Design of corner block with anchor bolt table joints

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Abstract

Corner block with anchor bolt joints are widely used in wooden table construction because their use allows the tables to be shipped in the knockdown condition which greatly reduces freight costs. In spite of their widespread use, little is known about those factors which govern the strength and stiffness of the joint. The objective of the research reported in this paper, accordingly, was to evaluate the most important parameters which affect strength and stiffness so that furniture manufacturers might be able to systematically design tables to meet anticipated service requirements.

Corner block with anchor bolt joints (CBA) are used in a wide variety of tables in both domestic and institutional furniture. This joint is popular because the table can be shipped in the knockdown condition and assembled on-site. As a result, shipping costs are greatly reduced. This is an important consideration both in the case of domestic and export furniture.

The basic support system in CBA construction consists of the front, back, and side rails together with the legs. The rails are arranged in the form of a rectangle with a pocket left at each exterior corner for the attachment of the legs. Corner blocks are installed at each of the interior corners formed by the rails, and one or more anchor bolts are inserted through the corner block into the edge of a leg in order to pull the leg into the pocket formed by the ends of the rails and to hold it tightly in place.

Four types of CBA joints are commonly used in tables. These joint constructions may be described as a) mitered corner block with screws, b) corner block with half-dovetail dado in rail, c) corner block with full dovetail, and d) corner block with V-groove in rails (with or without screws) (Fig. 1). As can be seen, these constructions differ from one another primarily in the manner in which the corner block either bears against or is attached to the side rails. The corner block with V-groove construction is of particular interest since it is commonly used in many of the dining tables imported into the United States.

Although the CBA joint is widely used, the factors which control its strength and durability have not been extensively researched and reported in the literature. In general, those papers which have been published on the strength design of tables have dealt primarily with the structural analysis of the table frame support system rather than with the construction of the joints (2, 3, 8). Information on the design of the members and on the design of joints other than CBA joints can also be cited (5, 6). A careful search of the literature, however, has not revealed a single paper dedicated to the rational design of CBA joints although it is known that Eckelman (4) has carried out informal studies of this joint.

Before tables constructed with CBA joints can be designed according to sound engineering principles, it is necessary that the factors which determine their strength and stiffness be defined. The primary purpose of this study, therefore, was to determine and evaluate those factors which govern the strength and stiffness of CBA joints. A secondary purpose was to provide estimates of the strength of this joint which could be used in the rational design of tables.

Factors affecting joint strength

An examination of CBA construction indicates that at least seven factors could affect the stiffness of the joint. These include rail height, rail thickness, number of anchor bolts, method of attachment of corner block to side rails, withdrawal strength of the anchor bolt, position of the anchor bolt, and strength of the attachment of the side rails to the top. Of these factors, rail height, number of anchor bolts used, and use of screws to attach the corner block to the side rails will be considered in this report.

Rail height — Rail height would be expected to be one of the most important measures of the strength of a joint. The moment arm of the resisting internal force in

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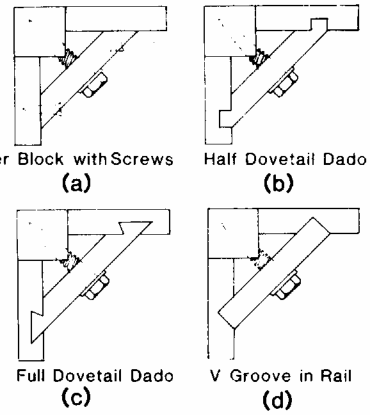

Figure 1. — Four variations of the corner block with anchor bolt construction.

the joint is a function of the distance from the longitudinal axis of the anchor screw to the top (or bottom) edge of the side rail. When a horizontal sidesway force acts on the table, the floor reaction force attempts to rotate the leg about a point located near the bottom (or top) "heel" of the rail. This action is resisted by the anchor bolt, which is loaded in tension, acting through the moment arm defined by the vertical distance from the longitudinal axis of the anchor bolt to the point of rotation of the leg. Thus, the greater the width of the rail, the greater the internal resisting moment arm.

Use of two anchor bolts — The use of two symmetrically spaced bolts rather than one would also be expected to increase joint strength. In this case, the tendency to rotate is resisted primarily by that bolt which is furthest from the point of rotation. Regardless of whether the joint is loaded in tension or compression, the moment arm of the internal resisting force will be greater when two bolts are used instead of a single centrally located bolt.

Use of screwed-in-place corner blocks — Screwed-in-place corner blocks would also be expected to strengthen the joint. Presumably, the normal forces exerted by the ends of the corner block on the rails cause the free ends of the rails to spread apart; they also exert lateral forces on the screws used to attach the side rails to the top. Ultimately, these actions limit the strength of the joint. If the corner blocks are securely attached to the rails with screws, however, the corner block tends to hold the rails together and thereby strengthens the joint. In an informal survey taken of tables in large retail stores, all of those with CBA joints had screws in the corner blocks. This finding indicates that manufacturers believe that screwed-in-place corner blocks contribute to the strength and durability of the CBA joint.

Design of specimens

Of the four types of CBA joints previously described, the V-groove in rail joint was selected for this investigation because a) it is commonly used, particularly in imported furniture, and b) its simplicity of construction makes it well-suited for study.

As previously stated, the joint construction variables taken into consideration included rail height, number of anchor bolts used, and manner in which the corner blocks were attached to the side rails, i.e., either with or without screws. The other factors discussed were held constant during the study. Identical screws were used to attach the rails to the underside of the top, for example, so that this factor could be treated as a constant (the screws were countersunk in the rails).

The general configuration of the specimens used is given in Figures 2 and 3. All of the specimens were constructed of sugar maple (*Acer saccharum* Marsh.). The modulus of elasticity of this material was determined by nondestructive bending tests (7). That portion of the specimen which represented the table top was fabricated from two thicknesses of industrial grade particleboard glued together; these sections measured 1-1/2 inches thick by 15 inches square.

Ten different joint groups were tested. Each joint group had 5 replications so that a total of 50 joints were constructed. Rail heights were 2, 3, and 4 inches. One anchor bolt was used in one set of 2-, 3-, and 4-inch rails. Two anchor bolts were used in another set of 3- and 4-inch rails; only one anchor bolt could be used in the 2-inch-wide rails because their width was too narrow to permit the effective use of two bolts. Corner blocks were attached to the side rails with screws in one-half of the specimens.

In constructing the joints, the rails were first attached to the table top sections with 2-inch-long No. 10 pan head sheet metal screws. Three screws were used in each rail section. Corner blocks were then inserted into the V-grooves. Half of the corner blocks were attached to the rails with No. 10 sheet metal screws which were 1-1/2 inches long. Lag bolts equipped with 3/8-inch zinc coated flat washers were then inserted through predrilled holes in the corner blocks into pilot holes in the legs and tightened until the corner blocks began to spread the rails apart at their free edge (avg. torque was 237.5 lb.-in.). The positions of the pilot holes for the lag bolt and screws are shown in Figure 4.

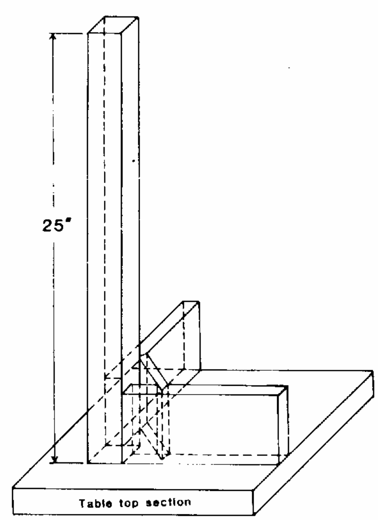

Figure 2. — Side view of a table section specimen.

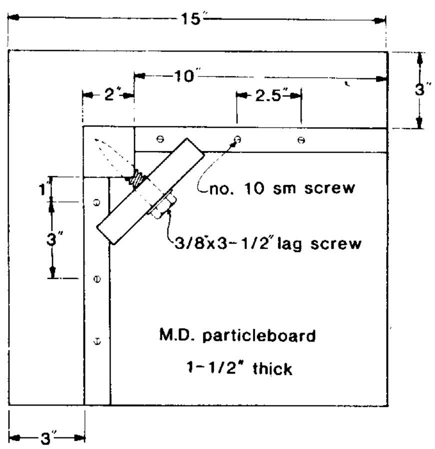

Figure 3. — Top view of a table section specimen.

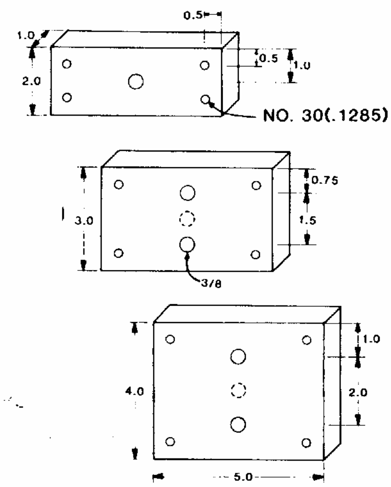

Figure 4. — Diagram showing the positions of the anchor bolts and the screws in the corner blocks.

Testing of joints

All tests were carried out on a Riehle universal testing machine. The top of each specimen was clamped to a steel base for testing with the leg in a horizontal position. Dial gauges, placed at the positions shown in Figure 5, were used to measure deflections. Measurements were taken at either 5- or 10-pound load increments until a leg deflection of 1-1/2 inches was obtained at the point of load application.

During the course of the tests, it was found that the joints did not undergo sudden catastrophic failure; rather they continued to carry load even after they had undergone a large deflection. It was necessary, therefore, to define a point or condition corresponding to an assumed limit of usefulness for the joints. This point was defined as the semi-rigid internal rotation in the joint which corresponded to a 1-inch sidesway deflection of a table with 28-inch legs. It was felt that this was about the limit of acceptable sidesway in a table. The external bending force acting on the leg at this rotation was then defined as "usable" strength.

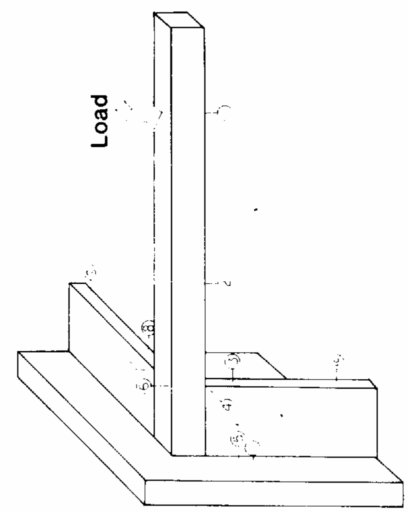

Figure 5. — Diagram showing the arrangement of a joint specimen for testing.

Analysis of stiffness

The stiffness characteristics of the joints were calculated by first subtracting the bending of the leg itself, when treated as a cantilever beam, from the measured deflection data for each load point. To obtain the best estimate and subsequent visual representation of the stiffness characteristics of each joint type, regression curves were fitted to the corrected moment versus rotation data. It was found that a non-linear relationship existed which could be expressed by a regression curve of the form

$$M = a\phi^b$$

where M refers to the bending force (or moment) up to the usable strength of the joint, ϕ refers to the internal or semi-rigid rotation of the joint, and a and b are regression coefficients. Moment-rotation curves within the range of usable strength are shown in Figures 6a through 6g.

To obtain a single stiffness factor, or Z-value as it is commonly called (1,9), for each joint type which could be used in the analysis of table frames containing similar joints (2), a straight line, which passed through the origin, was fitted to the moment-rotation data over the range of usable strength. The stiffness factor for each specimen group was then taken as equal to the reciprocal of the slope of the line.

The slope of the straight line and the R-squared value for each joint group, usable strength, and Z-values are given in Table 1. These Z-values ranged from 6.9×10^{-6} to 2.9×10^{-5} (radians/lb.-in.).

Analysis of strength data

Rail height effects

One anchor bolt without corner block screws (Fig. 6a) — As can be seen, the usable strength of this construction increased by 70.3 percent as rail height increased from 2 to 3 inches (1,036 vs. 1,764 lb.-in.). Similarly, the usable strength for the 4-inch-high rail construction with one bolt and no corner block screws

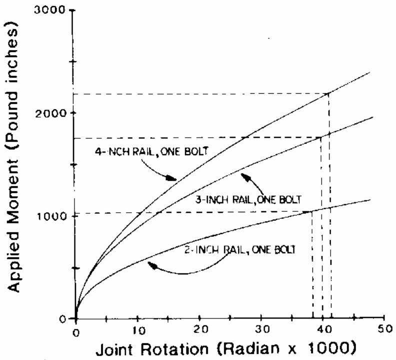

Figure 6a. — Moment-rotation relationships for specimens with one anchor bolt and no screws.

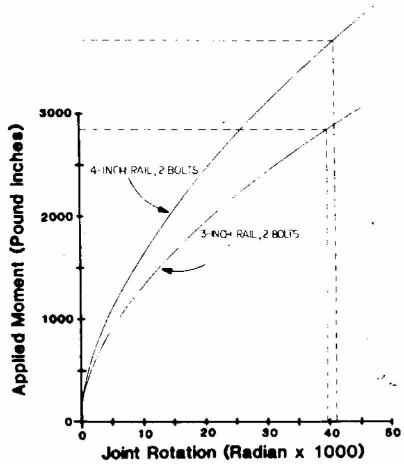

Figure 6b. — Moment-rotation relationships for specimens with two anchor bolts and no screws.

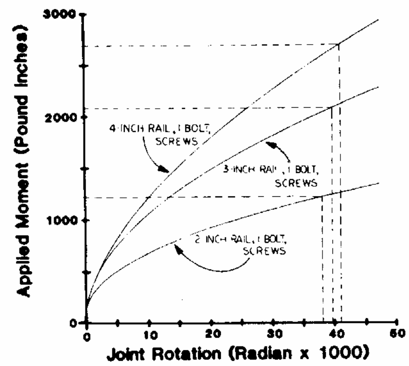

Figure 6c. — Moment-rotation relationships for specimens with one anchor bolt and screws.

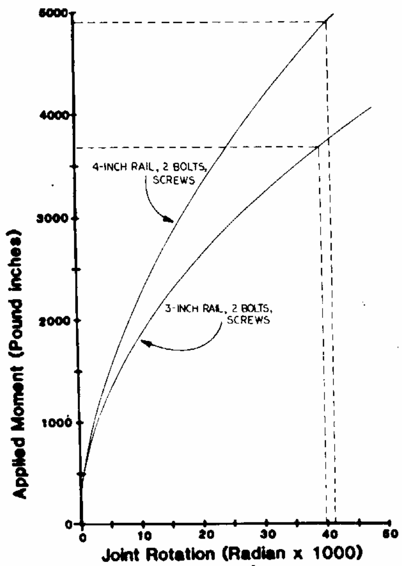

Figure 6d. — Moment-rotation relationships for specimens with two anchor bolts and no screws.

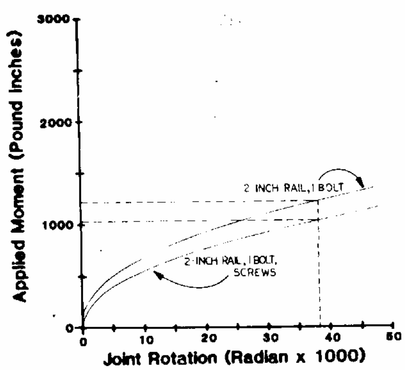

Figure 6e. — Moment-rotation relationships for specimens with 2-inch-wide rails.

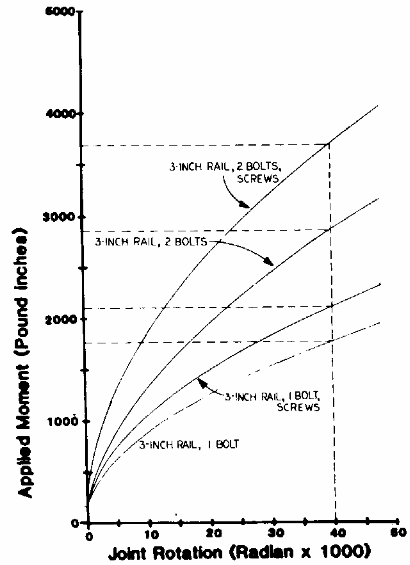

Figure 6f. — Moment-rotation relationships for specimens with 3-inch-wide rails.

was 25.0 percent greater than that for the 3-inch-high rail (2,205 vs. 1,764 lb.-in.). Finally, the usable strength for the 4-inch high rail was 112.8 percent greater than for the 2-inch-high rail (2,205 vs. 1,036 lb.-in.).

One anchor bolt with corner block screws (Fig. 6c) — Although the strengths of these joints were higher than those constructed without screws, the strength ratios between the 2-, 3-, and 4-inch joint constructions were quite similar. Usable strength of the joints with 3-inch rails averaged 70.7 percent greater than joints with 2-inch rails (2,096 vs. 1,228 lb.-in.). Similarly, joints with 4-inch rails averaged 29.8 percent greater than joints with 3-inch rails (2,721 vs. 2,096 lb.-in.). Finally, the strength of the joints with 4-inch rails was 121.6 percent greater than the joints with 2-inch rails (2,721 vs. 1,228 lb.-in.).

Two anchor bolts without corner block screws (Fig. 6b) — In this case, the usable strength for the 4-inch-high rail was 31.3 percent greater than for the 3-inch-high rail (3,744 vs. 2,851 lb.-in.).

Two anchor bolts with corner block screws (Fig. 6d) — In comparison to the joints constructed without screws, the usable strength of the joints with screws and 4-inch-high rails was 31.9 percent greater than joints constructed with 3-inch-wide rails (4,872 vs. 3,695 lb.-in.).

These results indicate that the height of the rail has an important effect upon joint strength, and that height effects are independent of screw effects.

Anchor bolt effects

Anchor bolts without corner block screws (Figs. 6f and 6g) — In the case of corner blocks without screws, usable strength increased by 61.6 and 69.8 percent in joints constructed with 3- and 4-inch rails, respectively, when two anchor bolts were used instead of one (2,851 vs. 1,764 lb.-in. and 3,744 vs. 2,205 lb.-in.).

Anchor bolts with corner block screws (Figs. 6f and 6g) — In the case of screwed-in corner blocks, usable strength increased by 76.3 and 79.1 percent for 3- and

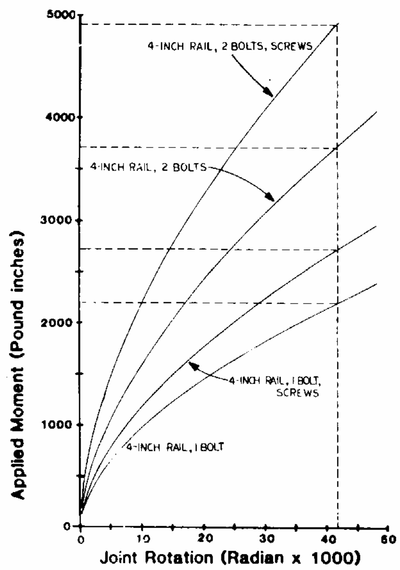

Figure 6g. — Moment-rotation relationships for specimens with 4-inch-wide rails.

Table 1. — *Stiffness and usable strength values for the various joint groups.*

Joint group	Slope (lb.-in./rad.)	*R* square	*Z*-values (rad./lb.-in.)	Usable strength (lb.-in.)
1	34885.5	0.836	2.867×10^{-5}	1,036
2	43271.6	0.883	2.311×10^{-5}	1,228
3	55857.5	0.908	1.790×10^{-5}	1,764
4	84327.4	0.905	1.186×10^{-5}	2,851
5	68224.2	0.933	1.466×10^{-5}	2,096
6	119585.1	0.935	0.836×10^{-5}	3,695
7	65646.6	0.914	1.523×10^{-5}	2,205
8	107666.8	0.923	0.929×10^{-5}	3,744
9	80019.9	0.924	1.250×10^{-5}	2,721
10	144579.2	0.946	0.692×10^{-5}	4,872

4-inch rails when two bolts were used (3,695 vs. 2,096 and 4,872 vs. 2,721 lb.-in.).

These results indicate that the use of two bolts instead of one obtains an enormous increase in strength. This increase in strength is greater than would be predicted from a consideration of the increase in the moment arm of the internal resisting force. Also, these results indicate that anchor bolt effects are not independent of screw effects since the percentage increase in strength noted when two anchor bolts were used instead of one was greater in specimens constructed with screwed-in corner blocks (76.3% and 79.1% vs. 61.6% and 69.8%).

Screw effects

One anchor bolt (Figs. 6e, 6f, and 6g) — For the 2-inch-high rails, usable strength increased by 18.5 percent when corner blocks were attached with screws (1,228 vs. 1,036 lb.-in.). Comparable values for 3- and 4-inch rails with one anchor bolt were 18.8 percent for the 3-inch and 23.4 percent for the 4-inch-high rails (2,096 vs. 1,764 lb.-in. and 2,721 vs. 2,205 lb.-in.).

Two anchor bolts (Figs. 6f and 6g) — When two anchor bolts were used, usable strength values increased by 29.6 percent for 3-inch rails and by 30.1 percent for 4-inch rails (3,695 vs. 2,851 lb.-in. and 4,872 vs. 3,744 lb.-in.).

In general, strength increased about 20 percent when screws were used in one-bolt constructions and about 30 percent in two-bolt constructions. Screw effects are essentially independent of rail height within the limits of the heights tested; however, as noted, screw effects are not independent of bolt effects (18.8% and 23.4% for one-anchor bolt constructions vs. 29.6% and 30.1% for two anchor bolts).

Summary of results

Results of the tests indicate that force versus deflection relationships in CBA joints are non-linear. Test results also indicate that CBA joints do not fracture within the limits of reasonable deflection but rather yield under load until an excessive deflection is obtained. The ultimate strength of CBA joints, accordingly, is not reached until acceptable joint deflection has been exceeded; therefore, it is necessary to define a "usable" strength for the joint.

Results also indicate that joint strength is strongly related to rail height. As rail height changed from 2 to 3 inches and from 2 to 4 inches, usable strength increased by an average of 70 percent and 115 percent, respectively. Also, rail height effects were found to be independent of bolt and screw effects.

The number of anchor bolts used was found to have a very significant effect on joint strength. Usable strength increased an average of about 70 percent when two anchor bolts were used in place of one.

It was also found that the use of screws to attach corner blocks to side rails has a significant effect on joint strength. Strength increased about 20 percent in both 3- and 4-inch rails with one anchor bolt when screws were added; strength increased about 30 percent in similar joints with two anchor bolts when screws were added. Thus, screw effects are independent of rail effects but do interact with bolt effects.

Semi-rigid joint factors, or *Z*-values, determined for the joints indicate that the CBA joint is comparable in stiffness to other commonly used furniture joints. Stiffness values ranged from 6.9×10^{-6} to 2.9×10^{-5} (radians/lb.-in.).

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