedure of ASTM F1575-03 (2013). At this time, GFRP-reinforced wooden pins, non-reinforced wooden pins and drift pins were loaded with span of 100 mm by a concentrated loading (loading speed: 10mm·min^{-1}). Bending yield moment was determined from method of 5% diameter off-set and calculated through Eq. 1. Initial stiffness was determined from elastic slope of the load-deformation curve (ASTM F 1575-3. 2013).

$$M_y = \frac{Ps_{bp}}{4} \tag{1}$$

where: P - 5% off-set yield load,
S_{bp} - spacing between supports.

Moment resistance test of column-beam joint

The prepared test member was set up in a jig, and then the beam at a distance of 200 mm from the column was loaded at a cross head speed of 5mm.min^{-1}. Displacement transducer (CDP-50) with max capacity 50 mm was set up and measured at the other end of cross head of loaded beam and the end side of beam joint. Also, in order to correct the test value of vertical displacement of column, Displacement transducer was also set up at the bottom side area of column (③) (Fig.5). The distance from the center of cylindrical-LVL column to ① was used to calculate the moment of the joint (Radius of cylindrical-LVL + 200 mm). The deformation of ① was corrected by using deformations of ② and ③. The values of load and displacement were acquired with Data logger TDS-303.

In this paper, it is suggested that maximum moment (M_{max}), yielding moment (P_y), rotation angle at yielding moment (γ_y) and rotational stiffness (K_y) are determined according to the perfect elasto-plastic model of Yasumura and Kawai procedure (Fig.6) (Yasumura and Kawai 1997).

The determination method is as follows:

1. Line 'I' is drawn through the points on the moment-rotation angle curve corresponding to 10 % to 40 % of the M_{max}.
2. Line 'II' is drawn through 40 % to 90 % point of the M_{max}.
3. Line 'II' is moved parallel so that it is tangent to the moment-rotation angle curve. This line is 'III'.
4. The moment of contact point where line 'II' meets line 'I' is called yielding moment (P_y).
5. Draw a straight line parallel to the rotation angle axis and pass through the yielding moment (P_y). The rotation angle of contact point where that line meets moment-rotation angle curve is called γ_y.
6. Draw a straight line through coordinate (0,0) to coordinate (γ_y, P_y). This line is called rotational stiffness (K_y).
7. The rotational stiffness was calculated using Eq. (2).

$$\text{Rotational stiffness } (K_y) = P_y/\gamma_y \tag{2}$$

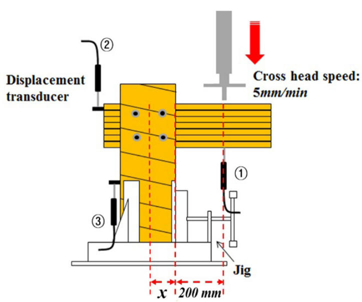

Fig. 5: Schematic diagram of moment resistance test.

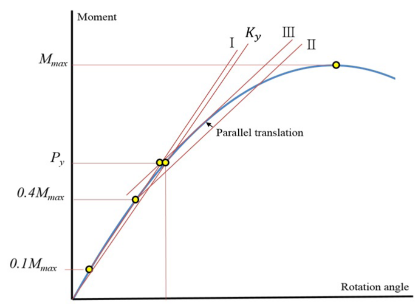

Fig. 6: Perfect elasto-plastic model of Yasumura and Kawai procedure. Yasumura.

RESULTS AND DISCUSSION

Bending strength performance of fastener

In our previous study, we conducted a bending strength test for the GFRP reinforced laminated wooden pin that had been manufactured in a pin shape after lamination and densification of a veneer or plywood with a GFRP plate (Song et al. 2014). As a result, the bending yield moment of the specimen that was densified by inserting reinforcement in each layer of the laminated plates was measured the highest at 259500 N•mm. This bending yield moment is 2.5 times as high as that of the GFRP-reinforced wooden pin in this study. However, a GFRP-reinforced wooden pin with a GFRP rod inserted in it was used in this study because the GFRP reinforced laminated wooden is not easy to produce and process.

As a result of bending strength test of fasteners, average bending yield moment of wooden pins, GFRP-reinforced wooden pins and drift pins were 31250 N•mm, 102500 N•mm, 476667 N•mm, respectively. The average bending yield moment of GFRP-reinforced wooden pin was measured approximately 3.3 times higher than that of non-reinforced wooden pin. The average bending yield moment of GFRP-reinforced wooden pins was about 4.7 times lower than that of the drift pins, and Ave. initial stiffness also was measured at approximately 13 times lower. The bending yield moment and initial stiffness of the drift pin was measured the highest among the specimens (Tab. 2).

Tab. 2: Properties of bending strength test for fasteners.

Type	Ave. bending yield moment (*N•mm*)	Ave. initial stiffness (*N•mm*)
GFRP-reinforced laminated wooden pin (2014)	259500	4760
Non-reinforced wooden pin	31250	357.7
GFRP-reinforced wooden pin	102500	550.9
Drift pin	476667	7432.4

Moment resistance of column-beam joint

Through the comparison of the GFRP-reinforced wooden pins with drift pins for test member using larch log column, it was found that the bending yield moment of the GFRP-reinforced wooden pins was 4.7 times lower than that of the drift pins. However, maximum moment of Type-A_1 and Type-A_2 were 9.2 kN•m and 10.5 kN•m, respectively, and test member using Type-A_2 GFRP-reinforced wooden pins showed a 14 % higher resistance property. The yielding moment of Type A_2 was 18 % higher than Type-A_1, but rotational stiffness of joint was measured 32 % lower by difference for stiffness of fastener. On the other hand, looking at Type-A_3 and Type-A_4 using cylindrical-LVL as column, the maximum moment of Type-A_3 using drift pin was 15.4 kN•m, and this Type-A_3 showed 69 % higher moment resistance performance than the Type-A_4 using GFRP-reinforced wooden pin. The rotational stiffness of Type A_3 was 29 % higher than Type-A_4. It is considered that the reason why the GFRP-reinforced wooden pin does not exhibit favorable performance in cylindrical-LVL column is the pin's poor adhesiveness with the column. Larch log column brought about high performance thanks to an even glue line formation with the GFRP-reinforced wooden pin. On the other hand, the cylindrical-LVL column contains many pores, and therefore integration between column and beam member was not realized due to poor glue line formation thanks to the flowing loss of resin spread on the GFRP-reinforced wooden pin. Furthermore, the measurement of rotational stiffness was low because of the difference in stiffness and end distance between the drift pin and the GFRP-reinforced wooden pin, the difference in specific gravity between the log column and the cylindrical-LVL column, and the greater diameter of the GFRP-reinforced wooden pin, resulting in low bearing stiffness by the dowel pin (Harada et al. 2000, Kennedy et al. 2014).

Comparing the results of larch log column and cylindrical-LVL column by use of drift pin, Type-A_3 using cylindrical-LVL column showed 67 % higher maximum moment.

As a result of a test according to the cylindrical LVL column at the Type A joint, the maximum moment of Type-A_3 was higher by 32% compared to Type-A_5, and the maximum moment of Type-A_4 was higher by 32% compared to Type-A_6. Thus, the performance of the reinforced cylindrical LVL column was lower regardless of the type of fastener. The cause of this is that even though the column reinforced with glass fiber cloth was protected from split by the bearing of fastener, splits occurred easily at the unreinforced beam. Therefore, the maximum moment was lower than that of Type-A_3 and Type-A_4 for which the column and beam were fractured together.

For Type-B joint, which inserted the beam into column, a reinforcing effect was found in resistance properties and failure mode. Type-B_1 non-reinforcing cylindrical-LVL column and Type-B_2 reinforcing cylindrical-LVL column showed maximum moment of 19.5 kN•m and 19.4 kN•m, respectively. The rotational stiffness of above two specimens were 139.4 kN•m/rad. and 272.2 kN•m/rad., respectively, and Type-B_2 was 95 % higher than Type-B_1. Based on this result it was assured that glass fiber cloth is able to reinforce the column.

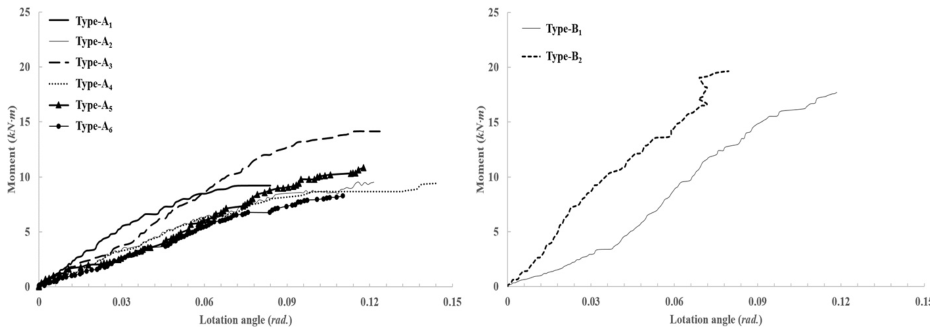

Fig. 7: Moment-rotation angle curves of moment resistance test.

Tab. 3: Properties of moment resistance test.

Specimens	M_{max} (kN•m)	P_y (kN•m)	γ_y (rad.)	K_y (kN•m/rad.)
Type-A_1	9.2	5.0	0.030	166.7
Type-A_2	10.5	5.9	0.048	122.9
Type-A_3	15.4	7.8	0.057	136.8
Type-A_4	9.1	5.1	0.048	106.3
Type-A_5	11.7	6.1	0.069	88.4
Type-A_6	8.5	5.1	0.060	85.0
Type-B_1	19.5	9.2	0.066	139.4
Type-B_2	19.4	9.8	0.036	272.2

M_{max} : Maximum moment, $_y$: Yielding moment, γ_y : Rotation angle at yielding moment, K_y : Rotational stiffness

Failure mode

Type-A_1 jointing column and beam with drift pin had high stiffness of fastener, and thus failed easily according to grain direction in the end-distance of larch log column. For Type-A_2 using a GFRP-reinforced wooden pin, failure in column and beam occurred. As the fastener's material is wood for Type-A_2, the difference in stiffness compared with jointed members was trivial. Therefore, beam member also was failed, as column and beam member were integrated and were resistant against moment.

A big difference in terms of failure mode was found in the test member using cylindrical-LVL column compared with the member using larch log column. Instant failure occurred in the end-distance of the larch log column; however, every glue line restrained failure in cylindrical-LVL column. Also, judging from the fact that loading was executed until all the beam failed regardless of the fastener type, it could be ascertained that strength performance of cylindrical-LVL column is higher than that of larch log column.

Type-A_5 and Type-A_6 with a reinforced column exhibited a lower maximum moment than the unreinforced Type-A_3 and Type-A_4. However, the reinforced cylindrical-LVL column showed less split to the end distance. In the case of Type-A_5, large fractures occurred by the drift pin from the inside of the cylindrical-LVL column that is in contact with the glulam beam, but unlike Type-A_3, the reinforcement restricted the progress of fractures to the outside of the cylindrical-LVL column. Type-A_6 also showed no fractures in the cylindrical-LVL column unlike Type-A_4, and fractures developed only in the glulam beam. Meanwhile, Kim et al. verified through a fracture toughness experiment that the glass fiber cloth restricted the split of glulam by pin bearing even though it does not affect the bearing strength and increased the stress intensity factor (Kim and Hong. 2008, 2015). Nevertheless, the reinforced cylindrical-LVL column joint cannot exhibit excellent moment resistance because as mentioned above in 'Moment resistance of column-beam joint', fractures developed easily in the beams which are weaker because only the columns were reinforced (Fig. 8).

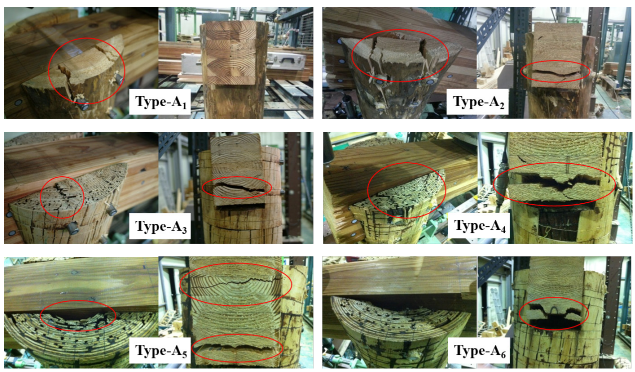

Fig.8: Failure modes of Type-A.

It was found that Type-B joint has a more stable reinforcing effect when compared with Type-A. The tensile stress in Type-B_1 occurred at the back side of the beam according to the loading on the beam, and then began to fail due to an unfavorable glue line, ultimately resulting in total failure. However, the failure did not occur in the GFRP-reinforced column, and cross-section was distorted. From this phenomenon, it was inferred that reinforcing material suppressed tensile failure of the column (Fig. 9).

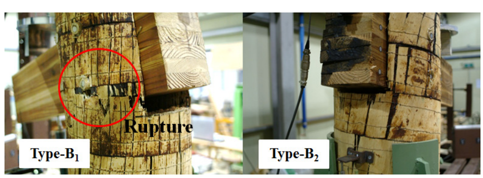

Fig. 9: Failure modes of Type-B.

If a general analysis of the failure mode in the above-mentioned moment resistance experiment results show that the laminated wood which is a beam fails before the reinforced cylindrical-LVL column or vice versa, it is difficult to expect a high moment resistance of the joint. The glulam beam in this study also easily developed fractures to the end distance along the fiber orientation, and this was the main cause of lowering the moment resistance. This failure mode exhibits a similar tendency in most cases when a glulam joint uses a metal connector (Wang et al. 2012, Song et al. 2014, Yeh et al. 2015, Dopeux et al. 2015). Therefore, a higher moment resistance performance will be achieved if the beams as well as the columns are reinforced to be protected from failure by fastener.

CONCLUSIONS

In this study, Type-A_3 using a cylindrical-LVL column improved strength performance by 67 % when compared with Type-A_1 using larch log column using drift pin. When using larch log column, Type-A_2 jointed with GFRP-reinforced wooden pin had 14% higher performance than Type-A1 jointed with drift pin. For cylindrical-LVL column jointed by GFRP-reinforced wooden pin, formation of glue line was incomplete, and thus there was low strength performance. However, if a fastener is inserted so that the gap between column and GFRP-reinforced wooden pin can be removed, it is expected that the joint would be better integrated. The result of the test by glass fiber cloth reinforcement or non-reinforcement of column showed that the rotational stiffness of reinforced specimen was measured 95 % higher, and the non-reinforced specimen brought about total tensile failure at joint. However, for the reinforced specimen, glass fiber cloth suppressed tensile failure, and thus performance of the joint could be enhanced. In conclusion, if only the cylindrical column is reinforced, it has a low moment because fractures occur easily at the beam. Therefore, a high moment resistance performance will be achieved if both the columns and beams are reinforced.

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