IN-PLANE BENDING MOMENT RESISTANCE OF T-SHAPED ONE-SIDED TWO-GUSSET-PLATE FURNITURE JOINTS IN ORIENTED STRANDBOARD

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Abstract. This study investigated the in-plane bending moment resistance of a T-shaped joint connected with two gusset plates stapled on one side of joint members in three oriented strandboard (OSB) materials. Experimental results indicated that in-plane moment resistance loads of T-shaped, one-sided, two-gusset-plate joints at ultimate point on average were about 1.9 times their corresponding moment loads at proportional limit. The proposed mechanical model was verified experimentally as a valid means for deriving estimation equations of in-plane bending moment resistance loads of T-shaped, one-sided, two-gusset-plate joints in OSB materials used in this study. Experimental results and derived equations of in-plane bending moment resistance loads indicated that a T-shaped, one-sided, two-gusset-plate joint in OSB materials will always have a higher in-plane bending moment resistance load than an L-shaped one if the rail width in a L-shaped joint is the same as the stump width in a T-shaped joint. The difference in magnitude was affected by the critical joint member width and distance from the point on the stump at which the external in-plane moment load was applied to the rail top edge.

Keywords: In-plane bending moment resistance, staple-connected joints, gusset-plate joints, T-shaped joints, joint mechanical model, oriented strandboard.

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INTRODUCTION

Gusset-plate joints are commonly seen in highly stressed connections, such as stump to front rail (Fig 1) and bottom-side rail to back-post connections in upholstery furniture frames. A gusset-plate joint in upholstered furniture frame construction can be defined as a place in the frame structure at which two members meet edge to edge and are connected with plates fastened to the member sides with mechanical fasteners together with optional adhesive. Gusset plates can be metal, wood, or wood-based composites such as plywood. There are two types of gusset-plate joint configurations based on the two-joint member layout, T- and L-shaped, commonly seen in upholstered furniture frame construction. T-shaped joints (Fig 2a) can be described as a connection in which a vertical stump end attaches to the side edge of a horizontal front rail. If the end of a horizontal rail attaches to the side edge of a vertical stump, the alternative L-shaped joint configuration is formed (Fig 2b).

The staple is one of the most common mechanical fasteners used to attach gusset plates to joint members in upholstered furniture frame construction. There are two physical appearance variations of gusset plates commonly seen in upholstery furniture frame construction: one wider gusset plate attached to the same side of two connected members alone and two narrower gusset plates attached to the same side of two connected members. A gusset plate can be attached to two jointed members using staples alone or staples with adhesive applied on the surfaces of members and gusset plates.

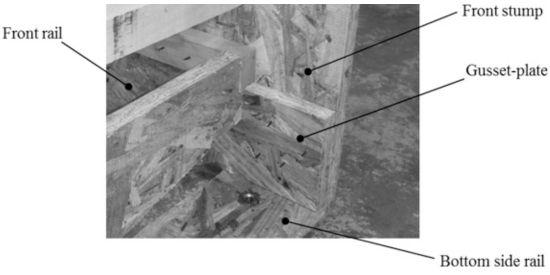

Figure 1. A typical L-shaped, one-sided, single-gusset-plate joint commonly seen in connection of front stump to front rail in a sofa frame construction.

Staples as mechanical fasteners in a gusset-plate joint resist lateral shear forces rather than direct withdrawal forces when the joint is subjected to an in-plane bending moment. Therefore, the bending moment resistance capacity of a staple-connected gusset-plate joint in wood-based composites such as oriented strandboard (OSB) materials might be governed by the resistance capacity of the face-to face lateral shear withdrawal load of the OSB staples. In addition, the layout of joint members can alter the forces subjected by gusset plates in terms of tensile and shear forces.

Demirel and Zhang (2014a) proposed a mechanical analysis model for deriving moment resistance loads of L-shaped, two-narrower-gusset-plate-connected joints in OSB. In the model, it was assumed that the top gusset plate is subjected to tensile force only when the stump is subjected to a horizontal external moment load. The mechanical model was verified experimentally as a valid means for deriving estimation equations of moment resistance loads of L-shaped, two-gusset-plate joints in OSB. There is no mechanical model developed for deriving moment resistance loads of T-shaped, two-narrower-gusset-plate-connected joints. The hypothesis of this study was that the in-plane moment resistance load of T-shaped, two-narrower-gusset-plate joints will be different from L-shaped joints because the gusset plate in T-shaped joints is subjected to tensile and shear forces, whereas the gusset plate in L-shaped joints is subjected to tensile forces only.

Limited studies have been found concerning the development of mechanical models for predicting in-plane bending moment resistances of stapled gusset-plate joints in OSB materials, especially for joints connected with two narrow gusset plates located on one side of joint members. Eckelman (1971), Zhang et al (2001), Erdil et al (2003), and Wang et al (2007) investigated in-plane bending moment resistance capacities of T-shaped, staple-glued gusset-plate joints in solid wood Douglas-fir and wood-based composites, such as plywood and OSB. In all these studies, two joint members were connected with two gusset plates symmetrically attached on both sides of joint members.

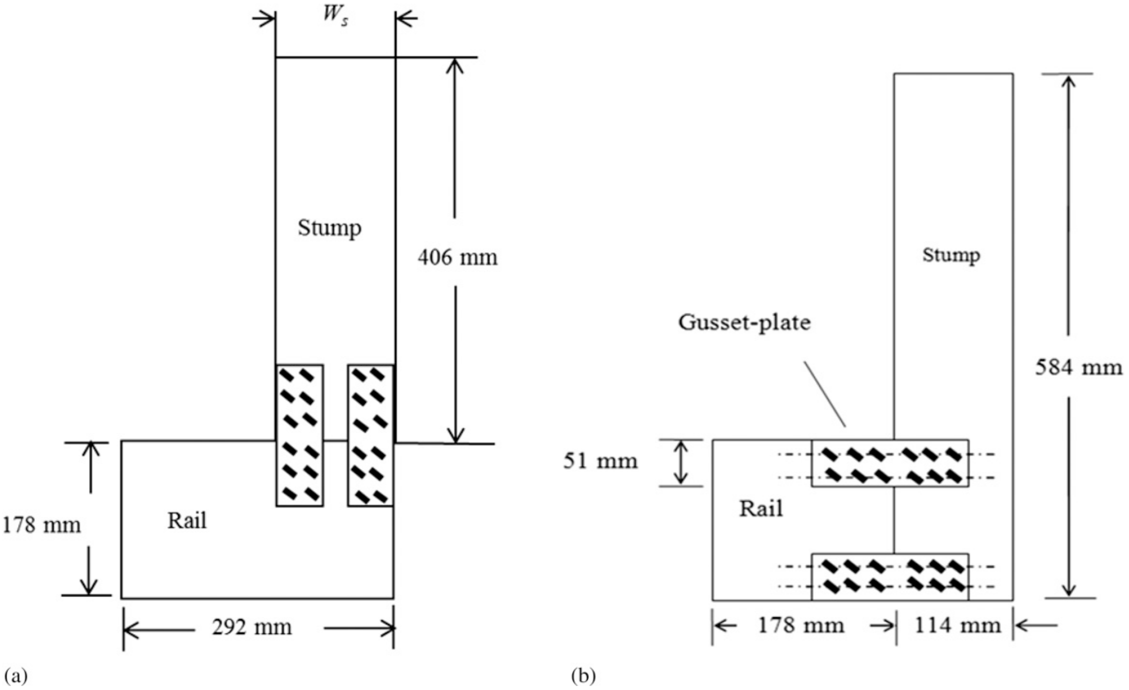

Figure 2. Configurations of (a) T-shaped and (b) L-shaped, one-sided, two-gusset-plate joints.

The main objective of this study was to investigate the in-plane bending moment resistance of T-shaped, one-sided, two-gusset-plate joints constructed with the same three OSB materials used in the previous study of L-shaped, one-sided, two-gusset-plate joints (Demirel and Zhang 2014a). The specific objectives were to 1) investigate the relationship between moment resistance loads at proportional limit and ultimate point of the T-shaped joint, 2) develop a mechanical model for analyzing the moment resistance load of the T-shaped joint, 3) derive equations for estimating the bending moment resistance of the T-shaped joint, 4) validate the proposed mechanical model and derived equations, and 5) compare in-plane bending moment resistance loads between the T- and L-shaped joints in OSB.

MATERIALS AND METHODS

Experimental Design

The general configuration of a T-shaped, one-sided, two-gusset-plate joint in this study is shown in Fig 2a. The joint consisted of a stump with its end attached to a rail side by a pair of plywood gusset plates stapled on the same side of the joint. The stump and rail were constructed of the same type of OSB. The stump measured 406 mm long × 18 mm thick with varying width. The rail measured 292 mm long × 178 mm wide × 18 mm thick. The gusset plate measured 152 mm long × 51 mm wide × 19 mm thick with its length parallel to the face-ply grain direction.

A complete 2 × 3 × 3 factorial experiment with 10 replications per cell was conducted to evaluate in-plane bending moment resistance capacity of T-shaped, two-gusset-plate joints in OSB materials. Factors were the number of staples (8 and 12), stump width (114, 152, and 178 mm), and material type (OSB-I, OSB-II, and OSB-III).

Table 1 summarizes mean values of physical properties of three different densities of 18-mm-thick commercial southern pine OSB materials (OSB-I, OSB-II, and OSB-III) used in this study. These properties were obtained from a previous study by Demirel and Zhang (2014a, 2014b) on L-shaped

Table 1. Mean values of physical properties of three tested oriented strandboard (OSB) materials.[a]

	Density (kg/m^3)			
Material type	Overall	Core	Surface	MC (%)
OSB-I	463 (8)	389 (11)	654 (16)	5.0 (6)
OSB-II	466 (6)	461 (4)	487 (7)	5.8 (6)
OSB-III	564 (11)	469 (4)	849 (9)	4.7 (3)
Plywood	657 (8)	N/A	N/A	5.6 (5)

[a] Values in parentheses are coefficients of variation in percentage. N/A, not applicable.

joints constructed with the same OSB materials used in this study. Face strands of these three OSB materials all were oriented in the direction parallel to the full-size panel (1.2 × 2.4 m) 2.4-m direction (machine direction). One type of furniture grade, 19-mm-thick five-ply southern pine plywood was used for gusset plates. The full-size sheet of plywood (1.2 × 2.4 m) was constructed with one center ply aligned parallel to the face plies and two even-numbered plies aligned perpendicular to the center ply. The face plies were aligned parallel to the sheet's 2.4-m direction.

The staples were SENCO (Cincinnati, OH) 16-gauge galvanized chisel-end-point types with crown widths of 11 mm and leg lengths of 38 mm. Leg widths of the staples were 1.6 mm, and thickness was 1.4 mm. The staples were coated with Sencote (Senco, Cincinnati, OH) coating, a nitrocellulose-based plastic.

Model Development

Figure 3a illustrates the proposed mechanical model for analysis of internal forces for a T-shaped, one-sided, two-gusset-plate joint subjected to an external in-plane moment load on the stump and deformed in the elastic range. It is assumed that when the joint is subjected to an external in-plane moment load, *P*, the internal tensile force, F_T, is carried by the left gusset plate along the centerline of the gusset plate. This tensile force is the resultant force of two tensile forces that act along the two rows of staples arranged vertically on the left gusset plate. It is also assumed that the neutral axis of the stump in bending is located at its centerline. The area to the right of the neutral axis is in compression with a triangularly distributed stress because of the elastic deformation assumed, ie the resultant of the triangular distributed compression force, F_C, acts at one-third of

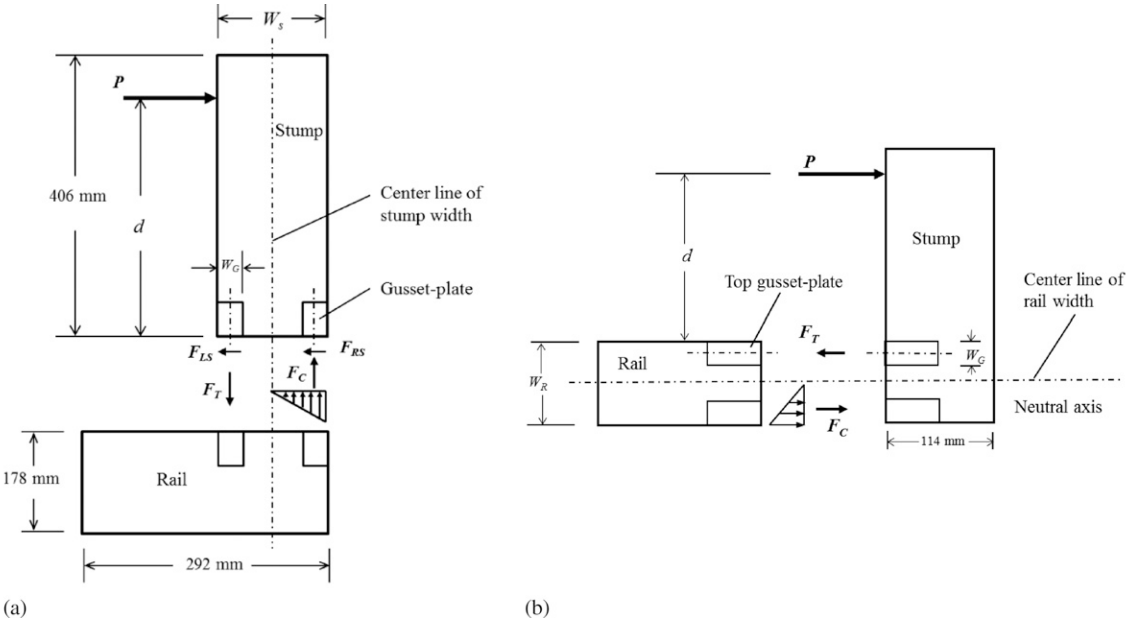

Figure 3. Mechanical analysis models for deriving in-plane moment resistance loads of (a) T-shaped and (b) L-shaped, one-sided, two-gusset-plate joints in oriented strandboard materials.

the half stump width from the stump right side. Summing all the forces and moments on the free-body diagram of the stump in Fig 3a yields the following equations:

$$\Sigma F = 0, F_C - F_T = 0 \tag{1}$$

$$\Sigma M = 0,\ F_T \times (W_S/2 - W_G/2) + F_C \times (2/3)(W_S/2) - P \times d = 0 \tag{2}$$

where d is distance from the point on the stump at which the external in-plane moment load is applied to the rail top edge (mm), W_S is stump width (mm), and W_G is gusset-plate width (mm).

Combining these two equations yields Eq 3, which is a calculation of the moment resistance load of the T-shaped, one-sided two-gusset-plate joints with the joint deformed in the elastic range:

$$P_{\text{T-shaped}} = F_T \frac{(5W_S - 3W_G)}{6d} \tag{3}$$

If Eq 3 for a T-shaped, one-sided two-gusset-plate joint is compared with the equation for the prediction of the moment resistance load of an L-shaped, one-sided two-gusset-plate joint (Demirel and Zhang 2014a), $P_{\text{L-shaped}} = F_T\,(5W_R - 3W_G)/(6d + 5W_R)$, with the condition of setting the stump width in the T-shaped joint to be equal to the rail width, W_R, in the L-shaped joint, the ratio of two moment resistance loads would be

$$\frac{P_{\text{T-shaped}}}{P_{\text{L-shaped}}} = 1 + \frac{5W}{6d} \tag{4}$$

where W is rail width in L-shaped joints or stump width in T-shaped joints (mm) and d is the distance from the point on the stump at which the external in-plane moment load was applied to the rail top edge.

This ratio indicates that a T-shaped joint will always have a higher in-plane moment resistance load than an L-shaped one when rail width in an L-shaped joint is the same as stump width in a T-shaped joint. This lower in-plane moment resistance load of an L-shaped joint is mainly because an L-shaped joint has a larger moment arm of $(d + W_R/2)$ for the external load (Demirel and Zhang 2014a) than a T-shaped one, which is d. In addition, this is because the top gusset plate in an L-shaped joint, which is in tension, is subjected to not only the tensile load caused by its resistance to the moment produced by the external load but also the tensile load from the external load itself (Fig 3b). But this tensile load, which occurs in an L-shaped joint, is not observed for the left gusset plate in a T-shaped joint, which is subjected to the tensile load (Fig 3a). Furthermore, this is because the T- and L-shaped joints have the same inherent moment resistance capacity when the stump width of a T-shaped joint equals the rail width of an L-shaped joint.

Specimen Preparation and Tests

Prior to joint construction, all cut OSB and plywood blanks were conditioned in an 8% EMC chamber. Staples were driven into the specimens with a pneumatic power stapler set to 483 kPa. All tests were performed immediately after stapling. Moisture contents of the three OSB materials were measured in accordance with ASTM (2010).

Figure 4 shows the setup for evaluating the in-plane bending moment loads of T-shaped, one-sided, two-gusset-plate joints. All T-shaped joints were tested on a hydraulic SATEC (Norwood, MA) universal testing machine at a loading rate of 2.5 mm/min. In-plane loads were applied to the

Figure 4. Test setup for the evaluation of in-plane bending moment resistance load capacity of T-shaped, one-sided, two-gusset-plate joints in oriented strandboard materials.

stump 305 mm in front of the rail. The test continued until the joints were disabled. The loads at proportional limit and ultimate points and joint failure modes were recorded.

RESULTS AND DISCUSSION

Table 2 summarizes mean ultimate moment resistance loads and moment resistance loads at the proportional limits of T-shaped, one-sided, two-gusset-plate joints in three OSB materials. Each value represents a mean of 10 joint specimens tested. Ratios of ultimate moment resistance loads to their corresponding moment resistance load values at proportional limit were calculated and summarized in the last column of Table 2. The average value of these ratios is 1.9, which indicates that the in-plane moment resistance load at the ultimate point is 1.9 times its corresponding moment resistance at proportional limit. This indicates that the in-plane ultimate moment resistance load, P_{ult}, of T-shaped, one-sided, two-gusset-plate joints in OSB can be estimated using the following equation with its corresponding moment resistance load at proportional limit, P_{PL}:

$$P_{\mathrm{ult}} = 1.9P_{PL} \tag{5}$$

Table 2. Bending moment resistance loads of T-shaped, one-sided, two-gusset-plate joints subjected to an in-plane load applied on the stump end 305 mm in front of the rail.[a]

Material type	Number of staples	Stump width (mm)	Ultimate load (N)	Load at proportional limit (N)	Load ratio
OSB-I[b]	8	114	979 (20)	552 (11)	1.8
	8	152	1397 (21)	752 (9)	1.9
	8	178	1717 (10)	968 (10)	1.8
OSB-II	8	114	979 (16)	525 (11)	1.9
	8	152	1486 (11)	747 (14)	2.0
	8	178	2051 (10)	1036 (10)	2.0
OSB-III	8	114	1351 (15)	707 (12)	1.9
	8	152	2046 (14)	996 (13)	2.1
	8	178	2375 (12)	1188 (16)	2.0
OSB-I	12	114	1339 (23)	747 (15)	1.8
	12	152	1979 (19)	1081 (11)	1.8
	12	178	2500 (16)	1401 (11)	1.8
OSB-II	12	114	1321 (12)	743 (9)	1.8
	12	152	2166 (15)	1192 (9)	1.8
	12	178	2856 (13)	1301 (13)	2.2
OSB-III	12	114	1659 (17)	845 (11)	2.0
	12	152	2709 (13)	1370 (18)	2.0
	12	178	3140 (10)	1557 (16)	2.0
				Average	1.9

[a] Values in parentheses are coefficients of variation in percentage.

[b] OSB, oriented strandboard.

In general, joint specimens failed at the left gusset plate in tension. The failure mode was staple leg withdrawal from either the rail or the stump or both members. Some fine wood particles or short fibers attached to staple legs were found. In addition, staple legs bent and crushed materials underneath were observed.

Estimated in-plane moment resistance loads at proportional limit, P_{PL}, were calculated with Eq 3 and shown in Table 3 in the "Estimated" column. The F_{T} value in Eq 3 was estimated using mean lateral resistance loads at the proportional limit of face-to-face two-row multistaple joints from the L-shaped joint study (Demirel and Zhang 2014a). This was because the same OSB materials and staples in the L-shaped joint study were used in this study. The ratios of estimated moment resistance load values to observed load values were calculated and shown in Table 3. The ratios ranged from 0.72 to 1.09, which indicates that, in general, the derived Eq 3 based on the proposed mechanical model can reasonably estimate in-plane bending moment resistance loads at the proportional limit of T-shaped, one-sided, two-gusset-plate joints in OSB. Still, some lower estimated values occurred, especially for those OSB-III joints connected with eight staples. This might have been because of the lower experimental data of lateral resistance loads at the proportional limit of face-to-face two-row multistaple joints (Table 3), which should be much higher than the other two OSB materials because OSB-III has a greater overall average density (FPL 2010) than the other two OSB materials (Table 1).

Eq 5 was proposed to predict the ultimate in-plane moment resistance load of T-shaped, one-sided, two-gusset-plate joints in OSB materials. The substitution of the verified Eq 3 for Eq 5 yields the following equation:

$$P_{\mathrm{ult}} = 1.9F_{\mathrm{T}}\frac{(5W_{\mathrm{S}} - 3W_{\mathrm{G}})}{6d} \tag{6}$$

Table 3. Comparisons of observed moment resistance loads at proportional limit of T-shaped, one-sided, two-gusset-plate joints in three oriented strandboard (OSB) materials with their corresponding values estimated using Eq 3.

Number of staples	Material type	W_S (mm)	W_G (mm)	d (mm)	F_T (N)	Estimated (N)	Observed (N)	Ratio
8	OSB-I	114	51	305	2233	509	552	0.92
		152	51	305	2233	741	752	0.99
		178	51	305	2233	899	968	0.93
	OSB-II	114	51	305	2233	509	525	0.97
		152	51	305	2233	741	747	0.99
		178	51	305	2233	899	1036	0.88
	OSB-III	114	51	305	2246	512	707	0.72
		152	51	305	2246	745	996	0.75
		178	51	305	2246	905	1188	0.80
12	OSB-I	114	51	305	3576	815	747	1.09
		152	51	305	3576	1186	1081	1.00
		178	51	305	3576	1440	1401	1.03
	OSB-II	114	51	305	3452	787	743	1.06
		152	51	305	3452	1145	1192	0.96
		178	51	305	3452	1390	1301	1.07
	OSB-III	114	51	305	3581	816	845	0.97
		152	51	305	3581	1188	1370	0.87
		178	51	305	3581	1442	1557	0.93

Table 4 shows the ultimate in-plane bending moment resistance loads of T-shaped, one-sided, two-gusset-plate joints estimated with Eq 6 and their corresponding observed values, as well as the ratios of estimated to observed values for all experimental combinations. The ratios ranged from 0.69 to 1.16, which indicates that overall, Eq 6 reasonably estimated ultimate in-plane bending moment resistance loads of L-shaped, one-sided, two-gusset-plate joints in OSB.

Table 4. Comparisons of observed ultimate in-plane moment resistance values of T-shaped, one-sided, two-gusset-plate joints in three oriented strandboard (OSB) materials with their corresponding values estimated using Eq 6.

			Estimated		Observed		
Number of staples	Material type	W_S (mm)	P_{ult} (N)	M_{ult} (N-m)	P_{ult} (N)	M_{ult} (N-m)	Ratio
8	OSB-I	114	967	295	979	299	0.99
		152	1408	429	1397	426	1.00
		178	1708	521	1717	524	0.99
	OSB-II	114	967	295	979	299	0.99
		152	1408	429	1486	453	0.95
		178	1708	521	2051	626	0.83
	OSB-III	114	973	297	1351	412	0.72
		152	1416	432	2046	624	0.69
		178	1720	525	2375	724	0.72
12	OSB-I	114	1549	472	1339	408	1.16
		152	2253	687	1979	604	1.14
		178	2736	834	2500	763	1.09
	OSB-II	114	1495	456	1321	403	1.13
		152	2176	664	2166	661	1.00
		178	2641	806	2856	871	0.92
	OSB-III	114	1550	473	1659	506	0.93
		152	2257	688	2709	826	0.83
		178	2740	836	3140	958	0.87

Moment Resistance Load Comparisons

To verify Eq 4, experimental data of in-plane bending moment resistance loads at proportional limits for T- and L-shaped joints were picked out from Table 2 of this study and Table 3 of the study done by Demirel and Zhang (2014a), respectively, and are summarized in Table 5. The grouping was mainly based on selection of the stump width of T-shaped joints with the same width of L-shaped joint rails. In other words, two critical joint member widths, 152 and 178 mm, were selected for all three OSB materials used in the studies. The average ratios of moment resistance loads at proportional limit for T- to L-shaped joints for each of two critical joint member dimensions are 1.47 and 1.56, respectively. These two ratios from experimental data together with their corresponding estimated values calculated using Eq 4 are summarized in Table 6 for comparisons. The comparison ratios between observed and predicted values for two different critical joint widths of 152 and 178 mm are 1.04 and 1.05, respectively. This indicates that Eq 4 can reasonably estimate the difference between in-plane bending moment resistance loads of T- and L-shaped, one-sided, two-gusset-plate joints in the OSB materials used in this study.

To further illustrate the relationship expressed in Eq 4 among variables, the ratio as a function of critical joint member size plotted against each of three distances from the loading point to the rail top edge (305, 356, and 406 mm) is shown in Fig 5. Figure 5 indicates that in general the ratio increased as critical member width increased, but the ratio decreased as distance from the loading point to the rail top edge increased. The estimated increase in moment resistance loads ranged from 21% to 55% when a T-shaped joint was used instead of an L-shaped joint under the condition of stump width in the T-shaped joints equaling rail width in the L-shaped joint.

Table 5. Mean differences among experimental data of in-plane bending moment resistance loads at proportional limit of T- and L-shaped, one-sided, two-gusset-plate joints in three oriented strandboard (OSB) materials.

Material type	Number of staples	Stump or rail width (mm)	L-shaped (N)	T-shaped (N)	Ratio (T/L)
OSB-I	8	152	494	752	1.52
OSB-II	8	152	516	747	1.44
OSB-III	8	152	592	996	1.68
OSB-I	12	152	965	1081	1.12
OSB-II	12	152	832	1192	1.43
OSB-III	12	152	856	1370	1.60
				Average	1.47
OSB-I	8	178	618	968	1.57
OSB-II	8	178	587	1036	1.76
OSB-III	8	178	707	1188	1.68
OSB-I	12	178	983	1401	1.42
OSB-II	12	178	974	1301	1.34
OSB-III	12	178	996	1557	1.56
				Average	1.56

Table 6. Comparisons of observed ratios of moment resistance loads at proportional limit for T-and L-shaped, one-sided, two-gusset-plate joints in oriented strandboard materials used in this study with their corresponding values estimated using Eq 4.

W (mm)	d (mm)	Observed (O)	Predicted (P)	Ratio (O/P)
152	305	1.47	1.42	1.04
178	305	1.56	1.49	1.05

Bending Moment

Based on the mechanical analysis model proposed (Fig 3a), the ultimate bending moment of a T-shaped, one-sided, two-gusset-plate joint in

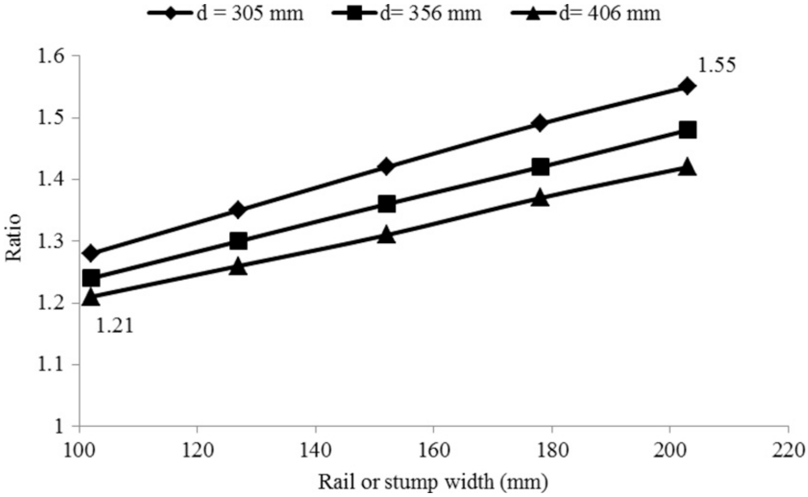

Figure 5. Ratios of T- and L-shaped joint loads as a function of critical joint member size, rail width for L-shaped joints, and stump width for T-shaped joints.

OSB evaluated in this study can be calculated using the following formulas with the moment arm considered to be d, ie the distance from the point on the stump at which the external in-plane moment load is applied to the top edge of the rail:

$$M_{\text{ult}} = P_{\text{ult}} \times d \tag{7}$$

Observed ultimate moment values of T-shaped, one-sided, two-gusset-plate joints in OSB materials used in this study were calculated using Eq 7, in which P_{ult} values were from experimental data. Corresponding estimated values of the observed values were calculated using Eq 7, but P_{ult} values were estimated using Eq 6. Both observed and estimated ultimate moment values of T-shaped, one-sided, two-gusset-plate joints in OSB materials were summarized in Table 4.

CONCLUSIONS

The in-plane bending moment resistance of T-shaped, one-sided, two-gusset-plate joints in OSB materials was investigated. Experimental results indicated that the ultimate in-plane bending moment resistance load of a T-shaped, one-sided, two-gusset-plate joint on average is about 1.9 times its corresponding moment load at proportional limit.

Experimental results and derived equations pertaining to in-plane bending moment resistance loads indicated that the T-shaped, one-sided, two-gusset-plate joint in OSB materials used in this study will always have a greater in-plane bending moment resistance load than an L-shaped one if the critical joint member width, ie rail width, in the L-shaped joint is the same as the critical joint member width, ie stump width, in the T-shaped joint. The magnitude of the difference is affected by the critical joint member width and distance from the point on the stump at which the external in-plane moment load is applied to the rail top edge.

The proposed mechanical model was verified experimentally as a valid means for deriving the estimation equation of the in-plane bending moment resistance loads of T-shaped, one-sided, two-gusset-plate joints in OSB materials used in this study. Development of mechanical models for deriving estimation equations of in-plane bending moment resistance loads of T-shaped, one-sided, two-gusset-plate joints in OSB materials, therefore, should eventually lead to the development of design procedures specifically suited to the needs of practicing furniture engineers.

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REFERENCES

American Society for Testing and Materials (ASTM) (2010) D 4442-92. Standard test methods for direct moisture content measurements of wood and wood-base materials. American Society for Testing and Materials, West Conshohocken, PA.

Demirel S, Zhang J (2014a) Bending moment resistances of L-shaped two-gusset-plate furniture joints in oriented strandboard. Wood Fiber Sci 46(3):356-367.

Demirel S, Zhang J (2014b) Face lateral resistance of oriented strandboard joints connected with two rows of 16-gauge coated staples. Wood Fiber Sci 46(2):280-290.

Eckelman CA (1971) Designing joints with gusset plates. Furniture Design Manufacturing 43(9):72-79.

Erdil YZ, Zhang J, Eckelman CA (2003) Staple holding strength of furniture frame joints constructed of plywood and oriented strandboard. Forest Prod J 53(1):70-75.

FPL (2010) Wood handbook: Wood as an engineering material. Gen Tech Rep FPL-GTR-190. USDA For Serv Forest Prod Lab, Madison, WI.

Wang X, Salenikovich A, Mohammad M, Echavarriar C, Zhang J (2007) Moment capacity of oriented strandboard gusset-plate joints for upholstered furniture. Part 1: Static load. Forest Prod J 57(7/8):39-45.

Zhang J, Lyon DE, Quin F, Tackett B (2001) Bending strength of gusset-plate joints constructed of wood composites. Forest Prod J 51(5):40-44.