

# Load Carrying Capacity of Drift Pin Joint of Cross Laminated Timber (CLT) with Steel Insert Plate

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## Abstract

Cross Laminated Timber (CLT) is a structural plate element which is approved in Europe and is intended to be approved in Japan. It consists of small dimension laminae, in which laminae parallel and perpendicular to longitudinal direction are interlaminated. We performed tensile tests for the drift pin joint with steel insert plate. Specimen consisted of CLT was made from Japanese cedar laminae (thickness of laminae  $t = 30\text{mm}$ , five laminae were layered), with steel drift pin plate. Odd-numbered layers were parallel to the longitudinal axis, and even-numbered layers were perpendicular to the longitudinal axis. The experimental parameters were edge distances ( $3d$ ,  $4d$  and  $7d$ ), end distances ( $3d$ ,  $4d$  and  $7d$ ) and diameters of pin (12 and 16 mm) and the replication were three respectively. Initial stiffness was lower than the results of glulam drift pin joint loaded in parallel to the grain, however second stiffness after the yield of drift pin was higher because the lateral compression occurred at even-numbered layers. Additionally, ductility was higher because split failures around the pin were prevented by the glued effect of interlaminated layers. As the characteristic value of test results, initial stiffness  $K$ , yield load  $P_y$ , maximum load  $P_{max}$ , indicated the effect of the difference of the diameter of the pin, while deformation capacity indicated the effect of edge distance.

**Keywords:** CLT, drift pin joint, tensile test, edge distance, load carrying capacity.

## Introduction

Cross laminated timber (CLT, shown in Figure 1) which is approved in Europe, is intended to be approved in Japan as a new engineered wood. CLT consists of small dimension laminae, which are interlaminated according to the grain direction. For the sake of applying them to multi-stories structures, it is necessary to consider the load carrying capacity of the joint of CLT members in the countries which are earthquake-prone like Japan or Indonesia, where the buildings must resist horizontal load not only by the wind but also by the earthquake.

One of interest point of CLT structure is effect of cross lamination for structural performance. Recent study showed

the out of plane bending and shear performances are weak of the cross layers (Mestek 2008). On the other hand, cross layers should be benefit when the dowels were used on the joint because cross layers prevent the split failure parallel to the grain. This paper focused on the failure of the dowel type joint with CLT. In this research we performed the parameter study for the drift pin joint of CLT. The part of these studies already published (Nakashima 2012). As the first step toward introduction of design method for the drift pin joint for CLT, a basic elemental test was carried out. Main purpose of this paper is observing and describing the behavior of CLT drift pin joint with steel plate. The effect of end distance and edge distance on the maximum load was considered.

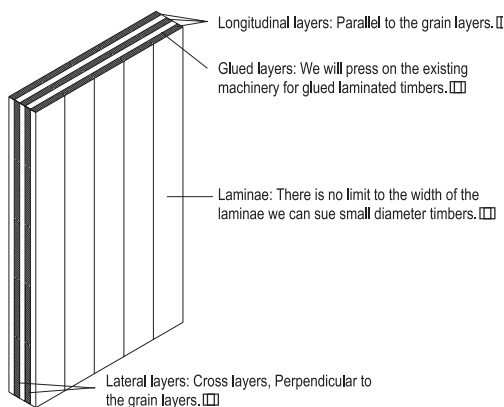


Figure 1. CLT (Cross Laminated Timber).



Figure 2. CLT specimens.

## Materials and Methods

### Materials

Figure 2 shows materials used as specimens. Specimens consists of Japanese cedar (*Cryptomeria japonica*) Cross Laminated Timber (thickness of each lamina is 30mm and five layered, in which the odd-numbered layers were arranged in parallel to the longitudinal axis, and the even-numbered layers were perpendicular to the axis), a steel drift pin (circular cross sectional steel bar, diameter  $d = 12$  and 16 mm, yield strength  $F = 309\text{MPa}$ : (test result)) and a steel plate (thickness  $t = 9\text{mm}$ ,  $F = 295\text{MPa}$ : (nominal value)).

### Test Methods

Figure 3 and 4 show the test set-up. The specimen laid on the roller support was subjected to the tensile load applied on the steel plate, while the other side was pin-

connected to the frame. The replication for each condition was three respectively. One of the three duplicates was monotonic tensile loaded and the other two specimens were cyclic loaded in seven steps which were specified according to the yield deformation  $\delta_y$  of the first one from  $1/2\delta_y$  to  $16\delta_y$ . The load and the relative deformation between steel plate and timber were measured by load cell and four transducers. The relative deformation was estimated by average of four transducers.

### Parameters

Parameters were shown in Figure 5 and Table 1. Parameters of specimen were the diameters of drift pin ( $d = 12, 16\text{mm}$ ), end distances ( $3d, 4d$  and  $7d$ ), edge distances ( $3d, 4d$  and  $7d$ ) and the composition of Young's modulus of each lamina (6-6-6-6-6, 8-6-6-6-8 GPa in 5 layers from one side).

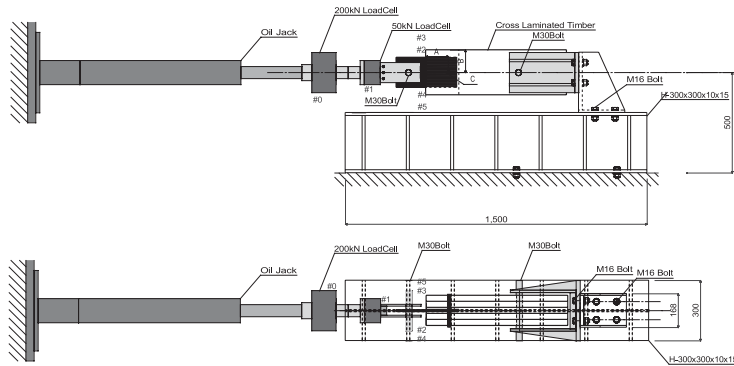


Figure 3. Set-up of tensile test.

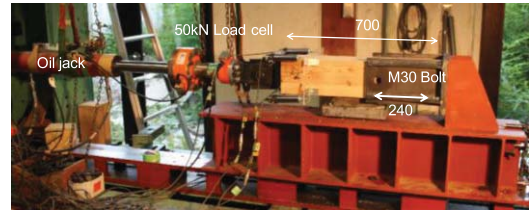


Figure 4. Actual feature of tensile test.

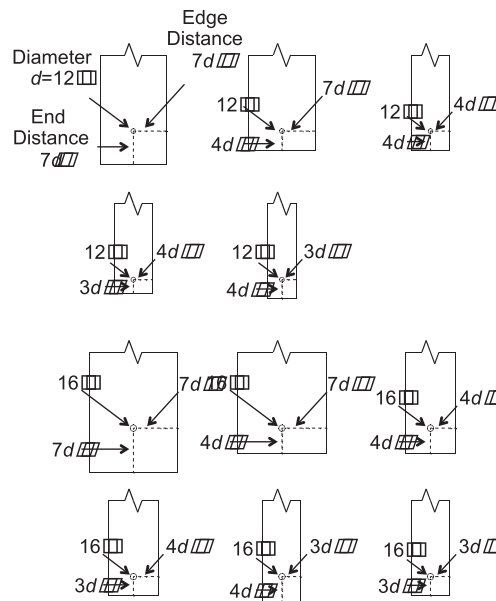


Figure 5. Parameters.

Table 1. List of specimens.

No	Material	Replication <i>n</i>	Diameter of fastener <i>d</i> (mm)	Edge distance (mm)	End distance (mm)
1	Japanede cedar ( <i>Cyprotomeria japonica</i> ) (L60 and L80), five layered cross laminated timber. Odd number specimens consist of L60 completely, and Even number specimens composed with L80 in outer layer	3	12	7 <i>d</i>	4 <i>d</i>
2					7 <i>d</i>
3					7 <i>d</i>
4					7 <i>d</i>
5				4 <i>d</i>	4 <i>d</i>
6					4 <i>d</i>
7					3 <i>d</i>
8					4 <i>d</i>
9					4 <i>d</i>
10					4 <i>d</i>
11			16	7 <i>d</i>	4 <i>d</i>
12					7 <i>d</i>
13					7 <i>d</i>
14					7 <i>d</i>
15				4 <i>d</i>	4 <i>d</i>
16					4 <i>d</i>
17					3 <i>d</i>
18					3 <i>d</i>
19				3 <i>d</i>	4 <i>d</i>
20					4 <i>d</i>
21					3 <i>d</i>
22					3 <i>d</i>

## Results and Discussion

### Load-deformation Curve

Figure 6 shows the load-deformation envelope curves obtained in the test. In both conditions of different diameters, obvious decrease in stiffness was observed and then curves showed second stiffness. It was supposed that this second stiffness happened on the layers perpendicular to longitudinal axis. That is because embedment perpendicular to the grain has second stiffness while that parallel to the grain does not.

It was found that initial stiffness was nearly identical among all conditions with drift pin of same diameter. There

were no significant difference between “6-6-6-6-6” specimens and “8-6-6-6-8” specimens.

The maximum deformations obtained in “end and edge distance: 7*d*” condition were around two or three times of diameter *d*. The failure modes were split from slit end in the case of 7*d* and rolling shear by the bent drift pin in the case of 4*d* (see Figure 9 and 10). Generally if the edge distance is less than 4*d*, specimens would not show ductile deformation because split or shear failure occur from the fastener. It was suggested that the ductility of CLT joint happened as the result of the prevention of split failure which is expected to occur around the pin by virtue of glued layers.

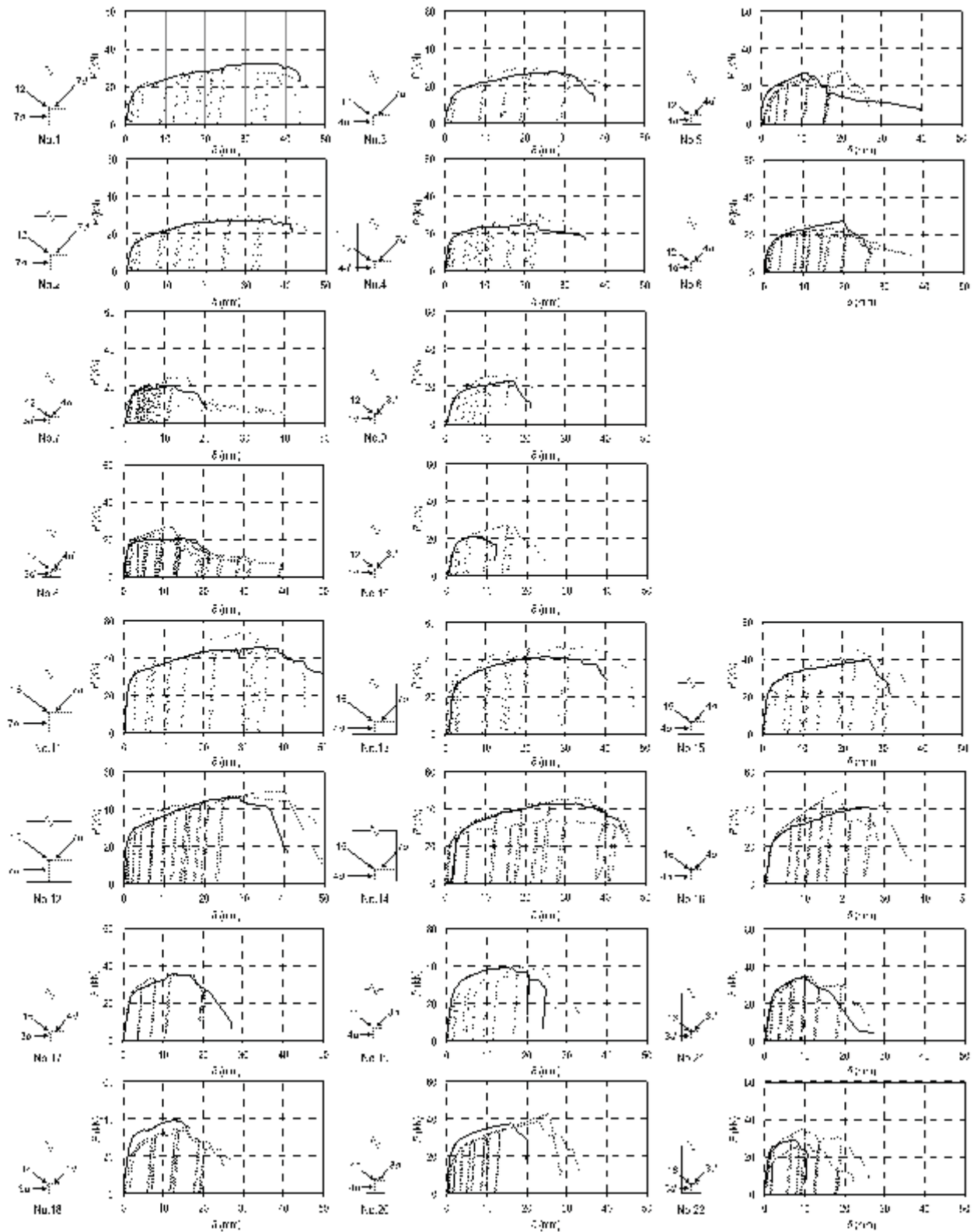


Figure 6. Load ( $P$ ) – Deformation ( $\delta$ ) envelope curves. Rigid lines are first specimens and dot lines are second specimens in same parameters.

### Characteristic Values

Figure 7 and 8 show the definition of characteristic values ( $P_{max}$ ,  $P_y$ ,  $P_{limit}$ ,  $K$ ) and test results. Each value was determined based on ASTM method. It can be seen in these figures that yield load and proportional limit load were only influenced by the diameter of drift pins. In other words, yield load ( $P_y$ ), yield deformation ( $\delta_y$ ), proportional limit load ( $P_{limit}$ ) and proportional limit deformation ( $\delta_{limit}$ ) were not affected by the edge distance and the end distance. Only maximum load ( $P_{max}$ ) was affected by the end distance and edge distance. This fact is discussed later in chapter 3.4.

In addition, because results of "6-6-6-6" and "8-6-6-6-8" specimens showed no significant differences, both results are averaged together in same graphs.

### Failure Mode

Figure 7 shows the typical failure mode observed in the test. There were three types of failure modes; (i) split failure from the slit, (ii) rolling shear failure on border of layers over the grain direction. In addition, (i) can be divided into two groups; (ii-1) is combination of shear on border of layers and split on border of layers, (ii-2) is pure shear on border of layers. Rolling shear means the to the grain shear on the cross layers (Okuma 1974).

In Table.2, split failure from the slits were only observed on specimens of end distance =  $7d$  and edge distance =  $7d$ . Rolling shear failure appeared on specimens of end distance is less than  $4d$  and edge distance is less than  $7d$ .

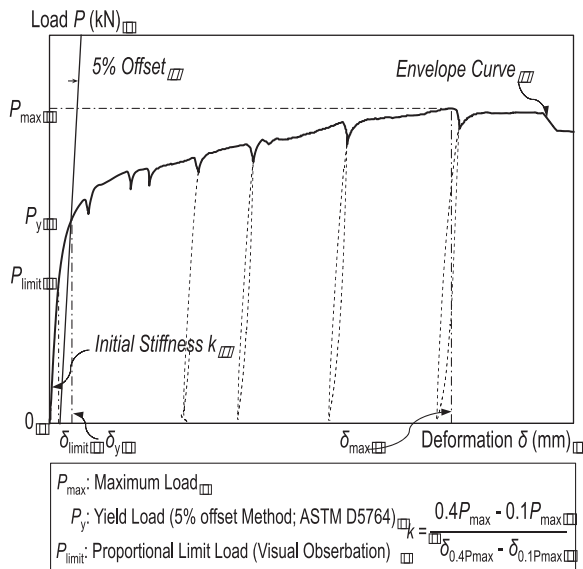


Figure 7. Definition of characteristic values.

Figure 10 shows the characteristic failures of (ii). Figures from (a) to (i) indicate the detail of failures as follows;

### Rolling Shear Failure

1. Rolling shear failure started from the border between central layer and next layer (Figure 8 (a)).
2. The fracture type may be different in the left and right across the steel plate (Figure 8 (b), (d), (e)).
3. The type of failure (i-1) and (i-2) cannot be separated each other obviously sometimes (Figure 8 (a) ~ (e)).

### Tensile to the Parallel to the Grain Failure

4. Split along Radial or tangential direction occur sometimes (Figure 8 (f) ~ (h)).
5. Split failures on the border of layers occur not only cross section but also parallel to the grain layer (Fig.8 (a), (d), (e)).
6. Failure on the butt joints sometimes occurred. Figure 8(c) and left of (i) is the case of failure on the butt joint, while split line stride across the butt joint sometimes (Figure 8 (d), (g), right of (i)).

Here, notations of (a) ~ (i) indicates the corresponding figures. Characteristic failure of dowel type joint with CLT is rolling shear failure. Critical rolling shear failure was brought out from the shear on the border between central layer and next layer.

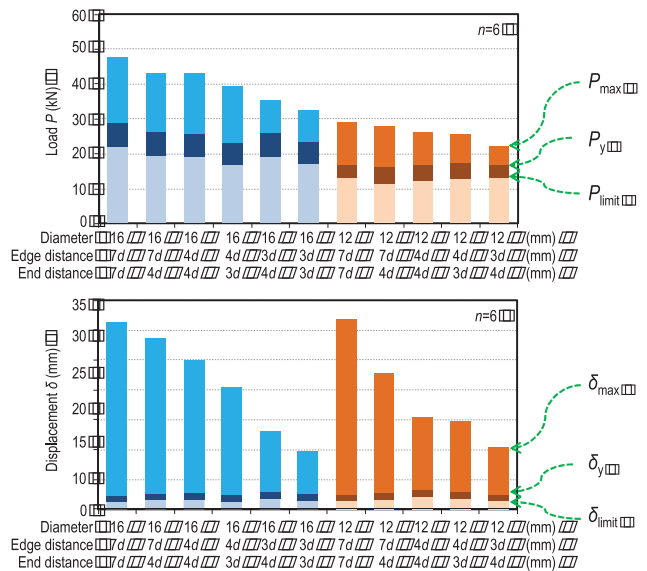
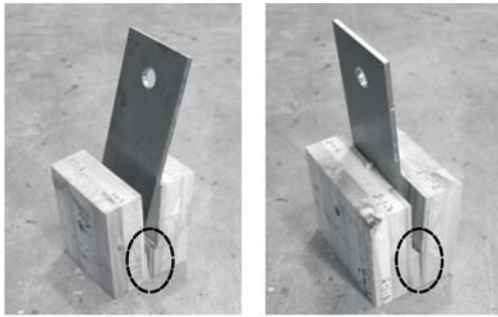
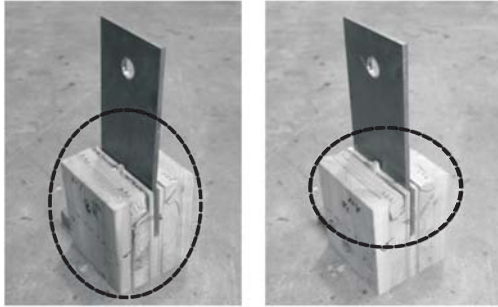


Figure 8. Characteristic values.



(i) Split from the Slit



(ii) Rolling Shear

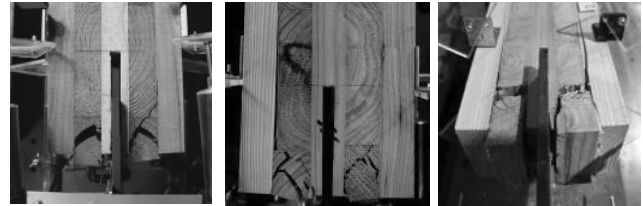
Figure 9. Failure of the specimens.



(a) (b) (c)



(d) (e) (f)



(g) (h) (i)

Figure 10. Detail of rolling shear failures.

Table 2. Failure type on each parameter.

No.	diameter of fastener $d$ (mm)	Edge distance (mm)	End distance (mm)	Failure type	
1	12	$7d$	$4d$	Rolling Shear	
2			$7d$		Split from the Slit
3			$7d$	Rolling Shear	
4			$7d$		Split from the Slit
5		$4d$	$4d$	Rolling Shear	
6			$4d$		Rolling Shear
7			$3d$	Rolling Shear	
8			$3d$		Rolling Shear
9			$3d$	$4d$	
10				$4d$	Rolling Shear
11	16	$7d$	$4d$	Rolling Shear	
12			$4d$		Split from the Slit
13			$7d$	Split from the Slit	
14			$7d$		Split from the Slit
15		$4d$	$4d$	Rolling Shear	
16			$4d$		Rolling Shear
17			$3d$	Rolling Shear	
18			$3d$		Rolling Shear
19			$3d$	$4d$	
20				$4d$	Rolling Shear
21	$3d$	Rolling Shear			
22	$3d$		Rolling Shear		

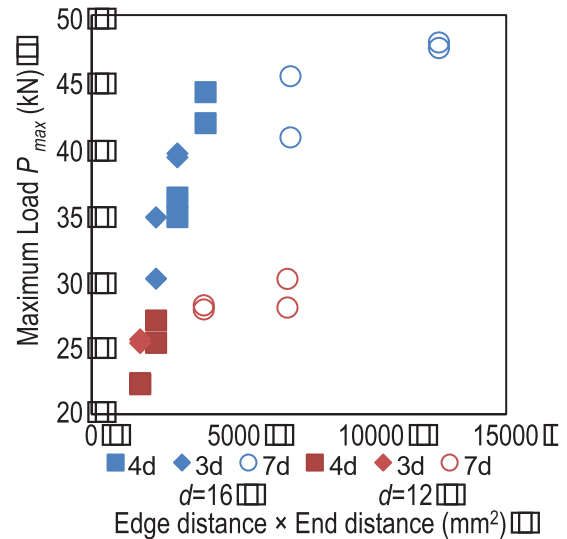


Figure 11. Relationship between maximum loads and Edge distance  $\times$  End distance.

### The Effect of Edge and End Distance on Maximum Load

Figure 9 shows the relationship between maximum load and edge distance  $\times$  end distance (nominal pure shear area). In this figure there is obvious proportional relationship among the specimens of edge distance =  $3d$  and  $4d$ . On the other hand, specimens of edge distance =  $7d$  shows different tendency. It indicates that edge distance =  $7d$  is the sufficient distance for preventing the shear failure on border of layers. Hence, an existence of this boundary distance whether shear failure occurs or not was suggested.

### Conclusions

In this paper, the tensile tests for the steel plate inserted drift pin joint of CLT were performed, the characteristic point of them behaviors and compared the effect of end distance and edge distance on maximum load.

As a result, it was found that proportional limit load ( $P_{\text{limit}}$ ) and deformation ( $\delta_{\text{limit}}$ ), yield load ( $P_y$ ) and deformation ( $\delta_y$ ) have no tendency for edge distances and end distances. Despite the edge distance =  $3d$  or  $4d$ , there is remarkable deformation capacity on load deformation curve. That is, the small edge distance of  $3d$  or  $4d$  on the joint may be allowed for CLT timber drift pin connection to secure the sufficient deformation capacity.

Difference of failure modes was observed at maximum load ( $P_{\text{max}}$ ). The rolling shear failure on the border of the layers occurred on the specimens of edge distance and end distance =  $3d$  or  $4d$ . This indicates that, we have to pay attention to not only shear on the drift pin or split failure on timber on longitudinal axis, but also shear failure on the border of layers. That must be considered as a new failure criterion for the drift pin joint of CLT. This shear affected from the end distance and edge distance.

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