The bending moment resistance of single-dowel corner joints in case construction

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Abstract
This study was carried out to obtain background information concerning the bending moment resistance of single-pin dowel joints in particleboard and also to provide the background information needed to formulate expressions for predicting the bending moment resistance of single-dowel, L-type, corner joints in particleboard. Test results indicated that the bending moment resistance of the single-dowel corner joints increased significantly as dowel diameter increased from 1/4 to 3/8 inch and as the depth of dowel embedment in the face member increased from 1/4 to 5/8 inch. Changes in depth of embedment in the edge member from 3/4 to 1-1/2 inches, however, had no effect on bending moment resistance. Single-dowel corner joints loaded in tension had slightly higher ultimate bending moment resistances than the joints loaded in compression. In the compression tests, the dowel withdrew from the edge member in a few cases when the depth of dowels in the edge member was 3/4 inch. In the tension tests, the edge member split when the depth was 3/4 inch. In order to obtain the maximum bending moment resistance, therefore, a conservative embedment depth of 1 inch is suggested as an optimal value for dowel embedment in the edge member. In general, the bending moment resistance of the joints in compression could be predicted by means of the expression:

\[ Y_c = 460.4 \times (D)^{0.452} \times (E)^{1.140} \]

and in tension by means of the expression:

\[ Y_t = 614.6 \times (D)^{0.591} \times (E)^{1.180} \]

where:

- \( Y \) = the bending moment resistance of the single-dowel joint in particleboard (lb.-in.)
- \( D \) = the dowel diameter (in.)
- \( E \) = the depth of dowel embedment in the face member (in.)

Although dowel-type fasteners are widely used in the construction of furniture cases such as kitchen cabinets, there is little information available that can be used to design the joints that characterize this construction. Most of the available information deals with the withdrawal strength of the dowel as a function of various construction parameters (3-6). Also, limited information is available on the bending moment resistance of corner joints constructed with one dowel, and a very limited amount of information is available concerning the bending moment resistance of corner joints constructed with two dowels (1,2,7,8). Most of these data are comparative in nature, however, so they cannot readily be used in an engineering design process. Often, for example, ultimate load is reported rather than ultimate bending moment resistance.

For furniture engineers to design cases on a rational basis, they must have specific quantitative information concerning the bending moment resistance of both single fastener and multifastener joints, which is expressed as a function of the various joint variables. Of particular importance, a design method is needed that will enable them to determine the highest practical level of resistance that may be obtained from a single fastener and the optimum spacing of fasteners in a joint.

As a first step toward developing rational joint design procedures for cases, this study was carried out to obtain background information concerning the bending moment resistance of single-pin dowel joints in particleboard and also to provide the background

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information needed to formulate expressions for predicting the bending moment resistance of single-dowel, L-type, corner joints in particleboard.

Materials and design of joint specimens

The configuration of the L-shaped, single-dowel, corner joint specimens used in the study is shown in Figure 1. In general, each specimen consisted of two principal structural members, a face member and an edge member, joined together by a dowel.

All the specimens were constructed of 3/4-inch-thick particleboard. Only one type of board was used in order to minimize board-to-board variations in mechanical properties. The face member measured 6-1/4 by 6 inches, whereas the edge member measured 5-1/2 by 6 inches; thus, when the two parts were joined together along the 6-inch edge, a symmetrical joint resulted. A hole for the dowel was drilled into the face member at a point midway across the 6-inch joining face at a point 3/8 inch from its edge, perpendicular to the face. A corresponding hole was drilled in the center of one edge of the edge member perpendicular to the face of that edge.

Multigroove yellow birch dowels with nominal diameters of 1/4, 5/16, and 3/8 inch were used in the study. Depths of embedment of the dowels in the face members were 1/4, 7/16, and 5/8 inch. Depths of embedment of the dowels in the edge members were 3/4, 1, 1-1/4, and 1-1/2 inches. In total, there were 36 diameter x face embedment x edge embedment combinations in the test.

Ten replications were made for each combination so that a total of 360 specimens were tested. Half of these specimens (180) were subsequently subjected to compression loading; the remaining 180 were subjected to tension loading.

To prepare the specimens, full-size sheets of particleboard (4 by 8 ft.) were first cut into face and edge member blanks. Blanks for face members measured 6 inches in length by 6-1/4 inches in width. Blanks for edge members measured 6 inches in length by 5-1/2 inches in width. Members for joints were randomly selected from this common supply.

Holes were drilled with precision wood drilling bits at a speed of 2,160 rpm (9,10). A rapid feed rate was used in order to avoid charring the walls of the holes.

The holes in the edge members were drilled 1/16 of an inch deeper than the desired depth of dowel embedment in order to allow for variations in the lengths of the dowels. After the drilling operation, 50 pieces were randomly selected from each diameter x member type class (120 pieces) and their hole diameters were measured to obtain mean and standard deviation values for the holes.

Cleanly machined multigroove dowel rods with no loose or torn surface fibers were selected for dowels. Fifty dowels were randomly selected from each diameter group and their diameters were measured. Both the maximum and the minimum diameter were recorded and the measurements were averaged because dowels tend to be elliptical in cross section.

All specimens were assembled with a polyvinyl acetate emulsion adhesive with 65 percent solids content. Differences between hole and dowel diameters averaged 0.007 inch for the 1/4-inch-diameter dowels, 0.007 inch for the 5/16-inch dowels, and 0.001 inch for the 3/8-inch dowels.

Before assembly, the holes in the members were cleaned with compressed air. Double gluing techniques were used in which both the walls of the holes
and the sides of the dowels were liberally coated with glue prior to insertion of the dowels, i.e., excess adhesive was used. The dowels were first inserted into the face members in order to ensure that the dowels were embedded to the required depth. During assembly, samples were randomly selected to measure the depths of dowel embedment in face and edge members. In all samples, a piece of wax paper was included between the two members to prevent the face from adhering to the edge member. All specimens were allowed to cure for at least 1 week before testing.

**Method of loading**

In a case, the corner joints are exposed to both compressive and tensile forces that tend to close or open the joint, respectively. To obtain these actions, both apex loading (tension) and loading of the sides (compression) were used, as shown in Figures 2 and 3.

The ultimate load resistance of the joints was defined as load resistance at failure. Ultimate load resistance values were then converted to corresponding bending moment resistance values by means of the expressions:

\[
M_c = 3.359 \text{ F lb.-in. for compression loading (Fig. 3)}
\]

\[
M_t = 1.945 \text{ F lb.-in. for tension loading (Fig. 2)}
\]

where:

\[
M_c \text{ and } M_t = \text{ the ultimate bending moment resistance in compression and tension, respectively}
\]

\[
F = \text{ applied force (lb.)}
\]

**Testing**

All tests were carried out on a Riehle universal testing machine. The specimens were loaded as shown in Figures 2 and 3 for tension and compression tests, respectively. In the tension test setup, each of the supports was placed on rollers so that the two joint members were free to move sideways. A rate of loading of 0.25 inch per minute was used in all tests.

**Results and discussion**

Moisture content of the particleboard averaged 9.0 percent, specific gravity averaged 0.71, internal bond strength averaged 98.05 psi, modulus of rupture averaged 2,000 psi, and modulus of elasticity averaged 400,000 psi; moisture content of the dowels averaged 9.48 percent.

Average results for the compression and tension tests are given in Table 1. Individual test results are discussed later.

**Mode of failure in compression tests**

In general, three clearly definable types of specimen failure occurred in the inward compression tests. In the first type, the dowel withdrew from the face member and the lower part of the hole of the face member was crushed somewhat inwardly in compression by the dowel. In the second type, the edge of the face member fractured and the dowel, along with a bell-

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**TABLE 1.** — Average bending moment resistances (lb-in.) of the single-dowel joint compression test for five replications of each combination of dowel diameter, depth of dowel embedment in face member, and depth of dowel embedment in edge member.

<table>
<thead>
<tr>
<th>Depth in edge (in.)</th>
<th>1/4 inch</th>
<th>5/16 inch</th>
<th>3/8 inch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth in face (in.)</td>
<td>1/4</td>
<td>7/16</td>
<td>5/8</td>
</tr>
<tr>
<td>Compression tests</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/4</td>
<td>51.1</td>
<td>95.1</td>
<td>131.3</td>
</tr>
<tr>
<td>1</td>
<td>43.0</td>
<td>90.4</td>
<td>145.8</td>
</tr>
<tr>
<td>1-1/4</td>
<td>47.0</td>
<td>94.4</td>
<td>143.4</td>
</tr>
<tr>
<td>1-1/2</td>
<td>51.1</td>
<td>104.1</td>
<td>143.8</td>
</tr>
<tr>
<td>Tension tests</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/4</td>
<td>51.7</td>
<td>112.4</td>
<td>149.8</td>
</tr>
<tr>
<td>1</td>
<td>47.3</td>
<td>103.9</td>
<td>142.0</td>
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<tr>
<td>1-1/4</td>
<td>51.7</td>
<td>102.9</td>
<td>145.3</td>
</tr>
<tr>
<td>1-1/2</td>
<td>47.5</td>
<td>111.1</td>
<td>146.3</td>
</tr>
</tbody>
</table>

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shaped piece of material, withdrew from the face member (Fig. 4). In the third type, the dowel withdrew from the edge member along with some core material attached to the dowel.

Of the joints tested, 20.6 percent of the specimens failed owing to dowel withdrawal from the face member (type 1 failure), 77.8 percent of the specimens failed owing to a bell-shaped plug of material breaking out of the side face (type 2 failure), and only 1.7 percent of the specimens failed owing to dowel withdrawal from the edge surface (type 3 failure) (Table 2). These results clearly indicate that the fracture strength of the face member was the limiting factor when the joints were loaded in compression. In general, the length of the fractured plug was from 1-7/8 to 3-5/8 inches long (Fig. 4).

The type of failure that occurred was strongly related to the diameter of the dowel used in the joint. Joints constructed with dowels that were either 5/16 or 3/8 inch in diameter ordinarily failed owing to fracture of a plug of material from the face of the one member (Table 2). However, in the case of specimens constructed with 1/4-inch-diameter dowels, 56.7 percent of the specimens failed owing to withdrawal of the dowel from the face (type 1 failure). This result indicated that the joints with dowel diameters of 5/16 and 3/8 inch obtained maximum joint strength, i.e., the face member fractured, whereas the joints constructed with 1/4-inch-diameter dowels did not obtain maximum possible strength.

Table 3 shows that the joints in which the dowels had a depth of embedment of only 1/4 inch in the face member had a higher percentage of dowel withdrawal (type 1 failure) than did the joints with dowel embedment depths of either 7/16 or 5/8 inch.

These results indicate that for optimum joint strength, larger diameter dowels and maximum depths of embedment should be used, particularly in the construction of cases with walls as thick as those used in this study. Specifically, in this study, dowels with diameters of 5/16 and 3/8 inch with depths of embedment in the face member of 7/16 and 5/8 inch obtained a greater fraction of ultimate potential strength, as evidenced by the mode of failure, than did joints constructed with 1/4-inch-diameter dowels.

**Mode of failure in tension tests**

In the case of the outward tension tests, two clearly definable types of failure occurred. In the first type, the edge of the face member fractured and the dowel, along with a bell-shaped plug of material, withdrew from the face member (Fig. 4). In the second type, the dowel itself fractured. Most failures were of the first type. Only 3.3 percent of the specimens failed owing to fracture of the dowel itself (type 2 failure), whereas 96.7 percent of the specimens failed owing to fracture of the edge of the face member (type 1 failure). These results indicate that the particleboard itself was the weakest part of the joint when the joint was loaded outward in tension.

The length of the fractured plug of material (Fig. 4) was from 1 to 2-3/4 inches. Fracture of the dowel itself occurred only in those specimens constructed with 1/4-inch-diameter dowels. Such joints, therefore, did not attain the maximum strength possible with the material used.

Other secondary types of failure, in addition to those previously described, also occurred. Among the 174 specimens that exhibited type 1 failure, for example, the surface of the dowel split in the longitudinal direction in two of the specimens (1.2%) constructed with 1/4-inch-diameter dowels with 5/8-inch depth of embedment in the face member. In seven specimens (4.0%) constructed with dowels that had a 3/4-inch depth of embedment in the edge member and 5/8-inch
TABLE 4. — Comparison of predicted values with observed values.

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Depth in face</th>
<th>Predicted</th>
<th>Observed</th>
<th>Mean difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(in.)</td>
<td>(lb./in.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compression</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.25</td>
<td>0.25</td>
<td>50.7</td>
<td>48.0</td>
<td>5.3</td>
</tr>
<tr>
<td>0.25</td>
<td>0.4375</td>
<td>95.9</td>
<td>96.0</td>
<td>-0.1</td>
</tr>
<tr>
<td>0.25</td>
<td>0.625</td>
<td>144.0</td>
<td>141.1</td>
<td>2.0</td>
</tr>
<tr>
<td>0.3125</td>
<td>0.25</td>
<td>56.0</td>
<td>60.6</td>
<td>-8.2</td>
</tr>
<tr>
<td>0.3125</td>
<td>0.4375</td>
<td>106.1</td>
<td>114.2</td>
<td>-7.6</td>
</tr>
<tr>
<td>0.3125</td>
<td>0.625</td>
<td>159.3</td>
<td>169.5</td>
<td>-6.4</td>
</tr>
<tr>
<td>0.375</td>
<td>0.25</td>
<td>60.8</td>
<td>60.1</td>
<td>1.2</td>
</tr>
<tr>
<td>0.375</td>
<td>0.4375</td>
<td>115.2</td>
<td>110.3</td>
<td>4.3</td>
</tr>
<tr>
<td>0.375</td>
<td>0.625</td>
<td>172.9</td>
<td>165.1</td>
<td>4.5</td>
</tr>
<tr>
<td>Tension</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.25</td>
<td>0.25</td>
<td>52.8</td>
<td>49.5</td>
<td>6.3</td>
</tr>
<tr>
<td>0.25</td>
<td>0.4375</td>
<td>102.1</td>
<td>107.6</td>
<td>-5.4</td>
</tr>
<tr>
<td>0.25</td>
<td>0.625</td>
<td>155.6</td>
<td>145.8</td>
<td>6.3</td>
</tr>
<tr>
<td>0.3125</td>
<td>0.25</td>
<td>60.2</td>
<td>63.8</td>
<td>-6.0</td>
</tr>
<tr>
<td>0.3125</td>
<td>0.4375</td>
<td>116.5</td>
<td>126.4</td>
<td>-8.5</td>
</tr>
<tr>
<td>0.3125</td>
<td>0.625</td>
<td>177.5</td>
<td>188.5</td>
<td>-6.2</td>
</tr>
<tr>
<td>0.375</td>
<td>0.25</td>
<td>67.1</td>
<td>66.0</td>
<td>1.6</td>
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<td>0.375</td>
<td>0.4375</td>
<td>129.8</td>
<td>125.5</td>
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<td>0.375</td>
<td>0.625</td>
<td>197.7</td>
<td>189.3</td>
<td>4.2</td>
</tr>
</tbody>
</table>

The depth of embedment in the face member, the edge member also split.

In general, therefore, the face member could be stated to be the weakest part of the joint connection for the joints included in this test, because most of the joint failures occurred owing to fracture of the wall with subsequent withdrawal of a plug of material from the side of the wall. Joints constructed with 5/16- and 3/8-inch-diameter dowels gave greater strength than those constructed with 1/4-inch-diameter dowels. In addition, depth of embedment of the dowel in the face member significantly affected strength.

**Data analysis**

To provide a means of comparing the results of the compression and tension tests as well as to obtain functional relationships between bending moment resistance and the various joint parameters, Curves were fitted to the individual test data points by means of regression techniques. The curves had the following form:

\[ Y = a \times D^b \times (E_1)^c \times (E_2)^d \]

where:
- \( Y \) = bending moment resistance (lb.-in.)
- \( D \) = dowel diameter (in.)
- \( E_1 \) = depth of dowel embedment in the edge member (in.)
- \( E_2 \) = depth of dowel embedment in the face member (in.)
- \( a, b, c, d \) = regression constants

For compression test data, essentially no correlation was obtained between bending moment resistance and depth of dowel embedment in the edge member. Therefore, bending moment resistance was expressed as a function of only dowel diameter and depth of dowel embedment in the face member. With this change, the following equation resulted:

\[ Y_c = 460.4 \times (D)^{0.452} \times (E)^{1.140} \]

where:
- \( E = E_2 \)

The \( R^2 \) value was 0.9479.

Similarly, no correlation was obtained between bending moment resistance and depth of dowel embedment in the edge member for the tension test data. Again, the term for edge embedment was eliminated so that the following equation resulted:

\[ Y_t = 614.6 \times (D)^{0.591} \times (E)^{1.180} \]

The \( R^2 \) value was 0.9470.

To provide a practical evaluation of how well the values predicted by this expression agreed with observed results, differences between predicted and observed values were determined and the differences were expressed as a percentage of predicted values (Table 4). Mean differences between predicted and observed values differed by less than 10 percent for the results of both the compression and tension tests.

**Bending moment resistance comparison**

Statistical comparisons of the results for the compression and tension tests indicated that the joints loaded in tension did, in fact, have greater resistance than those loaded in compression. The difference, however, is not great. Ultimate resistance values for the joints loaded in tension averaged only 10 percent greater than those for the joints loaded in compression.

Highest resistances in the compression tests were obtained with joints that had the greatest depth of embedment (5/8 in.) in the face member. Similarly, maximum resistances were obtained with joints constructed with the largest diameter (3/8 in.) dowels with maximum of embedment (5/8 in.) in the face member.

In the compression tests, it was found that only 1.7 percent of the specimens with 3/4- inch depth of dowel embedment in the edge member failed owing to dowel withdrawal from the edge member. In order to assure maximum bending moment resistance, therefore, a conservative 1-inch depth of embedment could be selected for design purposes.

**Conclusion**

In general, the bending moment resistance of the single-dowel corner joints increased significantly as dowel diameter increased from 1/4 to 3/8 inch and as the depth of dowel embedment in the face member increased from 1/4 to 5/8 inch. Changes in depth of embedment in the edge member from 3/4 inch to 1-1/2 inches, however, had no effect on bending moment resistance. Single-dowel corner joints loaded in tension had slightly higher ultimate bending moment resistances than the joints loaded in compression.

In the compression tests, the dowel withdrew from the edge member in a few cases when the depth of dowels in the edge member was 3/4 inch. In the tension tests, the edge member split when the depth
was 3/4 inch. In order to obtain maximum bending moment resistance, therefore, a conservative depth of embedment of 1 inch is suggested as an optimal value for dowel embedment in the edge member.

In general, the bending moment resistance of the joints in compression could be predicted by means of the expression:

\[ Y_c = 460.4 \times (D)^{0.452} \times (E)^{1.140} \]

and in tension by means of the expression:

\[ Y_t = 614.6 \times (D)^{0.591} \times (E)^{1.180} \]

where:

- \( Y \) = bending moment resistance of the single-dowel joint in particleboard (lb.-in.)
- \( D \) = dowel diameter (in.)
- \( E \) = depth of dowel embedment in the face member (in.)

**Literature cited**