THE FLEXURAL STRENGTH AND RIGIDITY OF *ALBASIA* NAIL-LAMINATED BEAM

J. A. Tjondro
Department of Civil Engineering, Parahyangan Catholic University, Bandung
E-mail: jatjondro@yahoo.com

H. Budianto
Alumni, Department of Civil Engineering, Parahyangan Catholic University, Bandung
E-mail: phines_man@yahoo.com

W. Aryakusuma
Alumni, Department of Civil Engineering, Parahyangan Catholic University, Bandung
E-mail: wenata_aryakusuma@yahoo.com

ABSTRACT

The horizontally and vertically nail-laminated beams were tested in this experimental study. Twelve specimens of horizontally nail-laminated beam with the same cross section and variation of four nail spacings were tested. Nine specimens of vertically nail-laminated beam with the same nail spacing and three variations of cross sections, namely rectangular, I and box also were investigated. The hardwood fast growing species, Albasia (Albizia Falcata) was used. All specimens were made from four Albasia wood planks with approximately has the same cross section area. The flexural strength, rigidity and ductility of beams were investigated. The vertically nail-laminated beam has greater strength and rigidity than horizontally nail-laminated beam, but less in ductility.

Keywords: nail-laminated, flexural strength, rigidity, ductility.

BACKGROUND

Since recently it is difficult to get a large cross section dimension of wood beam, laminated beam has become one of the alternatives as an engineered wood product to increase the cross section properties. It was common that people used glue adhesive, nail or bolt to laminate the lamina. In Indonesia glue was more expensive than nail. Nail was used because it was practical and cheaper than glue. It also caused no problems such as cracks when nailing in *Albasia (Albizia Falcata)* wood. The strength and the rigidity of beam also depend on the cross section form. The solid I or box cross section will normally be greater than rectangular section with the same cross section area.

MATERIAL AND METHODS

The hardwood fast growing species namely *Albasia* was used. All specimens was made from 4 *Albasia* wood planks with approximately has the same cross section area as illustrated in Figures 1 and 2. The original cross section dimension of one wood plank was 180 x 20 mm^2. All of lamina has a 20 mm of thickness.

The wood material properties were found by the ASTM D143-94 small clear specimen test. The specific gravity of *Albasia* was in the range of 0.25 to 0.35 and the modulus of elasticity in between 5,000 to 7,200 MPa. The moisture content during the test was in between 12% - 15%. The nail diameter was 2 mm and 38 mm in length. From the nail shear test, the ultimate shear strength of nail was in between 1.0 to 2.0 kN.

Both horizontally and vertically nail-laminated beams were tested in this experimental study, see Figures 1 and 2 for the arrangement of beam cross sections. The horizontally nail-laminated beam with variation of four nail spacings of 25, 50, 75 and 100 mm in 2 rows for A, B, C and D specimens were tested. The weight of the nails used for 2.4 m beam length was 2.0, 1.5, 1.0 and 0.5 kg in A, B, C and D specimens respectively. The effects of nail spacings on the flexural strength and rigidity of the beams were investigated, Tjondro (2010).

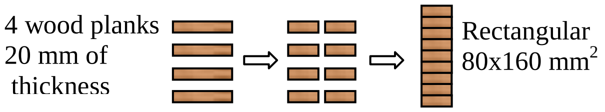

Figure 1. The arrangement of 4 wood planks on horizontally nail-laminated beam cross section.

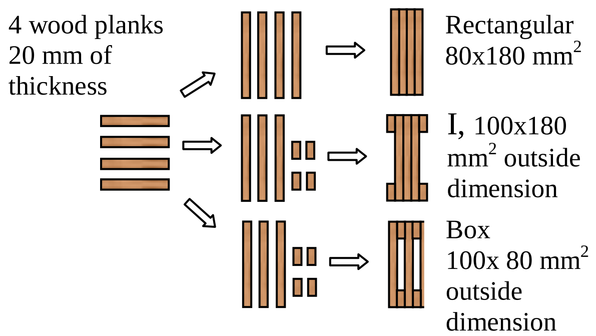

Figure 2. The arrangement of 4 wood planks on edge-wise nail-laminated beam cross sections

On the other hand, the vertically nail-laminated beam with 3 variations of cross section types, namely rectangular (R), I and box (B) all has the same nail spacing of 40 mm (2 rows in the flanges and 8 rows in the web with staggered arrangement, see Figures 3 and 4). Nine specimens of vertically nail-laminated beams were investigated to see the effect of different cross section types.

Figure 3. Nail spacing arrangement on vertically nail-laminated rectangular beam

Figure 4. Nail spacing arrangement on vertically nail-laminated I beam

The box cross section used fewer nails than rectangular and I sections, which is 1.3 kg compare to 2.0 kg for 2.4 m of beam length. The flexural strength and deformation of the beams at service-ability limit, proportional limit and ultimate load from the experimental test was investigated. The allowable deflection for serviceability requirement was 8 mm which is 1/300 of the span length. The beam specimen was tested under third point loading configuration as illustrated in Figure 5.

Figure 5. Third point bending test of a horizontally nail-laminated beam

The clear span length of the beam was L = 2400 mm and the two point loads position was one third from the support as illustrated in Figure 6.

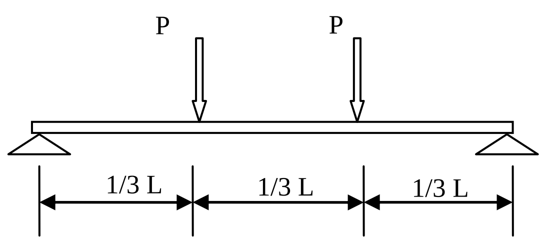

Figure 6. The schematic of beam on the third point loading test, ASTM D198-05a

The calculation of central point deflection due to the two points loading and neglecting shear deformation can be calculated as equation (1), Gere (2011).

$$\delta = \frac{23\, PL^3}{648\, E\, I_k} \tag{1}$$

where:
E = average modulus of elasticity (N/mm^2)
P = point load (N)
L = span length (mm)
I_k = corrected second moment of area (mm^4)
k = rigidity correction factor
$I_k = k.I_{solid}$

The corrected second moment of area I_k was found by equation (1), by measuring central point deflection by LVDT and total load of 2P. The average value of modulus of elasticity was taken from small clear specimen bending test.

RESULTS AND DISCUSSION

The result was presented in the load vs. displacement curves in Figures 7 to 10 for horizontally nail-laminated beam and Figures 14 to 16 for vertically nail-laminated beam. Table 1 and Table 2 present the load at service, proportional load, ultimate load, displacement related to each load, ratio of loads and ductility.

Horizontally nail-laminated beams:

The horizontally nail-laminated beam specimen variations are A, B, C and D, each of which has 3 specimens and the total of specimens was 12. The total load and displacement curve showed a similar result in each nail spacing variation. The failure mode was mainly due to flexure and slip occurred between the lamina because of the interaction between wood and nail in transferring shear between the lamina. The flexural failure happened near 200 mm displacement capacity of the testing machine.

The load P_a was load at allowable displacement δ_a = 8 mm, P_p was load at proportional load and P_u was load at ultimate load, the result was presented in Table 1.

The ratio of P_a/P_p was less than 0.76, which means that the beam was still in the elastic range at allowable displacement. The ratio of P_a/P_u was very small (0.16 – 0.29) showing that the flexural capacity is far below the elastic limit, see also Figure 11. The displacement ductility factor $\mu_u = \delta_u/\delta_p$ at ultimate was around 11.0.

The rigidity of the beam (EI_k) can be found by equation (1). The rigidity correction factor k as in Figure 12 can be calculated as $k = EI_k / EI_{solid}$. The correlation of k with nail spacing was found as in equation (2).

$$k = 0.000035\, s^2 - 0.00681\, s + 0.4577 \tag{2}$$
for 25 mm $\leq s$

The correlation between the proportional load (P_p) and nail spacing (s) was,

$$P_p = 0.000319\, s^2 - 0.06307\, s + 4.964 \tag{3}$$
for 25 mm $\leq s \leq$ 100 mm

The 25 mm nail spacing increased the proportional load twice than 100 mm spacing as was shown in Figure 13.

Vertically nail-laminated beam:

The vertically nail-laminated beam specimen variations of cross sections are R, B and I, each of which has 3 specimens and the total of specimen was 9. The total load and displacement curve at elastic range showed a quite similar result in all beams with different cross section. The failure mode of rectangular and box beam was mainly due to flexure. All of the I beam specimen failed because of shear fracture in the third row of nail. No significant slip occurred between the lamina

The ratio of P_a/P_p was around 0.60 that means at allowable displacement the beam still in the elastic range. The ratio of P_a/P_u was 0.26 – 0.37 showed that the flexural capacity is closer from the elastic limit rather than in the horizontally nail-laminated beam, see also Figure 17. The displacement ductility factor $\mu_u = \delta_u/\delta_p$ at ultimate load was in between 2.00 – 2.60. This value was lower than the ductility of horizontally nail-laminated beam.

Theoretically when the modulus of elasticity and strength of the wood planks was uniform, the rigidity correction factor for the rectangular section should be 1.0. The rigidity of the beam (EI_k) can be found as before by equation (1).

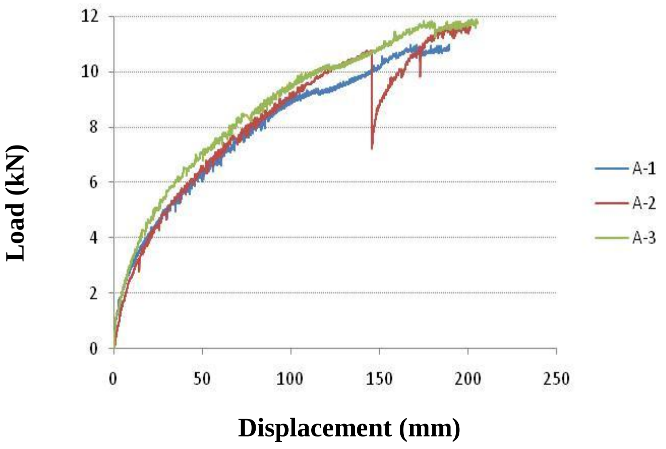

Figure 7. The load vs displacement curve of A specimens (25 mm nail spacing)

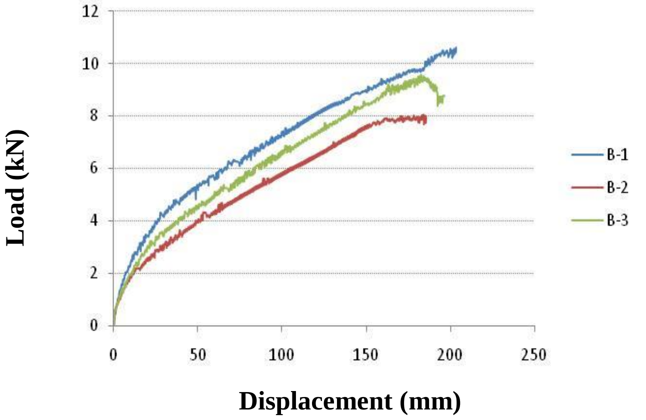

Figure 8. The load vs displacement curve of B specimens (50 mm nail spacing)

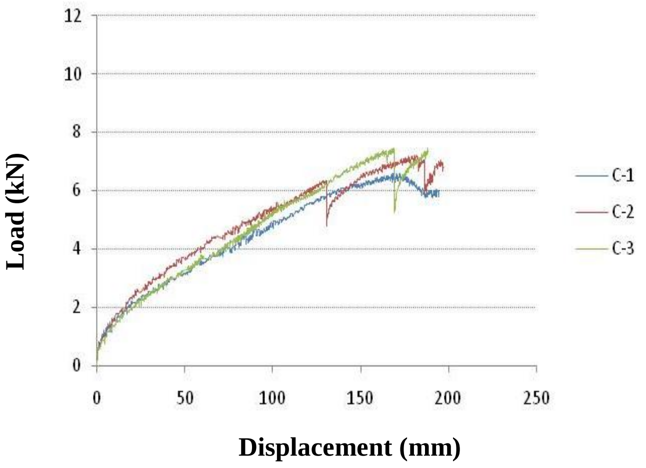

Figure 9. The load vs displacement curve of C specimens (75 mm nail spacing)

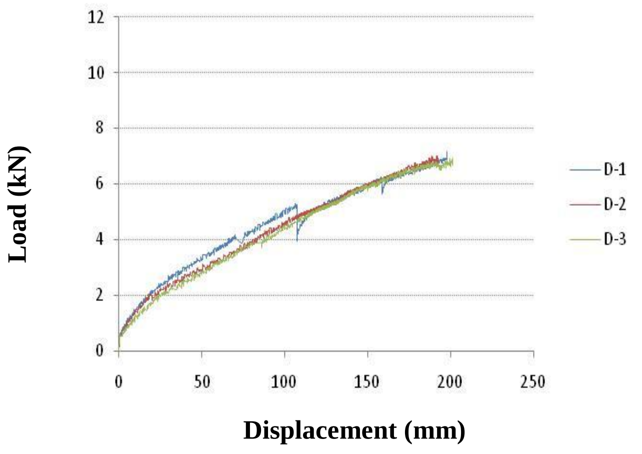

Figure 10. The load vs displacement curve of D specimens (100 mm nail spacing)

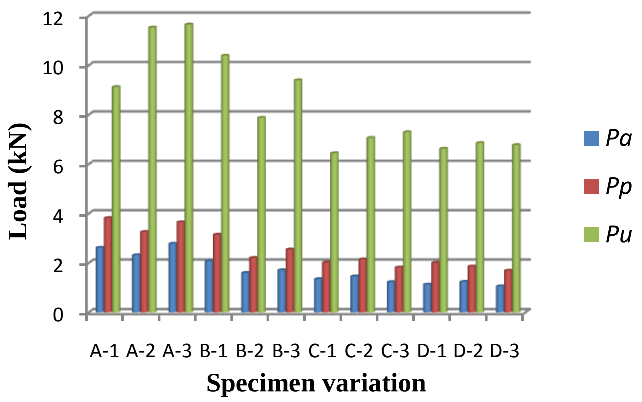

Figure 11. The comparison of loads P (kN) on the horizontally nail-laminated beam

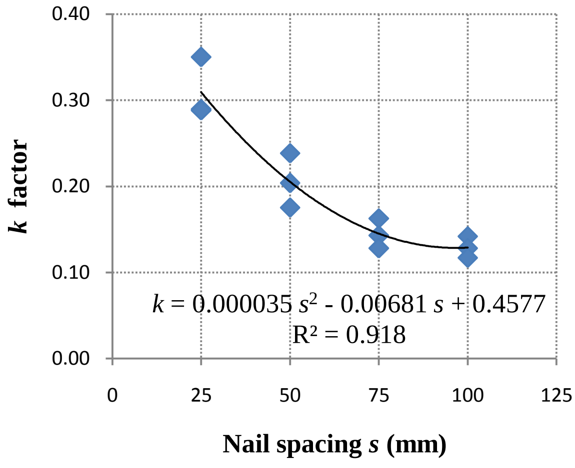

Figure 12. Rigidity correction factor (k) vs nail spacing (s)

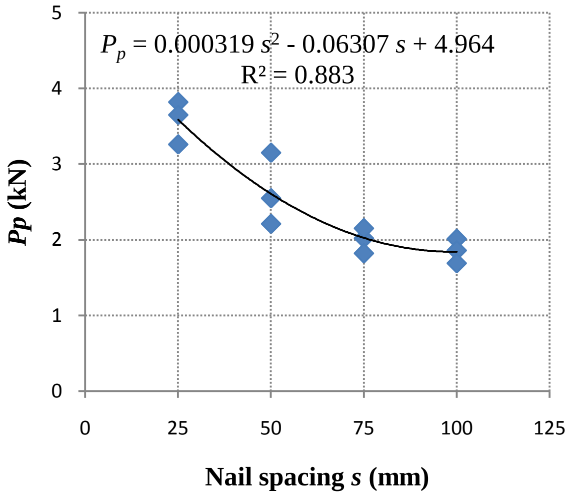

Figure 13. The proportional load (P_p) vs nail spacing (s)

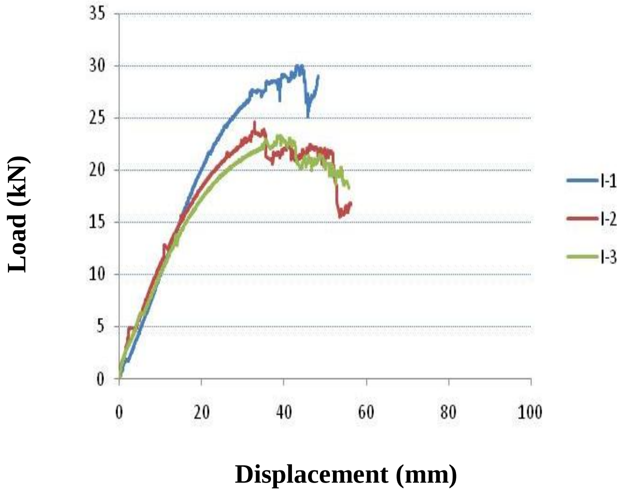

Figure 16. The load vs displacement curve of I specimens

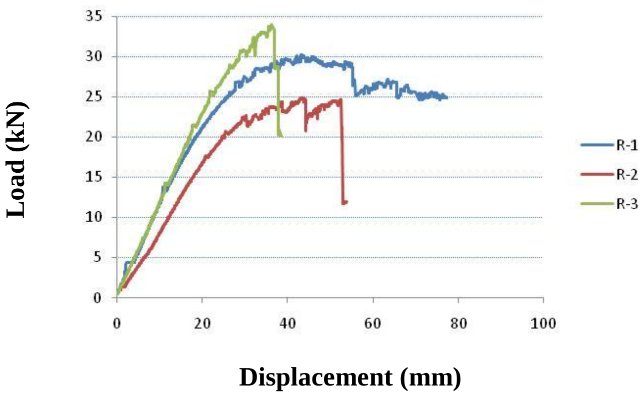

Figure 14. The load vs displacement curve of rectangular (R) specimens

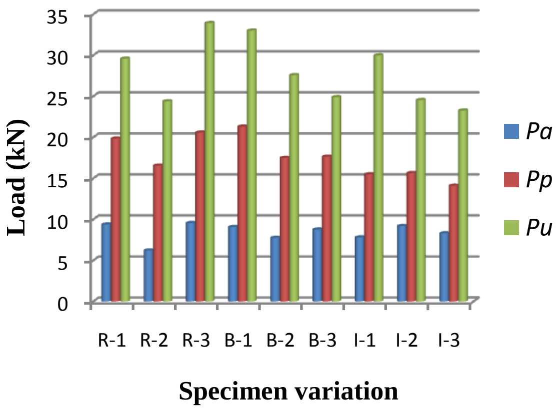

Figure 17. The comparison of loads P (kN) on the vertically nail-laminated beam

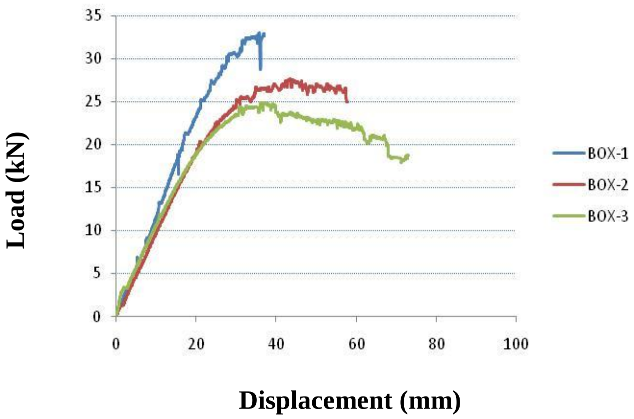

Figure 15. The load vs displacement curve of box (B) specimens

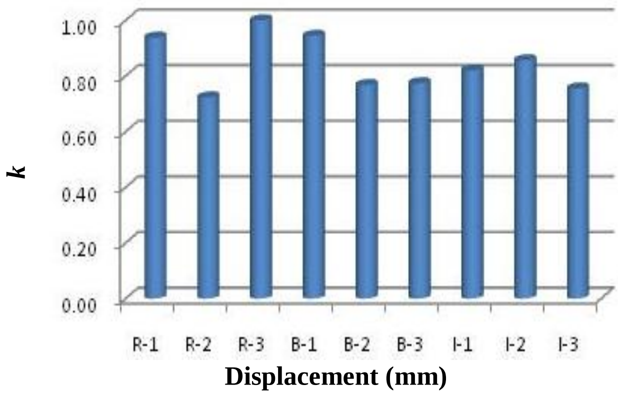

Figure 18. Rigidity correction factor (k) for each specimen

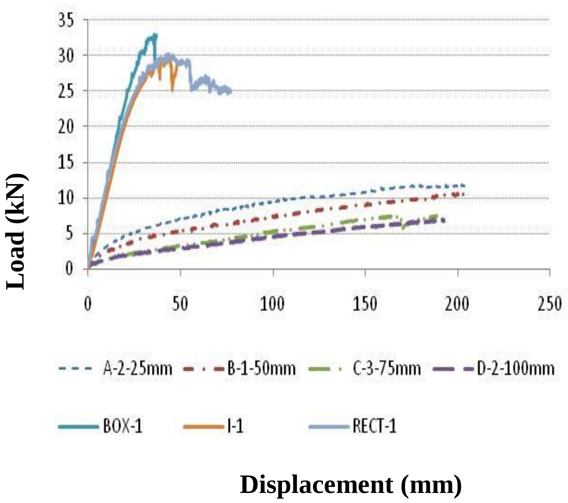

Figure 19. The load vs displacement curve of horizontally and vertically nail-laminated beams

The rigidity correction factor k can be calculated as $k = EI_k / EI_{solid}$. EI_{solid} was the rigidity as solid cross section of each type. But because of the non-uniformity of modulus of elasticity, the k factor became less than 1.0. At the box and I sections the k factor was around 0.7 to 0.8, see Figure 18. The closer spacing in the flange should increase the rigidity of the beam.

It was obvious in Figure 19 that the ultimate flexural strength of the vertically nail-laminated beam (specimen A, B, C and D) around 30 kN – 35 kN was higher than the horizontally nail-laminated beam (specimen R, Box and I) around 7 kN – 11 kN. But the ductility was higher for horizontally nail-laminated beam.

Table 1. Load, displacement, load ratio and ductility factor of A, B, C and D specimens

No	P_a(kN)	δ_a(mm)	P_p(kN)	δ_p(mm)	P_u(kN)	δ_u(mm)	P_a/P_p	P_a/P_u	μ_u	$\mu_{u\text{-}avr}$
A-1	2.62	8.00	3.82	16.64	9.13	109.60	0.69	0.29	6.59	
A-2	2.32	8.00	3.26	14.28	11.54	201.32	0.71	0.20	14.10	12.09
A-3	2.78	8.00	3.65	13.16	11.66	205.28	0.76	0.24	15.60	
B-1	2.08	8.00	3.15	16.68	10.40	203.24	0.66	0.20	12.18	
B-2	1.60	8.00	2.21	15.92	7.88	185.24	0.72	0.20	11.64	12.09
B-3	1.71	8.00	2.55	15.80	9.40	196.52	0.67	0.18	12.44	
C-1	1.35	8.00	2.02	17.84	6.45	194.48	0.67	0.21	10.90	
C-2	1.46	8.00	2.15	16.68	7.07	196.92	0.68	0.21	11.81	11.06
C-3	1.23	8.00	1.82	17.96	7.30	188.32	0.68	0.17	10.49	
D-1	1.13	8.00	2.01	17.88	6.63	195.64	0.56	0.17	10.94	
D-2	1.24	8.00	1.86	18.32	6.86	192.44	0.67	0.18	10.50	10.83
D-3	1.06	8.00	1.69	18.24	6.78	201.44	0.63	0.16	11.04	

Table 2. Load, displacement, load ratio and ductility factor of R, B and I specimens

No	P_a(kN)	δ_a(mm)	P_p(kN)	δ_p(mm)	P_u(kN)	δ_u(mm)	P_a/P_p	P_a/P_u	μ_u	$\mu_{u\text{-}avr}$
R-1	9.39	8.00	19.86	18.30	29.60	38.47	0.47	0.32	2.10	
R-2	6.22	8.00	16.57	19.80	24.40	38.50	0.38	0.25	1.94	2.04
R-3	9.57	8.00	20.60	17.40	33.94	36.20	0.46	0.28	2.08	
B-1	9.08	8.00	21.33	18.00	33.02	35.67	0.43	0.27	1.98	
B-2	7.76	8.00	17.50	18.17	27.59	44.10	0.44	0.28	2.43	2.15
B-3	8.78	8.00	17.65	18.17	24.91	37.00	0.50	0.35	2.04	
I-1	7.82	8.00	15.51	15.07	30.00	44.13	0.50	0.26	2.93	
I-2	9.20	8.00	15.66	14.57	24.56	32.83	0.59	0.37	2.25	2.60
I-3	8.32	8.00	14.12	14.90	23.28	39.00	0.59	0.36	2.62	

CONCLUSION

The vertically nail-laminated beam has greater strength and rigidity than horizontally nail-laminated beam, but less in ductility. The vertically nail-laminated beam rigidity factor can achieve more than 0.7. But horizontally nail-laminated beam really depends on the nail spacing and is lower than vertically laminated beam. The average ratio of load at proportional limit to the load at allowable displacement gives the safety factor of more than 1.6 which is commonly sufficient for allowable stress design. Shear failure in the web of I vertically nail-laminated beam needs more investigation.

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