Glued Corner Block Joints

Corner blocks are regularly used in furniture frame construction to reinforce highly stressed joints. Most often they are used to increase the bending moment resistance and stiffness of corner joints and thereby increase the resistance of frames and cases to racking forces. They are also widely used to resist shear forces which are imposed on joints by members such as the front and back rails of upholstered chairs and sofas that are often heavily stressed by the seat springs. Corner blocks are usually glued in place, and screws or staples are then used to pull them tightly down onto the mating faces of adjoining members and hold them in place until the adhesive dries. Because the bonding area between a corner block and each of the members it joins together may be reasonably large, the shear strength, in particular, of this construction would be expected to be relatively high. It is difficult to cut blocks that fit perfectly, however, and as a result, the blocks and the members often fit together poorly, and gaps can often be seen in the glue lines. Under these conditions, the strengths of the glue bonds are greatly reduced and the shear and bending moment resistance of the corner block itself are erratic and unpredictable. When screws are used to fasten a block in place, they will continue to provide some strength and perhaps hold a joint together even after the glue bond has failed. Such a joint would be much more flexible after the adhesive failed, however.

The strength obtained with glue block constructions, Figure 6-43, is, presumably, proportional to the bonding areas of the glue block itself. To produce effective joints, the faces of the glue blocks must mate properly with adjoining surfaces, adequate glue must be used between mating surfaces, and the blocks must be pulled down tightly in place with staples, nails, or screws until the adhesive dries. Poor fit and inadequate gluing are the two most common causes of weak corner block constructions.

Glue blocks can be quite effective in resisting bending forces which tend to close a joint, but they have limited strength in those joints which tend to open under load. In the latter case, it may be advantageous to install the block with screws rather than staples.

When the primary purpose of the block is to resist shear, it may be advantageous to cut the blocks so that the grain of the larger of the two perpendicular faces runs parallel to the grain of the block as a whole. This face should then be used as the shear carrying face.

Because of their uncertain and often unpredictable strength characteristics, glued corner blocks are not ideal fasteners for engineered furniture. Since they are, in fact, widely used in furniture construction, and will likely continue to be used, it is important that reliable estimates of their
strength properties be determined in the strength design of a piece of furniture.

Shear Strength Of Glued Corner Blocks

Research (Eckelman, 1972) carried out on joints constructed with the configuration shown in Figure 6-44 indicates that the shear strength of these joints can be predicted by the expression

\[ F = 0.253 \times S_x \times t \times L^{1.24} \]  

(6-17)

where \( S_x \) = the ultimate shear strength parallel to the grain of the members joined together, psi; \( t \) = the thickness of the glue block, inches; \( L \) = the lengths of the faces of the glue block, inches.

For convenience, various values of glue block face lengths raised to the 1.24 power are listed in Table 6-9. It should be noted here that all of the glue blocks used in this research were cut from yellow poplar and only one adhesive was used, namely, liquid hide glue, so that strictly speaking this expression applies only to joints constructed with yellow poplar glue blocks and assembled with liquid hide glue. Another factor that must be considered is the thickness of the corner blocks. All of the tests were carried out with 1-inch thick corner blocks. Presumably, shear strength and bending moment resistance would increase in direct proportion to the thickness of the blocks; e.g., a joint made with a 2-inch thick block would be expected to be twice as strong as one constructed with a 1-inch thick block. This relationship is taken into account in both predictive expressions, but it should be noted that even though we would expect this relationship to hold, it has not been experimentally verified. Precautionary judgment should accordingly be exercised in using these formulas to predict the strength of corner blocks with other thicknesses until additional experience is gained with these sizes.

Bending Moment Resistance of Glued Corner Blocks

Research indicates (Eckelman, 1972) that the average bending moment resistance of a corner joint constructed with a glued corner block can be predicted by means of the expression

\[ F_4 = 0.10 \times S_x \times t \times L^{1.66} \]  

(6-18)

where \( F_4 \) equals the bending moment resistance of the joint in inch-pounds and the other symbols retain their previous meanings. For convenience, various values of face length raised to the 1.66 power have been calculated and are also given in Table 6-9. All of the qualifications previously noted that must be observed when predicting the shear strength of
corner blocks must also be observed when predicting their bending moment resistance.

These formulas, therefore, can be used to provide estimates of corner block strength which must then be adjusted on the basis of engineering judgment and experience in order to obtain allowable design values. This is a particularly important consideration in designing joints made with glued corner blocks since considerable variation must be expected in their strength. An analysis of the data on which the previous equations are based indicates that, on the average, we could not expect more than 95 percent of such specimens to be any more than one-half as strong as the average value predicted for each size class. Because of this consideration, it seems reasonable to reduce the values predicted by equation (6-17) and equation (6-18) by a factor of at least one-half to obtain a basic design value. It is worthwhile noting here that none of the joints tested by the author developed less than 50 percent of the strength predicted by these equations - the lowest value noted was actually 56 percent of the predicted--so that there is some experimental evidence to support this procedure. This value can then be further reduced to obtain appropriate factors of safety.

To illustrate the use of both corner joint expressions, let us consider an example problem. Suppose that an analysis of the forces imposed upon the back spring rail of an upholstered chair indicates that the seat springs impose horizontal front to back shearing forces of 250 pounds on each end of the rail (and therefore on the back spring rail to side rail joints) and that the ends of the rails must also resist an out-of-plane bending force of 100 pound inches. Let us assume here that the manufacturer would like to reinforce the back spring rail to side rail joints with corner blocks, and furthermore, that he would like the blocks, by themselves, to be able to carry the forces imposed upon the joints by the ends of the rail. For convenience, let us further assume that all of the rails are constructed of sweetgum which has been conditioned to 7 percent moisture content.

In the previous discussion it was shown that predicted average ultimate strength values should be reduced by a factor of at least 2 to account for natural variations in strength that are likely to occur because of material differences in construction practices. Let us also assume that the manufacturer wishes to build in a factor of safety of 2 in the design so that the values predicted by equation (6-17) and equation (6-18) must be reduced by a factor of four in our calculations.

The shear strength of sweetgum at seven percent moisture content is given by the expression

$$S_g(\text{gum}) = [1.0 + 3 \times (12 - 7)] \times 1,600 = 1,840 \text{ psi}.$$
If we now substitute the appropriate values into the predictive expression for shear strength, equation 6-17, the following expression results

\[ F_3 = 0.253 \times 1,840 \times 1.0 \times \left( \frac{L}{1.24} \right) / 4 = 250 \text{ lbs} \]

where \((LF)\) is the length factor which is equal to \((L^{1.24})\) in the case of shear. Length factors corresponding to various glue-face lengths have been calculated and are tabulated in Table 6-9. Solving the above expression gives

\[ (LF) = \frac{250}{116.4} = 2.15 \]

Referring to Table 6-9, it can be seen that the length factor nearest in value to 2.15 is 2.18 which corresponds to a glue-face length of 1-7/8 inches. It should be noted here that the next largest length factor should always be used in order to obtain conservative results.

Let us next compute the bending moment resistance of a joint constructed with this size of block to see if it will satisfy the specified bending moment resistance requirements. Substituting the appropriate values (including the length factor for bending) for 1-7/8 inch blocks from Table 6-9 into the bending moment resistance expression, equation 6-18, gives

\[ F_i = 0.10 \times 1,840 \times 1.0 \times 2.84 = 522.6 \text{ in} - \text{lb} \]

Reducing the bending moment resistance just calculated for 1-7/8 inch corner blocks by a factor of 4 gives \( F_4 = 522.6/4.0 \), or, 130.6 pound-inches. Since this reduced value is still 1.3 times the strength required, our design process is completed, and we can state that a 1-7/8 inch corner block is required.

It should be noted that in the above calculations, the reduction factors used to obtain design values were based only upon the tolerance limits and reduction factors calculated for corner joints fabricated under laboratory conditions. This should not be taken to imply that this is a recommended method of determining design values for such joints. In practice, a manufacturer may want to use even larger reduction factors to account for variations in production line practices.

### Staple-Glued Plywood Gusset Type Joints

Joints made with staple-glued plywood gusset-plates have been used in furniture construction for several years—apparently with good success. These joints have high strength, are readily fabricated, and perform reliably in service. Furthermore, the ends of the members that frame into these joints need not be machined to such close tolerances as are needed for doweled and mortise and tenon joints. Perhaps the most important characteristic of this type of joint, however, is that it can be inspected visually with considerable confidence to determine whether or not it has been properly assembled. If the parts mate reasonably well, if there is adequate “squeeze-out” of adhesive around the edges of the plates, if the heads of the staples have been driven soundly into the wood so that the gussets have been pulled tightly down on the members, then we may be reasonably sure that the joint is sound. Since potential defects can be so easily detected with the staple-glued gusset-plate joint, subsequent joint
failures can be more readily avoided, and a more reliable product manufactured.

Strength of a given joint is limited by the rolling shear strength of the plywood and also by its thickness. For most purposes, 1/4-inch thick plywood can be used; in some instances, however, it may be desirable to use 3/8-inch thick material to more nearly maintain the full section of the member. Rolling shear strength of the plywood is important, and hence, quality plywood should be used for plate stock. Adequate glue must be used—the underside of the plate should be fully covered—and the plates should be pulled down tightly on the members joined together.

There is little information available which can be used to design staple-glued plywood gusset-plate type joints. These joints have been relatively widely studied with respect to wood roof truss construction, but the results cannot be readily extrapolated to furniture frame construction. The results which are available, however, indicate that staple-glued gussets can be used to fabricate joints of high strength. In particular, as the width of a member framing into a joint increases to 3 inches and greater, the strength of a joint constructed with staple-glued gussets located on each side of the joint and whose width is equal to the member becomes greater than what could normally be achieved with either doweled or mortise-and-tenon construction. Even when a plate can be used on only one side of the joint, a satisfactory level of strength often can still be obtained. Furthermore, the strength of joints can be increased even more, simply by using oversize gussets. This technique can be used to significantly increase the strength of joints that connect smaller size members together. Ordinarily, the strength of a joint is limited by the maximum dowel spacing that can be used or the widest tenon width that can be cut. With staple-glued gusset construction these limitations are overcome, and the bending moment resistance of a joint can be increased up to the ultimate bending moment resistance of the members themselves simply by increasing the size of the gussets. These are important considerations when engineering furniture with designer-specified safety characteristics. In certain critical areas, for example, it is largely impractical to try to design joints which can carry the loads imposed upon them with an adequate factor of safety with the joint systems that are commonly used today.

Test results indicate that the variation in strength from joint to joint is also relatively low with this type of joint. Results also indicate, however, that joint strength is likely to be dependent on the shear strength of the plywood itself. Since furniture manufacturers usually cannot exercise control over this factor, joint strength can be expected to vary in proportion to the difference in shear strength that exists from sheet to sheet of plywood.

It must be remembered that there are also other limitations associated with these joints which actually make them suitable for only certain applications. For one thing they are usually unsightly, which limits their use primarily to upholstered furniture. Another factor to be considered is that they are more costly and take more time to construct than a dowel joint, for example. Because of this, gusset type joints should be consid-
ered primarily for applications such as the side rail to back post joint in an upholstered chair or sofa where high strength and reliability are essential.

**Bending Moment Resistance**

There are a number of ways in which staple-glued plywood gussets can be used to join members together to resist bending forces, as shown in Figures 6-43a through Figure 6-45d. In the joint shown in Figure 6-45a, equal portions of the rectangular plate are attached to the rail and post members. There is no general formula available which can be used to predict the strength of this type of joint but the results of tests (Eckelman, 1971c) carried out on specimens of several different sizes are given in Table 6-10a. It should be noted that these values were recorded for doubly gussetted joints; that is, joints in which gussets were applied to both sides of the member. For singly gussetted joints, these values should be reduced by one-half. The results given in the table may be closely approximated by the expression

\[ F_4 = 600 \times (W - 0.5)^{1.3} \times L^{0.6} \]

where \( F_4 \) refers to the bending moment resistance, lb-in., \( W \) refers to the width of the plate, in., and \( L \) refers to the total length of the plate, in. Except for the largest gussets tested (5 by 10 inches) all of the plates failed in rolling shear. Hence, the results would be expected to be independent of the type of adhesive used to attach the gussets to the main frame members, and they should also be independent of the thickness of the plywood used.

Another type of plate is shown in Figure 6-45b. This particular configuration can be used when greater strength is required than can be obtained with plates that are limited to the width of the member. Since the gusset is not supported on all edges, the strength of the gusset itself is of importance in this type of joint. Joints constructed with 3/8-inch thick plates will, accordingly, be stronger than those constructed with 1/4-inch thick plates, Table 6-10b.

It should also be noted that the orientation of the grain in the face plies has a pronounced effect on this type of joint. The grain orientation shown in Figure 6-45b, for example, is preferable to that shown in Figure 6-45c.

Another type of plate that can be used to develop high strength is shown in Figure 6-45d. In this case, triangular gussets are used that are cut so that the direction of the face grain is parallel to the free edge of the plate. These joints

<table>
<thead>
<tr>
<th>Gusset Dimensions (in)</th>
<th>Bending Strength (in-lb)</th>
<th>Standard Dev. (in-lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/4 x 1 x 1-1/2</td>
<td>294</td>
<td>24</td>
</tr>
<tr>
<td>1/4 x 1 x 2</td>
<td>362</td>
<td>41</td>
</tr>
<tr>
<td>1/4 x 1-1/2 x 2</td>
<td>684</td>
<td>70</td>
</tr>
<tr>
<td>1/4 x 1-1/2 x 3</td>
<td>1020</td>
<td>123</td>
</tr>
<tr>
<td>1/4 x 2 x 2</td>
<td>1454</td>
<td>119</td>
</tr>
<tr>
<td>1/4 x 2 x 3</td>
<td>2100</td>
<td>88</td>
</tr>
<tr>
<td>1/4 x 2 x 4</td>
<td>2424</td>
<td>208</td>
</tr>
<tr>
<td>1/4 x 3 x 3</td>
<td>4320</td>
<td>444</td>
</tr>
<tr>
<td>1/4 x 3 x 4</td>
<td>5568</td>
<td>562</td>
</tr>
<tr>
<td>1/4 x 3 x 6</td>
<td>6486</td>
<td>1232</td>
</tr>
<tr>
<td>1/4 x 4 x 4</td>
<td>6084</td>
<td>444</td>
</tr>
<tr>
<td>1/4 x 4 x 6</td>
<td>8618</td>
<td>927</td>
</tr>
<tr>
<td>1/4 x 4 x 8</td>
<td>9600</td>
<td>1316</td>
</tr>
<tr>
<td>1/4 x 5 x 5</td>
<td>10704</td>
<td>1570</td>
</tr>
<tr>
<td>1/4 x 5 x 7-1/2</td>
<td>14184</td>
<td>1661</td>
</tr>
</tbody>
</table>

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are particularly useful for resisting forces which are normally much greater in one direction than another. The side rail to back post connection of a sofa, for example, is usually loaded in only one direction. In this case the unsupported edge of the gusset will be loaded in tension and the full strength of the joint will be developed. Strength values for this joint are given in Table 6-10c.

**Illustrative Example**

Let us suppose that a furniture manufacturer wishes the side rail to back post joint in a particular side frame, Figure 6-46, to be able to resist the entire bending force exerted on the frame by a 125 pound front to back force applied to the top of the post.

As can be seen from Figure 6-46 the bending moment exerted on this joint is $F_m = 125 \times lb \times (12 + 12) \text{ in} = 3000 \text{ in-lb}$. Since the side rail is only 3 inches wide, the maximum width of gusset that can be used is 3 inches. Furthermore, a gusset can be used only on the inside of the joint since it would produce an unsightly bulge in the upholstery if it were placed on the outside surface.

Referring to Table 6-10a, it can be seen that 3 x 6 inch plates have an average bending moment resistance of 6,486 pound-inches in a double gusseted joint, or, 3,242 pound-inches in a single gusseted joint, so that a single 3 x 6 inch gusset should give the desired strength.

**Tensile Strength**

There are no general design formulas available for calculating the tensile strength of joints constructed with staple-glued plywood gussets, but research results (Eckelman, 1971c) are available that can be used to estimate their strength. The results of tests carried out on specimens similar to those shown in Figure 6-47 are given in Table 6-11. As can be seen the tensile strength of this type of joint is quite good.

---

**Table 6-10b. Ultimate bending moment resistance of doubly gusseted joints with plate orientations as shown.**

<table>
<thead>
<tr>
<th>Gusset</th>
<th>Bending Strength (in-lb)</th>
<th>Dev. (in-lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/4 x 5 x 5</td>
<td>5424</td>
<td>369</td>
</tr>
<tr>
<td>3/8 x 5 x 5</td>
<td>7392</td>
<td>691</td>
</tr>
<tr>
<td>1/4 x 5 x 5</td>
<td>4188</td>
<td>412</td>
</tr>
<tr>
<td>3/8 x 5 x 5</td>
<td>6300</td>
<td>909</td>
</tr>
</tbody>
</table>

Figure 6-46. Staple-glued gussets are well-suited for joints where high strength is required such as the side rail to back post joint in an upholstered chair side frame.

---

**Table 6-10c. Bending moment resistances of joints shown in Figure 6-45d.**

<table>
<thead>
<tr>
<th>Gusset</th>
<th>Ultimate Bending (in-lb)</th>
<th>Dev. (in-lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/4 x 8 x 8</td>
<td>10,056</td>
<td>987</td>
</tr>
<tr>
<td>3/8 x 8 x 8</td>
<td>12,912</td>
<td>589</td>
</tr>
</tbody>
</table>
Holding Strength of Screws

Wood screws were first utilized in furniture construction about 1725, primarily to attach hinges to drop-leaf tables. In modern times, screws are still used widely to fasten hardware to furniture, but they are also extensively used in place of other fasteners such as dowels and nails to form structural, load-bearing joints. In particular, there is a growing tendency to use screws in many of the small but highly stressed joints found in upholstered frame construction. Critically stressed corners, for example, are often reinforced with blocks that are glued and screwed in place. Also, many of the highly stressed braces used in furniture construction such as the center rail to center upright braces and the front rail to stretcher braces are attached with screws. The importance of such joints cannot be over-emphasized since the structural integrity of the frame as a whole will often depend upon their quality. It is important, therefore, that these joints be properly designed so that they can safely carry the loads imposed upon them in service.

For most construction purposes, clearance holes should be drilled for the shank of the screw. These holes serve to locate the position of the screw as well as to facilitate “starting” of the threads and to prevent splitting of the wood. Pilot holes should be drilled to receive the threaded portion of the screw for the same reasons. Furthermore, screws may be difficult to insert into dense hardwoods unless appropriately sized pilot holes are drilled, and even then, common wood screws may “twist-off” unless they are lubricated. For this reason it is often advantageous to use “sheet-metal” type screws which have hardened steel shanks. Ordinarily these screws can be driven to any reasonable depth in a member regardless of whether or not a pilot hole has been drilled.

Care should also be taken in designing a screw-type joint to insure that the threads cut into the wood are not stripped while the screw is being driven home. One method of preventing this when joining two members together is to use screws with hardened shanks which are of sufficient length (and therefore have sufficient withdrawal strength) so that the head

<table>
<thead>
<tr>
<th>Gusset Dimensions (inches)</th>
<th>Mean Ultimate Strength (lb.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/4 x 1 x 1-1/2&quot;</td>
<td>676#</td>
</tr>
<tr>
<td>1/4 x 1 x 2&quot;</td>
<td>933#</td>
</tr>
<tr>
<td>1/4 x 1-1/2 x 2&quot;</td>
<td>1138#</td>
</tr>
<tr>
<td>1/4 x 1-1/2 x 3&quot;</td>
<td>1637#</td>
</tr>
</tbody>
</table>

Table 6-11. Tension strength of doubly gussetted joints when loaded as shown in Figure (6-45).

Figure 6-47. Diagram showing staple-glued plywood gusset type joint loaded in tension. These joints have high strength when loaded in this manner.
of the screw simply crushes the wood beneath it if the screw is driven in too far. When highly stressed or when over-size pilot holes have been used, screws may have a tendency to “work loose” in service. To some extent this problem can be remedied by filling the pilot holes with a poly-vinyl acetate adhesive before inserting the screws so that they are bonded in place. This procedure should not be considered as a substitute for proper design, however.

### Solid Wood

**Table 6-12. Length diameter factors for screws driven into the side grain of solid wood.**

These factors represent values of the quantity $3.2 \cdot D \cdot (L - D)^{3/4}$ and are to be used with equation 6-19 of the text.

<table>
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<th>Screw Depth of Penetration - inches</th>
<th>1/4</th>
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<th>1/2</th>
<th>5/8</th>
<th>3/4</th>
<th>7/8</th>
<th>1</th>
<th>1-1/4</th>
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</table>

### Withdrawal from Side Grain

The average ultimate withdrawal strength of common wood screws from the side grain of wood may be predicted by the expression (Eckelman, 1973)

$$F = 3.2 \times D \times (L - D)^{3/4} S_x$$  \hspace{1cm} (6-19)

where $F =$ withdrawal strength from side grain of the wood in pounds; $D =$ screw diameter, in; $L =$ depth of penetration of the threaded portion of the screw, in; $S_x =$ shear strength of the wood parallel to the grain at current moisture content, psi. For convenience values of $3.2 \times D \times (L - D)^{3/4}$ for various screw sizes and depths of penetration and are listed in Table 6-12.

This expression indicates that withdrawal strength varies directly with the diameter of the screw and the shear strength of the base material, and finally, with the “corrected length”, or, effective depth of penetration to the 3/4 power. A correction in length is needed to take into account the...
Table 6-12. Length diameter factors for screws driven into the end grain of solid wood. These factors represent values of the quantity 8.75\cdot D^{7/4}(L-d)^{3/4} and are to be used with equation (6-20) of the text.

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fact that a portion of the tip of the screw is not as effective in resisting withdrawal loads as is the full-diameter shank portion. If this tip effect is not taken into account, the strength of short screws will be greatly overestimated.

To illustrate, the withdrawal resistance of a #10 screw embedded 1 inch in the side grain of sugar maple at 12 percent moisture content would be

\[ F_2 = 3.204 \times D \times (L - D)^{3/4} \times (2,330) = 0.519 \times (2,330) = 1,210 \, lb \]

Similarly, the withdrawal resistance of the same screw from yellow-poplar would be

\[ F_2 = 0.519 \times 1,190 = 618 \, lb. \]

Screw withdrawal is significantly affected by pilot hole size; pilot hole diameters, accordingly, should be chosen to provide maximum strength. Ordinarily, the pilot hole should be no larger than the root diameter of the screw. Too large holes are more frequently used than too small because of the difficulty of driving the screws in small holes.

Fairchild (1926) recommended that for maximum strength in hardwoods, pilot holes should be used which are equal to about 70 percent of the root diameter of the screws. In the case of the denser hardwoods, however, it may be necessary to use larger pilot holes in order to prevent splitting of the wood and twisting off of the screws. For convenience, the nominal diameter of several screw sizes along with their average root diameters are given in Table 6-13. Various drill sizes are also listed along with the corresponding percentage of the root diameters of the screws.

Research results tend to discount large differences in the holding strengths of various types of screws. Manufacturers should conduct their own tests, accordingly, to obtain the least cost screw which will fulfill their needs.

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### Table 6-13. Screw diameters and suggested pilot hole sizes.

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1Screw diameter, D, in inches is related to screw gage by the expression, D= 0.06 +0.013N, where N = screw gage. On the average, mean root diameter is equal to about 72% of nominal diameter. Important differences exist, however.

**Sample problem:** To illustrate the use of equation (6-19) along with Table 6-12 and Table 6-13, let us say that we wish to find the average ultimate withdrawal strength of a number 10 screw which has a depth of penetration of 1 inch in the side grain of sweetgum (7 percent moisture content).

Referring to Table 6-9, we see that the appropriate diameter-length factor is 0.520. Similarly, from Appendix 6-1 we find that the shear strength of sweetgum at 12 percent mc is 1,600 psi. Converting this value to a base of 7 percent mc gives a transformed shear stress of 1,840 psi. The withdrawal strength of the screw, accordingly, would be expected to be

**Ans.**

\[
F = 0.520 \text{ in}^2 \times 1,840 \text{ lb/in}^2 = 956.8 \text{ lb.}
\]

### Withdrawal Strength of Screws From End Grain

There is usually a tendency to doubt or question the withdrawal strength of screws driven into end grain surfaces, and where splitting has occurred, some doubt is certainly justified. In constructing furniture frames, however, it is often necessary to fabricate joints in which screws are, in fact, driven into end grain. The strength of these joints is often critical to the structural integrity of the total assembly so that it is important that methods be available for reliably predicting the withdrawal strength of the screws used in their construction.

Only a limited number of investigations of the withdrawal strength of screws from end grain have been carried out. Fairchild (1962) found that withdrawal strengths from end grain varied from 52 to 108 percent of the...
value obtained for side grain and averaged 83 percent as great. Cockrell (1933) obtained values that varied from 44 to 88 percent of those obtained for side grain and averaged 65 percent as great. The Wood Handbook (Anon., 1955) states that end grain withdrawal strengths should average 75 percent as great as side grain withdrawal strengths. All of the researchers agree that splitting of the end grain has a profound effect upon withdrawal strength.

Based on the data presented by Fairchild (1962) and Cockrell (1933) it appears that the average ultimate expected withdrawal strength of common wood screws from the end grain surface of wood can be predicted by the expression

$$F = 8.75 \times D^{7/4} \times (L - D)^{3/4} \times S_x$$

(6-20)

where \(F\) = withdrawal strength of the screw from end grain, pounds; \(D\) = diameter of the screw, in; \(L\) = depth of penetration of the threaded portion of the screw, in; \(S_x\) = the shear strength of the wood parallel to the grain, psi. For convenience, frequently used values of \(8.75 \times D^{7/4} (L - D)^{3/4}\) have been tabulated in Table 6-12.

To illustrate the use of the above expression, consider the arm to back post joint shown in Figure 6-48a. A screw is driven through the back post into the end grain of the arm, Figure 6-48b. If we idealize the frame as shown in Figure 6-48c, then the withdrawal force acting on this screw amounts to 200 pounds. Let us determine what size screw is required to safely resist this force. As a first estimate, let us calculate the withdrawal strength of a number 10 screw, 1-1/2 inches long, from the arm. Since the back post is 7/8-inch thick, the depth of penetration of the screw is 0.625 inches. Referring to Table 6-12, we see that the length diameter factor for this screw is 0.256 in². From Appendix 6-1, we find that the shear strength of sweetgum at 12 percent moisture content is 1600 psi so that the withdrawal strength of the screw is

$$F = 0.26 \text{ in}^2 \times 1,600 \text{ lb/in}^2 = 409.6 \text{ lbs}.$$  

This result indicates that a single screw could carry the load. Two other factors must be considered, however. The first consideration is that withdrawal strength is quite variable from end grain so that it might, in fact, be much lower than the average predicted value. The second consideration is that we want to be sure that the threads are not inadvertently “stripped” when the screw is driven into the end grain of the arm. Because of these factors, a longer screw, say 2 inches long, should be considered. The depth of penetration of a 2-inch screw would be 1-1/8 inches so that
by interpolation the length-diameter factor would be 0.454 in\(^2\). Inserting this value into equation (6-20) along with the shear stress value for sweet-gum gives
\[
F = 0.454 \text{ in}^2 \times 1600 \text{ lb/ in}^2 = 726.4 \text{ lbs.}
\]
This size screw gives a much more comfortable margin of safety; namely, 726/200, or 3.6.

Another factor to consider in the design of this particular joint is that the strength of the entire back system depends to a large extent solely upon it. Should this joint fail, the back system would no longer be functional. It is desirable, therefore, to build a degree of redundancy into this joint to insure that it does not fail in service. One method of doing this is to attach the back post to the arm with two screws instead of one. In one respect, this procedure is wasteful and inefficient in that twice as many screws are used as are actually needed, and this procedure is, in fact, not recommended for all joints. But in those constructions where the functional properties of the entire frame depend upon the structural integrity of certain key joints, it appears worthwhile to use more than a single fastener in fabricating these joints so that the joint will remain sound even if one of the fasteners fails.

**Lateral Strength of Screws In Side Grain**

A common use of wood screws is to attach cleats to the side of a case. These cleats in turn are used to support shelves. When the shelves are loaded, the forces exerted on the cleats are transmitted to the screws as lateral shear forces. Various kinds of hardware such as coat hooks are also installed with screws. When the coat hooks are loaded, the forces are again transmitted to the screws primarily as shear forces.

The strength of this type of joint depends not only upon the size of screw used, but also upon the characteristics of the cleat or hardware and also upon the slip that takes place in the joint. Usually, lateral load carrying strength increases as joint slip increases until a critical slip displacement is reached. Beyond this point, strength then decreases.

There is not a great deal of information available concerning the lateral shear strength of screws driven into side grain surfaces. Research (Kolberek and Birnbaum, 1913) has shown, however, that when wood screws are used to attach wooden cleats to main members, the average lateral shear strength of the screw is given by the expression
\[
F = 8782.3 \times D \times L^{1/2} \times G_x^{7/4} \times d^{0.306} \quad (6-21)
\]
where \(F\) = lateral shear strength of the screw in pounds; \(D\) = screw diameter in inches; \(L\) = depth of penetration of the screw into the main member; \(G_x\) = specific gravity of the wood at current moisture content; \(d\) = slip of the joint in inches.

For convenience, values of \(8782.3 \times D \times L^{1/2}\) and \(d^{0.306}\) have been calculated for various diameter-length combinations and several displacements and are given in Table 6-15 and Table 6-14, respectively. Values of specific gravity raised to several powers are given in Table 6-17. It should be noted that this expression holds only when the main member
and the cleat are of about the same relative density, and the thickness of

Table 6-15. Length diameter factors for the lateral holding strength of screws in wood.

These factors represent values of the quantity $8782 \cdot D \cdot L^{1/2}$ and are to be used with equation (6-21) of the text.

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<td>2588.6</td>
<td>2824.3</td>
<td>3010.5</td>
</tr>
<tr>
<td>35</td>
<td>1348.1</td>
<td>1681.1</td>
<td>1830.1</td>
<td>2020.1</td>
<td>2152.0</td>
<td>2302.0</td>
<td>2432.6</td>
<td>2668.6</td>
<td>2904.3</td>
<td>3090.5</td>
</tr>
</tbody>
</table>

Illustrative Example

Consider the simple bookcase shown in Figure 6-49. Let us assume that this bookcase is to be designed to carry heavy bound technical journals so that the load on the shelf will amount to approximately 5 pounds per inch or 200 pounds per shelf. Each shelf is supported by a 3/4-inch square cleat at either end which runs the full width of the shelf, and each cleat in turn is to be attached to the sides of the case by means of 3 screws. Let us now determine what size screws are needed to support the shelf load.

As a first estimate let us try a number 8 screw 1-1/2 inches long. The diameter of the screw is 0.164 inch, and since the cleat is 3/4-inch thick, the depth of penetration of the screw into the main member will be 3/4 of an inch. Let us assume that the moisture content of the white pine side members is 12 percent. According to Appendix 6-1, the specific gravity of this material at 12 percent moisture content is 0.35. Let us further assume that we wish to calculate the lateral strength of these screws at a given load slip displacement of 1/32 of an inch. Substituting these values into equation 6-21 gives the following expression

Table 6-14. Displacement factors which are to be used with equation (6-21) of the text.

<table>
<thead>
<tr>
<th>Joint Displacement (inch)</th>
<th>$d^{lon}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/32 - .0313</td>
<td>.3464</td>
</tr>
<tr>
<td>2/32 - .0625</td>
<td>.4281</td>
</tr>
<tr>
<td>3/32 - .0938</td>
<td>.4847</td>
</tr>
<tr>
<td>4/32 - .1250</td>
<td>.6543</td>
</tr>
</tbody>
</table>
\[ F_3 = 8,782.3 \cdot 164 \cdot (3/4)^{1/2} (0.35)^{7/4} (1/32)^{0.306} = 68.7 \cdot \text{lbs.} \]

Since the load per screw is equal to 200/6, or 33.3 pounds per screw, this design provides a safety factor of 68.7/33.3, or 2.06.

Figure 6-49. Primitive bookcase used in calculating the lateral holding strength of screws.