Abstract

Power-driven staples are commonly used to join framing members in upholstered furniture construction because of their quick and easy installation. To successfully introduce oriented strandboard (OSB) into upholstered furniture as frame stock, moment capacity data for stapled gusset-plate joints constructed of OSB are needed. In this study, the static moment capacity of T-shaped, end-to-side joints with two gusset-plates was determined experimentally and analytically for gusset-plates of different lengths (4, 6, 8, 10, and 12 inches) attached with 1.0-inch- and 1.5-inch-long staples with and without adhesive. The moment capacity of the joint increased in proportion with the length of the gusset-plate until the strength of the gusset exceeded that of the main joint member. Analytical prediction of the moment capacity of an unglued stapled joint was found satisfactory. Application of glue to the connection surface changed the failure modes of the joints and increased their moment resistance capacity.

Today, 75 percent of homes built in North America utilize oriented strandboard (OSB) panels for floor, wall, and roof sheathing (SBA 2004). OSB producers continue to supply the market with large quantity of panels. However, OSB consumption by the housing industry has matured and offers limited growth; therefore, the OSB manufacturers should seek new markets, with the furniture industry being a prime candidate. In today’s competition with foreign manufacturers, furniture industry needs innovative products more than ever. In general, OSB panels cost less than plywood or solid wood; therefore, the use of OSB in upholstered furniture frames can reduce the cost of production and produce more profits. Modifying a product or designing a new one requires reliable information about the performance of materials and joints that are going to replace traditional ones in order to maintain the quality and to meet the consumer expectations. In order to encourage the furniture industry to consider OSB as a new material for their products, technical information on the performance of OSB as a framing member must be made available for the industry.

Because power-driven staples are quick and easy to install, they are the most commonly used fasteners to join framing members and to attach fabric to the frame in upholstered furniture. Generally, it is believed that staples have limited holding strength in withdrawal. When staples are used to attach two members by gusset-plates, the joint may develop considerable strength as the staples resist shear load rather than withdrawal (Zhang and Maupin 2004). Therefore, the gusset-plate joints could be used for critical joints, such as...
back bottom rail–back post and bottom side rail–back post joints in upholstered furniture frames as shown in Figure 1 since these joints are highly stressed and difficult to reinforce.

Limited information is available about the moment capacities of gusset-plate joints constructed of wood composites. Eckelman (1971) and Zhang et al. (2001) studied the performance of T-shaped, end-to-side joints with glued-on plywood gusset-plates of different configurations. Eckelman (1971), using Douglas-fir plywood as joint members, showed that the strength of the joints was limited by the properties of gusset-plate materials, specifically, by rolling shear strength and in-plane shear strength. Zhang et al. (2001) expanded Eckelman’s research by using southern yellow pine plywood, aspen Timberstrand® laminated strand lumber (LSL), and aspen engineered strand lumber (ESL) as joint members and gusset-plates made of southern yellow pine plywood attached with glue and staples. It was reported that the material of the joint member and the number of staples did not influence the joint strength, as all failures occurred in gusset-plates.

Performance of OSB as a frame member or a gusset-plate in a T-shaped joint has not been studied.

In North America, design values for stapled connections are based on empirical data, and not on mechanics-based models. In this paper, the European Yield Model (EYM) equations from Eurocode 5 (2004) and geometry considerations are used for analysis of the connection capacity. The equations used in the EYM are based upon a theory first developed by Johansen (1949). The equations predict the ultimate strength of a dowel-type joint due to either a bearing failure of the joint members or the simultaneous development of a bearing failure of the joint members and plastic hinge formation in the fastener. In deriving Johansen’s ultimate load equations it is

![Figure 1. — Schematic of a three-seat sofa frame (Critical joints—Side rail to back post joint & Back rail to back post joint).](image1.png)

![Figure 2. — Configuration of a typical staple-glued gusset-plate joint.](image2.png)

### Table 1. Description of the specimens, load capacities, and failure modes of gusset-plate joints constructed of OSB.

<table>
<thead>
<tr>
<th>Joint configuration</th>
<th>Gusset-plate length</th>
<th>Staple length</th>
<th>Staples Specimens</th>
<th>Predicted ultimate load (Kip)</th>
<th>Mean ultimate load (Kip)</th>
<th>COV (%)</th>
<th>Reference resistance resistance* (Kip)</th>
<th>Dif. b</th>
<th>Mode of failure c</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unglued a</td>
<td>4</td>
<td>1.5</td>
<td>20</td>
<td>10</td>
<td>0.694</td>
<td>0.67 A</td>
<td>4.8</td>
<td>0.646</td>
<td>−7</td>
</tr>
<tr>
<td>b</td>
<td>6</td>
<td>1.5</td>
<td>20</td>
<td>10</td>
<td>0.729</td>
<td>0.85 B</td>
<td>7.6</td>
<td>0.825</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>c 8</td>
<td>1.5</td>
<td>20</td>
<td>10</td>
<td>0.857</td>
<td>1.01 C</td>
<td>5.3</td>
<td>0.973</td>
<td>14</td>
</tr>
<tr>
<td>d</td>
<td>10</td>
<td>1.5</td>
<td>20</td>
<td>10</td>
<td>0.937</td>
<td>1.02 C</td>
<td>5.3</td>
<td>0.980</td>
<td>5</td>
</tr>
<tr>
<td>e</td>
<td>12</td>
<td>1.5</td>
<td>20</td>
<td>10</td>
<td>1.032</td>
<td>0.98 C</td>
<td>6.3</td>
<td>0.947</td>
<td>8</td>
</tr>
<tr>
<td>f</td>
<td>10</td>
<td>1.0</td>
<td>32</td>
<td>10</td>
<td>0.786</td>
<td>0.87 B</td>
<td>7.8</td>
<td>0.841</td>
<td>7</td>
</tr>
<tr>
<td>g</td>
<td>10</td>
<td>1.0</td>
<td>32</td>
<td>10</td>
<td>0.756</td>
<td>0.87 B</td>
<td>7.0</td>
<td>0.842</td>
<td>11</td>
</tr>
<tr>
<td>h</td>
<td>10</td>
<td>1.0</td>
<td>36</td>
<td>10</td>
<td>0.811</td>
<td>0.97 C</td>
<td>9.4</td>
<td>0.942</td>
<td>16</td>
</tr>
<tr>
<td>i</td>
<td>8</td>
<td>1.0</td>
<td>40</td>
<td>10</td>
<td>0.799</td>
<td>0.92 B,C</td>
<td>8.4</td>
<td>0.895</td>
<td>12</td>
</tr>
<tr>
<td>Glued a</td>
<td>4</td>
<td>1.0</td>
<td>8</td>
<td>10</td>
<td>0.68 A</td>
<td>7.0</td>
<td>0.661</td>
<td>S 100%</td>
<td></td>
</tr>
<tr>
<td>b</td>
<td>1.0</td>
<td>8</td>
<td>10</td>
<td>9.2</td>
<td>0.698</td>
<td>6.9</td>
<td>0.890</td>
<td>MR 10%, GR+S 30%, S 60%</td>
<td></td>
</tr>
<tr>
<td>c</td>
<td>1.0</td>
<td>8</td>
<td>10</td>
<td>1.15</td>
<td>8.7</td>
<td>1.116</td>
<td>100%</td>
<td>MR 30%, GR+S 60%, S 10%</td>
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</tr>
<tr>
<td>d</td>
<td>1.0</td>
<td>8</td>
<td>10</td>
<td>1.27</td>
<td>11.6</td>
<td>1.250</td>
<td>MR 40%, GR 60%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>e</td>
<td>1.0</td>
<td>8</td>
<td>10</td>
<td>1.24</td>
<td>11.8</td>
<td>1.216</td>
<td>GR 100%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Reference resistance computed using experimental data and ASTM D5457 procedure (\(K_R = 1\)).

bDif. = difference between predicted ultimate load and reference resistance.

cW = staple withdrawal; S = in-plane shear failure of OSB; SO = shear-out of OSB; MR = member rupture; GR = gusset-plate rupture.

dKip = 1000 lbf = 4.448 kN.

eValues with the same capital letter are not statistically different at 95 percent significance level.
assumed that both the fastener and the timber are ideal rigid-plastic materials. The precise mode of failure and the ultimate shear strength for a single fastener is determined by the thickness and the embedding strength of the main and the side members and by the fastener diameter and yield moment.

The primary objective of this research was to develop basic technical data on static moment capacities of stapled and glued-stapled, T-shaped, end–to–side gusset-plate joints constructed of OSB. The specific objectives were to 1) understand how gusset-plate length, number and size of staples affect the moment capacity of T-shaped joints, 2) compare moment capacities of gusset-plate joints with and without glue application, and 3) verify analytical equations of the EYM for prediction of load capacity of stapled gusset-plate joints. The data will be further used for fatigue testing of joints and for optimization of upholstered furniture frames designs.

### Materials and Methods

The T-shaped, end–to–side stapled gusset-plate joint specimens comprised two principal members, a post and a rail, joined by two gusset-plates symmetrically attached on both sides of the joint as shown in Figure 2. The joints were constructed of OSB produced by Norbord (Canada). The principal members were 23/32 in (18 mm) thick, 6 in (152 mm) wide, 16 in (406 mm) long, and the gussets were 7/16 in (11 mm) thick, 6 in (152 mm) wide, and five different lengths: 4, 6, 8, 10, and 12 in (102, 152, 203, 254, and 305 mm). The width of the principal members was taken based on recommendations by Chen (2003).

The number of staples per side and their length varied with the length of the gusset plate as is shown in Table 1. Figure 2 shows the staple placement pattern for glued joints, and Figure 3 shows the placement of staples in gusset-plates of unglued joints. The staples, commonly used in furniture production, were SENCO N17 16-gage galvanized chisel-end-point type with a crown width of 7/16 in (11 mm) and leg lengths of 1.0 and 1.5 in. (25 and 38 mm) with leg cross section of 0.062 × 0.055 in (1.57 × 1.40 mm). The staples were coated with Sprintec coating, a nitro-cellulose based plastic. The staples were power-driven flush into specimens with a pressure of 55 psi (380 kPa). Five series of tests were conducted with the glued-on gusset-plates. A PVA adhesive with solid content of 47 percent, typically used in furniture manufacturing, was supplied by Adhpro Adhesives Inc.

To prepare the components, 4 by 8-ft (1.22 by 2.44 m) panels were cut into 6-in (152-mm) strips along the 8-ft (2.44-m) direction, then cut to length, and randomized. Static tests on the glued joints were conducted at least 48 hours after the application of glue to allow for curing. Density, moisture content (MC), internal bond strength, and flat and edgewise bending properties of OSB were determined using the matching specimens. The mechanical properties were evaluated in accordance with ASTM D 1037 (ASTM 2005a).

In order to conform to durability performance test standards such as the General Service Administration (GSA) test regimen FNAE-80–214 A (GSA 1998), strength design of upholstered furniture frame requires information about the performance of each joint in a sofa frame. According to the GSA, the bending moment acting on the back rail to back post joint is considered very high. For a 72-in (1.83-m) long three-seat sofa of medium duty category, three concentrated vertical loads of 300 lbf are applied to the back rail with a total of 900 lbf (Table 2). If the back rail has two rigid joints with back posts, each joint carries a bending moment of 300 × 72/8 + 300 × 12 × (72–12)/72 = 5700 lbf-in in fatigue test (see Fig. 4). To estimate the static load capacity, the load is doubled, resulting in a static moment capacity of 11,400 lbf-in. To comply with the GSA requirements, the target static load on the joint with a 14-in (356-mm) long arm used in the tests is approximately 11,400/14 = 814 lbf.

All specimens were tested using a Tinius-Olsen universal testing machine. The post of the joint was bolted to the test fixture with 2/3-in (17-mm) aluminum spacers so that the gusset-plates could deform freely during the test. Vertical upward load was applied to the rail at a rate of 0.2 in/min (5.1 mm/ min), and the load at failure was recorded using a load cell with the accuracy of 0.2 percent.

### Predicted Ultimate Load

To predict the load capacity of the moment resisting connection, the analysis of a single dowel-type fastener (staple)
was combined with the analysis of its performance in the joint of a given geometry. To ensure the design performance of the joint, the location of the fasteners with respect to the end and the edge of the members should conform to the assumptions of the EYM (Eurocode 5 2004). However, the design is not always controlled by the load-carrying capacity of the single fastener. It depends on the configuration of the connection that may induce supplementary moment couple and shear stresses in the joint due to eccentricity.

**Analysis of a single staple.** — To estimate the load capacity of a single staple, $R$, the following properties were assumed: embedding strength of OSB = 9120 psi (63 MPa), tensile strength of the staple = 87,020 psi (600 MPa), and the cross section of the staple leg 0.062 in by 0.055 in (1.57 mm by 1.40 mm). Calculations for staples using EYM equations (see Appendix) showed that in the joint of a given configuration, staples yield in bending at two plastic-hinge points per shear plane, with limited localized crushing of OSB near the shear planes in the side members. The characteristic resistance values were estimated at 190 lbf (860 N) and 150 lbf (670 N) for the 1.5-in and 1.0-in staples, respectively.

**Performance of the staple in the moment resisting connection.** — To derive the design equations, the mechanical behavior of the moment resisting connection is examined. To counteract the applied moment, each fastener is loaded at a different angle depending on the layout of the joint. The assumption is made that the eccentric load $P$ can be replaced by an equivalent force and an eccentric moment of magnitude $M = P \times e$ acting at the geometrical center of the group and the maximum resultant shear force in the most-stressed fastener is determined from the fastener located furthest from the centroid using the following procedure.

For any fastener with coordinates $(x_i, y_i)$ at a radial distance $r_i$ from the centroid of a group of $n$ fasteners under the load $P$, the resultant force $R_i$ can be presented by its components $R_{xi}$ and $R_{yi}$, as shown in Figure 6. For the most-stressed fastener at the point with coordinates $(x_a, y_a)$, the resultant force is calculated from:

$$R_a^2 = R_{xa}^2 + R_{ya}^2 \quad [1]$$

where:

$$R_{xa} = \frac{M(y_a)}{\Sigma r_i^2} \quad [2]$$

$$R_{ya} = \frac{P}{n} + \frac{M(x_a)}{\Sigma r_i^2} \quad [3]$$

$$\Sigma r_i^2 = \Sigma x_i^2 + \Sigma y_i^2 \quad [4]$$

The connection design is adequate if $R_a$ is less than the ultimate shear strength $R$ of a single fastener. Equations [1] to [4] can be used to estimate the load-carrying capacity $P$ of the moment resisting joint when $R$ is known.

**Results and discussion**

**Mechanical and physical properties of OSB**

Table 3 shows the mechanical and physical properties of OSB panels used in the tests. For each property shown in the table, between 22 and 44 specimens were tested.
Failure modes

In tested samples, five types of failure modes were observed: staple withdrawal, OSB shear-out, in-plane shear failure of OSB, gusset-plate rupture and rail member rupture as shown in Figure 7 and Table 1. In the joints with intermediate gusset-plates (6, 8, and 10 in), a mixture of failure modes was observed. Note, however, that in unglued stapled joints, shear-out was the dominating failure mode in short (4-in) gusset-plates, whereas staple withdrawal was most often observed in the joints with long (12-in) gusset-plates. Differences in performance of the short and long gusset plates became more obvious in the glued joints. All 4-in gusset-plates failed in shear in plane of the panel (Fig. 7f), while all 12-in gusset-plates failed in rupture (Fig. 7c). These results indicate that the 4-in gusset-plate was not adequately sized for the optimum capacity and the 12-in gusset-plate was oversized. The discussion of load capacities presented below confirms this conclusion.

Table 3. — Average values (COV) of physical and mechanical properties of joint members and gusset-plates.

<table>
<thead>
<tr>
<th>Materials*</th>
<th>Density (kg/m³)</th>
<th>MC (%)</th>
<th>Internal bond (MPa)</th>
<th>MOE (GPa)</th>
<th>MOR (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joint member:</td>
<td>23/32 in (18 mm)</td>
<td>594 (6.8)</td>
<td>6.8 (7.7)</td>
<td>0.426 (18.2)</td>
<td>6.33 (8.2)</td>
</tr>
<tr>
<td>Gusset-plate:</td>
<td>7/16 in (11 mm)</td>
<td>590 (6.8)</td>
<td>6.2 (7.0)</td>
<td>0.417 (17.5)</td>
<td>6.66 (15.7)</td>
</tr>
</tbody>
</table>

*Oriented strandboard.

Based on the experimental data, the reference resistance values were calculated as the lower 5th percentile with a 75 percent confidence using the procedure described in ASTM D5457 (ASTM 2005b), assuming two-parameter Weibull distribution and a reliability normalization factor $K_R = 1$. Table 1 and Figure 8 show a comparison between the experimental reference resistance values and the predicted ultimate loads of stapled joints calculated using the EYM equations and the connection geometry. The experimental values for stapled
joints were 5 to 16 percent higher than the predicted loads with two exceptions. The loads carried by 4-in and 12-in gusset-plates were 7 to 8 percent less than predicted. This can be explained by the analysis of the failure modes observed during the tests. The 4-in gusset-plates were inadequately short, and the densely placed staples often caused shear-out failure in the post before the fasteners developed their full capacity (See Fig. 7a). On the other hand, the 12-in gusset-plates were excessively large for this joint; most staples did not reach their shear capacity and failed in withdrawal because of lateral instability of the rail. These results warrant caution when applying the principles of the EYM to the joint design where the sizes of the members and placement of fasteners may not be adequate to develop plastic hinges as assumed in the theory.

Despite of the satisfactory prediction of static strength of stapled gusset-plate joints, the use of so many staples to construct the joint is not desirable for furniture makers. The use of glue to attach gusset-plates is much more efficient and requires the minimum number of staples to fabricate a joint of the same size with the same or higher load capacity. Experimental results showed that the load capacity of glued joints increased in proportion with the size of the gusset-plates up to the length of 10 in (Fig. 8). Further increase in length of the gusset-plate did not lead to any significant improvement because the strength of the glue bond exceeded the strength of the gusset-plate material (see Fig. 7c). In comparison with unglued joints with 20 staples, the mean ultimate load capacities of joints with 6, 8, 10, and 12-in gusset-plates were increased by 8 percent, 14 percent, 25 percent, and 27 percent, respectively.

### Conclusion

Effects of gusset-plate length, number and length of staples, placement of staples, and glue application on the static load capacity of T-shape OSB gusset-plate joints were investigated. Application of glue was the most important factor affecting the performance of the joints, which allowed for strength increase up to 27 percent. An increase in length of gusset-plate from 4 to 8 inches boosted peak load for both glued and unglued joints, but further increase of gusset-plate length did not enhance the strength of the joints. Twice as many 1.0-in-long staples had to be used to achieve similar load levels with 1.5-in-long staples for unglued gusset-plate joints. Changing positions of staples in gusset-plates did not affect the strength of the joints of tested configurations. Failure modes depended on the size of the gusset-plates. Predicted and experimental reference resistance values for stapled joints were in satisfactory agreement; however, there is a limit to the application of the yield theory when the geometry of the joint prevents development of the full shear capacity. It is advisable to verify extreme cases by tests.

### Literature cited


### Appendix

Formulas for characteristic strength of staples

\[ F_{v,Rk} = \min \left\{ \begin{align*}
& \frac{f_{h,1} d_1}{1 + \beta} \left[ \sqrt{\beta + 2\beta^2} \left( 1 + \frac{1}{t_1} + \frac{t_2^2}{t_1^2} \right) \right] + \frac{F_{ax,Rk}}{4} \\
& 1.05 \frac{f_{h,1} d_1}{1 + 2\beta} \left[ \sqrt{2\beta(1 + \beta) + \frac{1}{f_{h,1} d_1^2}} - \beta \right] + \frac{F_{ax,Rk}}{4} \\
& 1.15 \sqrt{2M_{v,Rk} f_{h,1} d_1} + \frac{F_{ax,Rk}}{4}
\end{align*} \right\}
\]
where:

\[ F_{u,Rk} = \text{characteristic load-carrying capacity per shear plane per fastener, N;} \]

\[ t_i = \text{panel thickness or penetration depth, with } i = 1 \text{ or } 2, \text{ mm;} \]

\[ f_{h,i,k} = 65d^{-0.7}t_i^{0.1}, \text{ characteristic embedment strength in } \text{i}^{\text{th}} \text{ member, N/mm}^2; \]

\[ d = \sqrt{1.57 \times 1.40} = 1.48, \text{ fastener diameter, mm;} \]

\[ M_{y,Rk} = 0.45f_ud^{2.6}, \text{ characteristic fastener yield moment, Nmm; where } f_u = 600, \text{ tensile strength of the wire, N/mm}^2; \]

\[ \beta = f_{h,2,k}/f_{h,1,k}, \text{ ratio between the embedment strength of the members;} \]

\[ F_{ax,Rk} = f_{ax,k}d_{pen}, \text{ characteristic axial withdrawal capacity of the fastener, N; where } f_{ax,k} = 20 \times 10^{-6} \rho_h, \text{ characteristic pointside withdrawal strength, N/mm}^2; \rho_h = 500, \text{ characteristic panel density, kg/m}^3. \]

Notes:

1) 1.5-in-long staples were considered in single shear, because \( t_{pen} = 8.6 \text{ mm} = 6d \) is not sufficient to develop the second shear plane.

2) For 1-in-long staples, \( t_{pen} = 14.3 \text{ mm} \leq 14d \), therefore a factor of \( t_{pen}/14d = 14.3/20.7 = 0.69 \) was applied.

The figures A1 and A2 demonstrate 1.5-in and 1-in-long staples in the panels:

Figure A.— Schematic of 1.5-in (A1) and 1-in (A2) long staples penetration in the panels.