Forestry & Natural Resources

Furniture Manufacturing

Joint Design Manual for Furniture Frames Constructed of Plywood and Oriented Strand Board

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Introduction

Although plywood has been used in furniture frame construction for many years and oriented strand board for a lesser period, their use has dramatically increased in recent years owing to several inherent advantages of panel materials compared to solid lumber. Specifically, they eliminate the need for drying yards and dry kilns devoted to the drying of frame stock, they eliminate cutting to eliminate defects, and they eliminate planing of parts to obtain a smooth surface. In addition, use of material in sheet form facilitates optimization of cutting schedules with accompanying high yields and accelerated production. In short, rough mill operations are reduced and greater productivity obtained from a smaller rough mill facility.

Imaginative use of these materials also allows the design and construction of forms, shapes, and constructions which are not feasible with solid wood construction. One-piece side and back frames provide examples of such opportunities. In addition, these parts can be cut with CNC routers and thus lend themselves to ever-more efficient production methods.

As engineered materials, plywood and oriented strand board also provide the opportunity for furniture manufacturers to produce frames rationally designed to meet specified in-service strength and durability requirements. Before such frames can be produced, however, information must be available concerning the strength of joints constructed with these materials. Research underway at the Furniture Research Center of the Wood Research Laboratory of Purdue University is currently addressing this problem also. The information provided in this paper is based on extensive testing and research sponsored by the (APA) that has been completed during the last year.

Design Parameters

The rational design of joints in a furniture frame implies that the joints are designed to have sufficient strength to carry the loads that will be imposed upon them in service. Design loads have never been developed for sofa frames, however. Hence, it is necessary to obtain estimates of such loads from other sources. Perhaps the best source of such information comes from the "GSA Test Method for Upholstered Sofas." This is a cyclic stepped load test method in which the strength and durability of one part of the sofa is determined independently of the other parts. The loads, load increments, and acceptance levels used in the test method are given in Table 1. The test procedure is carried out as follows. A part of the sofa is subjected to a given load for 25,000 cycles at a rate of 20 cycle per minute. Once 25,000 cycles have been completed at this load level, the load is increased a specified amount and testing continued for another 25,000 cycles. This procedure is repeated until the sofa suffers disabling damage or until a desired acceptance level has been reached. In the case of the sidethrust load test on arms, for example, an arm is loaded sideways at its most forward point in the outward direction. The test is begun at the 50 lb load level and increased in increments of 25 lbs. after 25,000 cycles have been completed at each preceding load level. Testing is continued until the desired acceptance level is met or the sofa suffers disabling damage.

Table 1. Initial loads, load increments, and acceptance levels used in GSA tests.

		Initial	Load	Acceptance Levels		
	No. of	Load	Increment	Light	Medium	Heavy
Description of Test	Loads	(lbs)	(lbs)	(lbs)	(lbs)	(lbs)
Seat Load Foundation	3	150	37.5	300	375	412.5
Backrest Foundation	3	50	12.5	112.5	125	150
Backrest Frame	3	75	25	100	125	150
Front to Back on Leg	1	150	50	150	200	300
Sidethrust on Arm	1	50	25	75	150	200
Sidethrust on Legs	1	200	50	200	250	350

A problem exists in using the loads specified in this standard for static design purposes in that a relationship between cyclic load strength and static load strength, which is needed for design purposes, has never been defined. Experience has shown, however, that cyclic load strength should not be assumed to be higher than 50 percent of static load strength.

It must also be remembered that the acceptance levels specified were developed for institutional furniture. The light duty acceptance levels, however, were established with the intent of providing an acceptance level that could be applied to family housing in the military. Presumably, therefore, this level may also be rationally applied to furniture intended for non-military domestic use.

Dowel Joints

Dowel joints are widely used in furniture frame construction, both as structural load bearing connections and also as simple locators for parts. Joints constructed with dowels may be subjected to withdrawal, bending, shear, and torsional forces. The individual dowel pins used in the joints, however, are subjected to withdrawal and shear forces only.

In the sections which follow, quantitative information is presented covering the withdrawal and shear strength of individual dowel pins along with the bending strength of two-pin moment resisting joints and two-pin torsion resisting joints. This information in itself is sufficient to permit furniture engineers to rationally design frames constructed of plywood and oriented strand board. In addition, predictive expressions are presented which allow the withdrawal strengths of individual dowel pins and the bending strengths of two-pin moment-resisting joints to be estimated.

Construction Practice

The withdrawal strength of dowels in plywood is very strongly affected by the manner in which the connection is constructed and the quality of the dowels. Dowels should be straight-grained and geometrically exact -- many dowels are decidedly oval rather than round in cross section. A micrometer should be used to determine maximum and minimum diameters. Dowels from several suppliers should be obtained and compared in order to determine the best sources. In solid wood, the shear strength of the wood from which the dowels are constructed has been found to significantly affect withdrawal strength (Eckelman, 1969). Hence, it also appears prudent to select dowels for use with plywood and oriented strand board from among those woods with higher shear strengths parallel to the grain such as yellow birch (Wood Handbook). Either multi-groove or spiral groove dowels may be used, but in either case, dowels with fine grooving provide a better gluing surface.

Research in other areas has shown the importance of maintaining dowel vs. hole diameter differences at a minimum (Eckelman, 1969). Dowel hole diameters are often considerably larger than the diameter of the drill bit used to bore them. A hole gage and micrometer should be used in order to determine true hole diameters.

A zero clearance fit is optimum but is seldom achieved because of difficulties in assembly. The minimum difference that can be tolerated will likely be found by trial and error, but it is important that it be held to a minimum. Delamination and splitting of the base material usually limits clearances in edge joints -- use of materials with high internal bond strength may help to reduce this problem.

The adhesive used in construction of a dowel joint has an overwhelming affect on its strength. In the case of PVA adhesives, the higher the solids content, the stronger the joint, i.e., a PVA adhesive with 60 percent solids content will produce a stronger joint than one with 40 percent solids. Even more important than the type of glue used are the amount of glue used and its distribution. Dowel joints are adhesive-based joints, i.e., they rely on the adhesive for their strength. For maximum strength and durability, it is absolutely essential that the walls of the dowel hole be thoroughly coated with adhesive. Any other practice will lead to a weaker joint. Production of robust frames of uniform quality necessarily requires such gluing practice. In edge joints, even better results are obtained when excess glue is used provided conditions are such that the excess adhesive is forced into the surrounding substrate where it serves to reinforce the base material. Furthermore, use of excess adhesive will tend to "heal" splits in the edge of the base material since it effectively re-bonds the material.

Withdrawal

The withdrawal strength, i.e., the face and edge holding strength of yellow birch dowels in Douglas-fir, Southern yellow pine, and hardwood plywood along with oriented strand board may be predicted by means of the expressions given in Table 2. Estimated withdrawal strengths for dowel embedded 3/4 inches in the face of Douglas-fir, Southern yellow pine, and hardwood plywood along with oriented strand board are given in Table 3. Estimated withdrawal strengths for dowels embedded 1 inch in the edge of the same materials are also given in Table 3. These values should be treated as estimates subject to variation rather than as absolute values. Depending on differences in construction, strength differences as great as 50 percent might be expected.

As can be seen in Table 3, withdrawal strength depends strongly on dowel diameter. In the case of 3/8-inch diameter dowels, face withdrawal strengths varied from 750 to 1000 pounds for 3/4-inch depth of penetration. Likewise, edge withdrawal strengths varied from about 1000 to 1300 pounds for 1-inch depth of penetration. Use of these values in design of a frame is demonstrated in the following example.

Consider the side frame constructed of Southern pine plywood and 3/8-inch diameter dowels shown in Figure 1. If this frame were subjected to the heavy duty GSA tests for upholstered furniture, the top rail would be required to carry three 150-pound loads so that the top of the back post

Table 2. Expressions used to estimate the withdrawal strength of yellow birch dowels in the face and edge of Douglas-fir-, southern yellow-, and hardwood plywood along with oriented strand board with related statistics. D refers to dowel diameter, L to depth of penetration, and W to density (pounds per cubic foot). R^2 is the correlation coefficient, "under" and "over" refer to the differences between estimated and test values (%), and STD refers to the standard deviation of the differences (%).

		R^2	Under	Over	STD
Material	Expression	Percent			
Face Withdrawal					
Douglas-fir Plywood	$y = 64DLW$	81.6	+31	-42	
Southern Pine Plywood	$y = 55\ DLW$	79.4	+38	-43	16.5
Oriented Strand Board	$y = 55DLW$	86.8	+28	-40	16
Hardwood Plywood	$y = 44D^{0.5}LW$		+27	-38	16
Edge Withdrawal					
Douglas-fir Plywood	$y = 85DLW$	70.5	+44	-31	15
Southern Pine Plywood	$y = 75.5DW$	62.3	+35	-35	17
Oriented Strand Board	$y = 179D^2L^{0.5}W$	78.0	+34	-32	16
Hardwood Plywood	$y = 96DW$	68.5	+23	-23	11

would be subjected to a front to back force of 225 pounds as shown in the figure. The axial forces exerted on the dowels in the arm to back post and arm to front post joints may be found by summing forces about the side rail to backpost joint, Figure 2. Carrying out this operation gives

$$F = 225(10.5+17)/17 = 364 \text{ lbs.}$$

where F refers to the axial force acting along the longitudinal axis of the arm. Referring to Table 3, it is seen that the withdrawal strengths of a 3/8-inch diameter dowel embedded 3/4 inches in the face and one inch in the edge of Southern yellow pine are 759 and 1042 pounds, respectively. Hence, as a first estimate, it would appear that satisfactory joints could be constructed with a single 3/8-inch diameter dowel. As indicated previously, however, even joints constructed as described above may have strengths 50

Table 3. Estimated withdrawal strength of yellow birch dowels in the face and edge of Douglas-fir, Southern yellow pine, and hardwood plywood along with oriented strand board.

Face Withdrawal (lbs) --3/4-inch Depth of Penetration					
	Density	Dowel Diameter (inch)			
Material	(pcf)	1/4"	5/16"	3/8"	7/16"
Douglas-fir Plywood	32.6	530	662	795	927
Southern Pine Plywood	36.8	598	633	759	886
Hardwood Plywood	36.8	810	905	992	1071
Oriented Strand Board	44.8	728	770	924	1078
Edge withdrawal (lbs) -- 1-inch Depth of Penetration					
	Density	Dowel Diameter (inch)			
Material	(pcf)	1/4"	5/16"	3/8"	7/16"
Douglas-fir Plywood	32.6	693	866	1039	1212
Southern Pine Plywood	36.8	695	868	1042	1216
Hardwood Plywood	36.8	883	1104	1325	1546
Oriented Strand Board	44.8	501	783	1128	1535

percent less than indicated in Table 3. Thus, these values should be reduced to 380 and 521 pounds, respectively, for design purposes. Even under these assumption, the dowels would still be able to carry the static design load.

The GSA test method, however, calls for cyclic loading. In addition to cycling at lower load levels, the test method requires that the 225-pound load be applied and removed for 25,000 cycles. Experience has shown that the cyclic strength of frames under these circumstances is no more than 50 percent of static strength, i.e., the cyclic strengths of the joints are 190 and 260 pounds, respectively. Hence, a joint constructed with one dowel remains inadequate. The obvious solution is to use two dowels. This action presumably doubles the strength and also increases the reliability of the joint. Furthermore, it is already common practice. Thus, the design procedure leads to a solution which is already common practice. What these calculations emphasize, however, is that if these joints are to pass the heavy duty GSA tests, optimum construction practices must be followed.

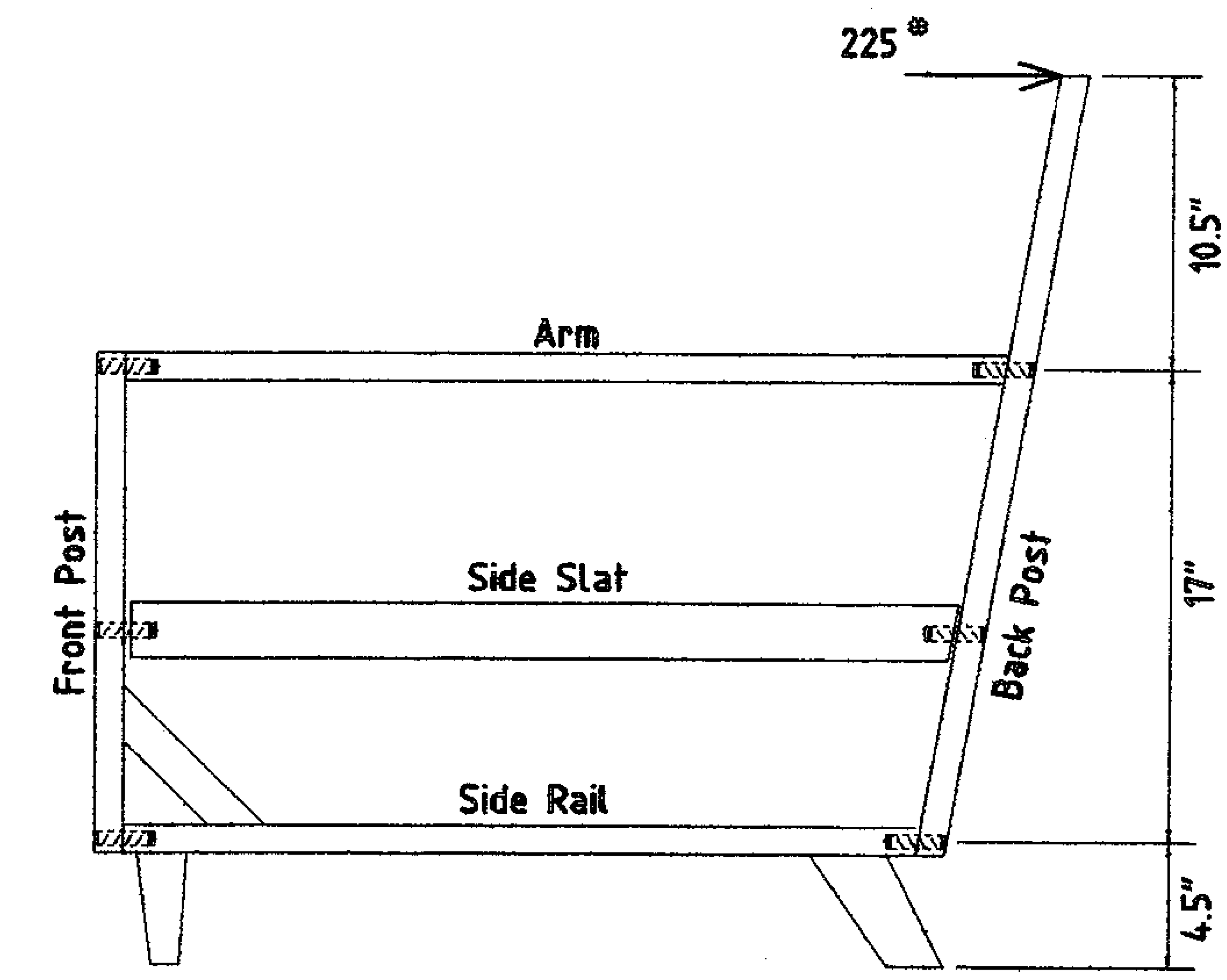

Figure 1. Design of dowel-based arm to back post joint.

Two-Pin Moment Resisting

Two-pin moment-resisting dowel joints are among the most important structural joints in upholstered furniture frame construction. They are commonly used, for example, to connect the front rail to the front post and the side rail to the back and front posts. The bending strengths of T-shaped joints constructed of Douglas-fir plywood, Southern pine plywood, hardwood plywood, and oriented strand board in which the end of rail framed into the side of a post as determined by experiment are given in Table 4. Values are given for two rail widths, namely 4 and 6 inches. Dowel diame-

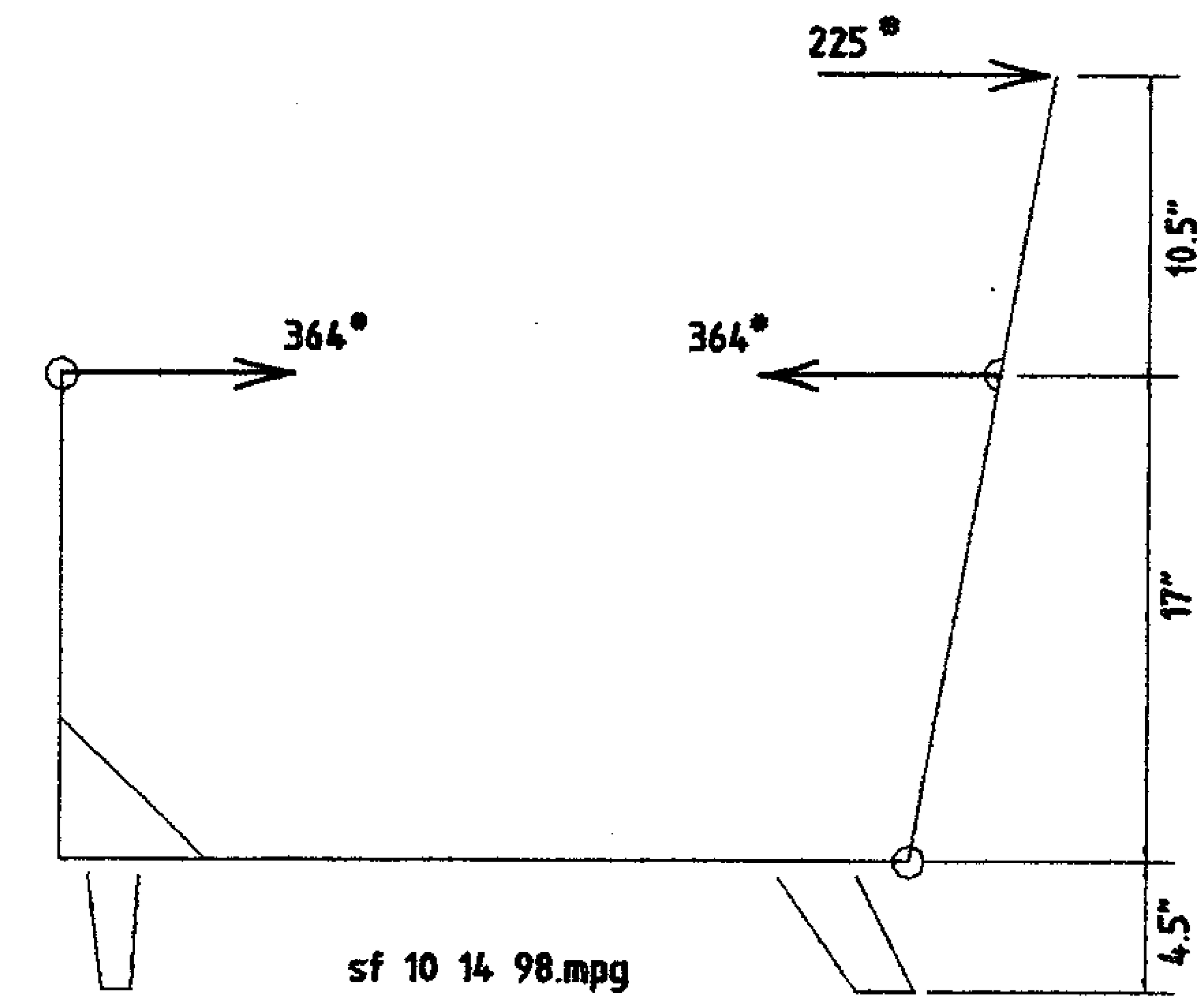

Figure 2. Simplified line drawing of side frame shown in Figure 1.

ter was 3/8 inches; depth of penetration of the dowel in the sides of the posts was 1 inch. Dowels were located 1-inch from the edges of the rail in both the 4- and 6-inch wide rails.

Because test results are available for only two rail widths, it is important that a rational method be available for estimating the bending strengths of joints of other widths and of joints with other dowel spacings. In the case of solid wood, research (Eckelman; 1969, 1971) has shown that the bending strength of two-pin joints, Figure 3, may be closely predicted by means of the expression

$$F_4 = F_2(d_1 + d_2/2)$$

where F_4 = the bending strength of the joint, in-lb, F_2 = the withdrawal strength of the dowel loaded in tension from the side grain of the member, d_1 = the spacing between the longitudinal axes of the dowels, and d_2 = the distance from the longitudinal axis of the dowel loaded in tension to the adjacent edge of the rail. This relationship was found to accurately predict bending strength for specimens with rail widths which varied from 1.5 to 3.5 inches in depth with corresponding dowel spacings which varied from 0.5 to 2.5 inches.

Research (Eckelman and Erdil, 1998) has shown that this expression may also be used to predict the bending strength of two-pin moment-resisting joints constructed of plywood and oriented strand board. To illustrate the use of this expression, let us calculate the bending strength of the joint shown in Figure 4. Width of the rail is 5 inches; dowel spacing is 2 inches. The joint is constructed with 3/8-inch diameter dowels that are embedded 1 inch in the edge of the post. Finally, the joint is constructed of southern yellow pine plywood that has a density of 37 pcf.

Table 4. Bending strength of two-pin moment-resisting dowel joints.

Material	Statistic	Bending Strength 4-inch (In-Lb)	Bending Strength 6-inch (In-Lb)
OSB-1	avg.	3480	5350
	std dev	266	1175
OSB-2	avg.	2490	4430
	std dev	250	569
OSB-3	avg.	3045	5088
	std	426	743
SPLY-1	avg.	3330	5380
	std dev	393	817
SPLY-2	avg.	3100	5510
	std dev	178	1007
SPLY-3	avg.	2930	5340
	std dev	266	364
HPLY-1	avg.	2940	5900
	std dev	675	567
WSPLY	avg.	2640	4640
	std dev	52.7	910
All	avg.	2994	5205
	std dev	327	475

Referring to Table 2, it is seen that the withdrawal strength of a dowel embedded in the edge of Southern yellow pine may be predicted by means of the expression

$$F = 75.5 \cdot DW \text{ lbs.}$$

where F refers to the withdrawal strength of the dowel, lbs; D refers to the diameter of the dowel, inches; and W refers to the density of the plywood, pounds per cubic foot (pcf). substituting the appropriate values into this expression gives

$$F = 75.5(0.375)(37) = 1048 \text{ lbs.}$$

The spacing between the longitudinal axes of the dowels is 2 inches so that d_1 of the bending moment expression = 2; likewise the distance from the longitudinal axis of the lower dowel to the lower edge of the rail is 1.5 inches so that d_2 = 1.5 inches. Substituting these values into the predictive expression gives

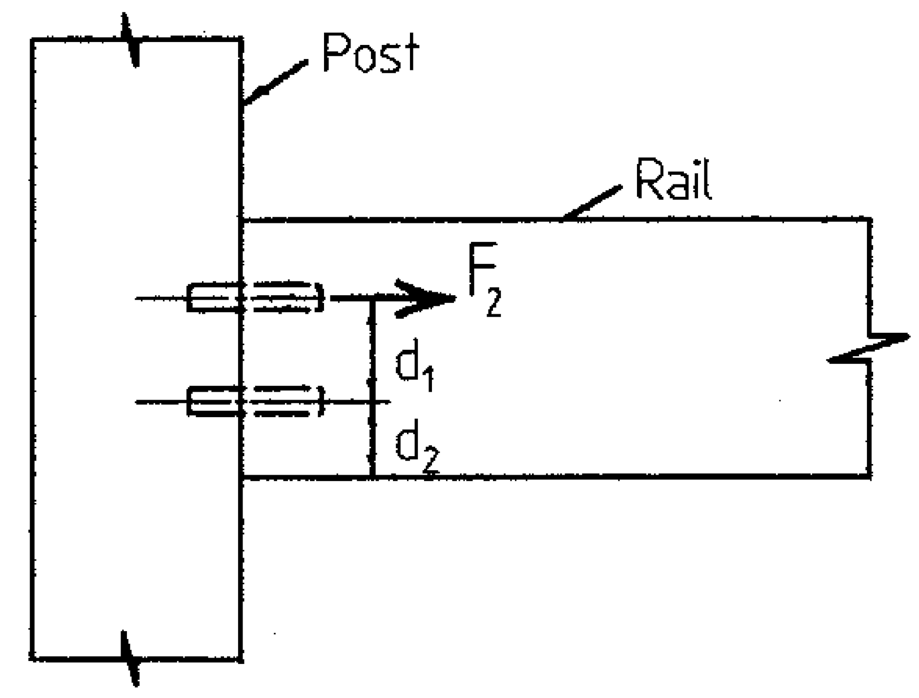

Figure 3. Diagram defining F_2, d_1, and d_2.

$$F_4 = 1048(2 + 1.5/2) = 1048 \cdot 2.75 = 2882 \text{ in-lb.}$$

A stronger joint would have resulted if the dowels been spaced 3 inches rather than 2 inches apart. For a 3-inch spacing, d_1 = 3 inches and d_2 = 1 inches. Substituting these values into the predictive expression gives

$$F_4 = 1048(3 + 1/2) = 1048 \cdot 3.5 = 3668 \text{ in-lb.}$$

As these calculation show, a 27 percent increase in strength was achieved at no expense simply by using a wider dowel spacing.

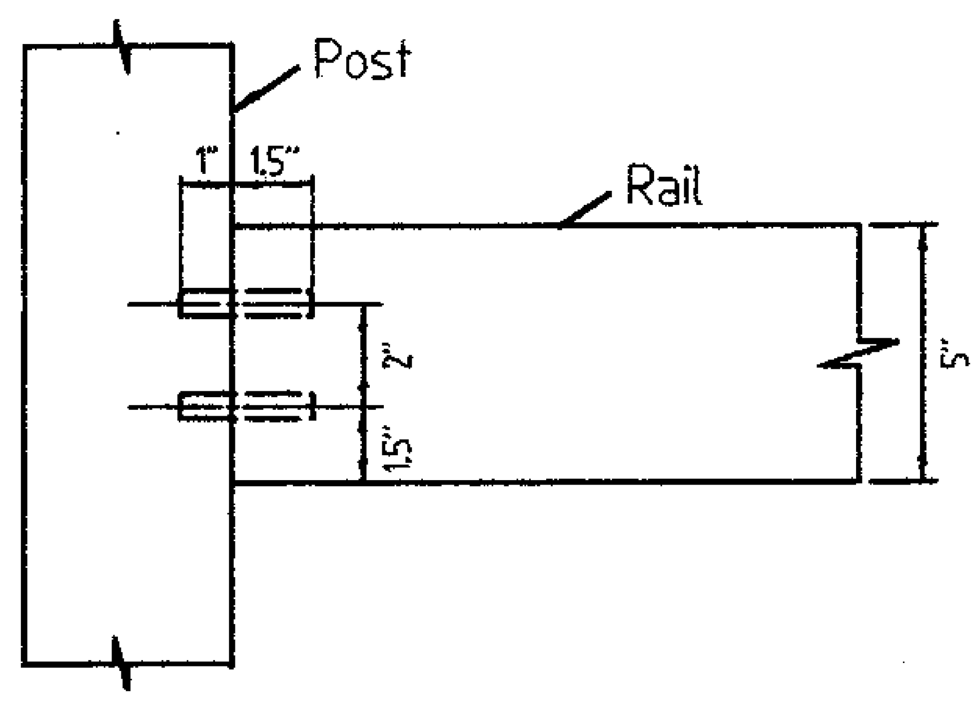

Figure 4. Example two-pin moment-resisting dowel joint used in calculations in text.

To illustrate the design of a practical frame joint, consider the front rail to stump connection shown in Figure 5. If this frame were subjected to the heavy duty GSA tests for upholstered furniture, the arm (at the arm to stump connection) would be required to resist a sidethrust force of 200 pounds applied in the outward direction as shown.. The bending force, F_4, acting on the joint is found by multiplying the side-thrust force applied to the arm times the vertical distance from the point of load application to the longitudinal axis of the front rail, i.e.,

$$F_4 = 200(13 + 5/2) = 3100 \text{ in-lb.}$$

As a first trial in designing the joint, let us assume that the joint is constructed with 3/8-inch diameter yellow birch dowels that are embedded 1 inch in the edge of the stump. Assuming that the frame is constructed of hardwood plywood with a density of 37 pcf, the withdrawal strength of the dowels would be

$$F_2 = 96DW = 96(0.375)(37) = 1332 \text{ lbs.}$$

Also, d_1 in the trial joint is 3 inches and d_2 is 1 inch. Substituting these values into the predictive expression for two-pin moment-resisting dowel joints and solving gives

$$F_4 = 1332(3 + 1/2) = 4662 \text{ in-lb.}$$

As can be seen, the trial joint has 4662/3100, or, 50.4% more strength the previous calculation indicated was needed to carry a 200 pound sidethrust force applied to the arm. As indicated earlier, however, the GSA specification calls for the use of cyclic loads, and cyclic strength should not be assumed to be greater than 50 percent of static strength. Thus, the cyclic strength should not be assumed to be greater than 4662/2, or 2331 in-lb. Under this condition, the joint has only 2332/3100, or, 75 percent of the strength required to meet the GSA specification for heavy duty service. Thus, the design would not be considered satisfactory for heavy duty institutional service.

The solution to this problem lies in the use of a dowel of greater diameter with greater depth of embedment. The withdrawal strength of a 7/16-inch diameter dowel with 1-1/4-inch depth of embedment in the edge of the stump, for example, is

$$F_2 = 96(7/16)(1.25)(37) = 1943 \text{ lbs.}$$

This translates into a bending strength of

$$F_4 = 1943(3 + 1/2) = 6799 \text{ in-lb.}$$

which is sufficient to meet the strength requirement.

The calculations carried out above pertain to furniture to be subjected to heavy duty institutional use which is the most severe case. The light duty and medium duty acceptance levels call for sidethrust loads of 75 pounds and 150 pounds respectively. These loads correspond to bending forces of 75(13+5/2) = 1163 in-lb and 150 (13+5/2) = 2325 in-lb, respectively. Thus, the joint as originally designed would be able meet both the light and medium duty GSA acceptance levels. Since the light duty GSA acceptance level essentially corresponds to domestic service, this design would be more than adequate for home use.

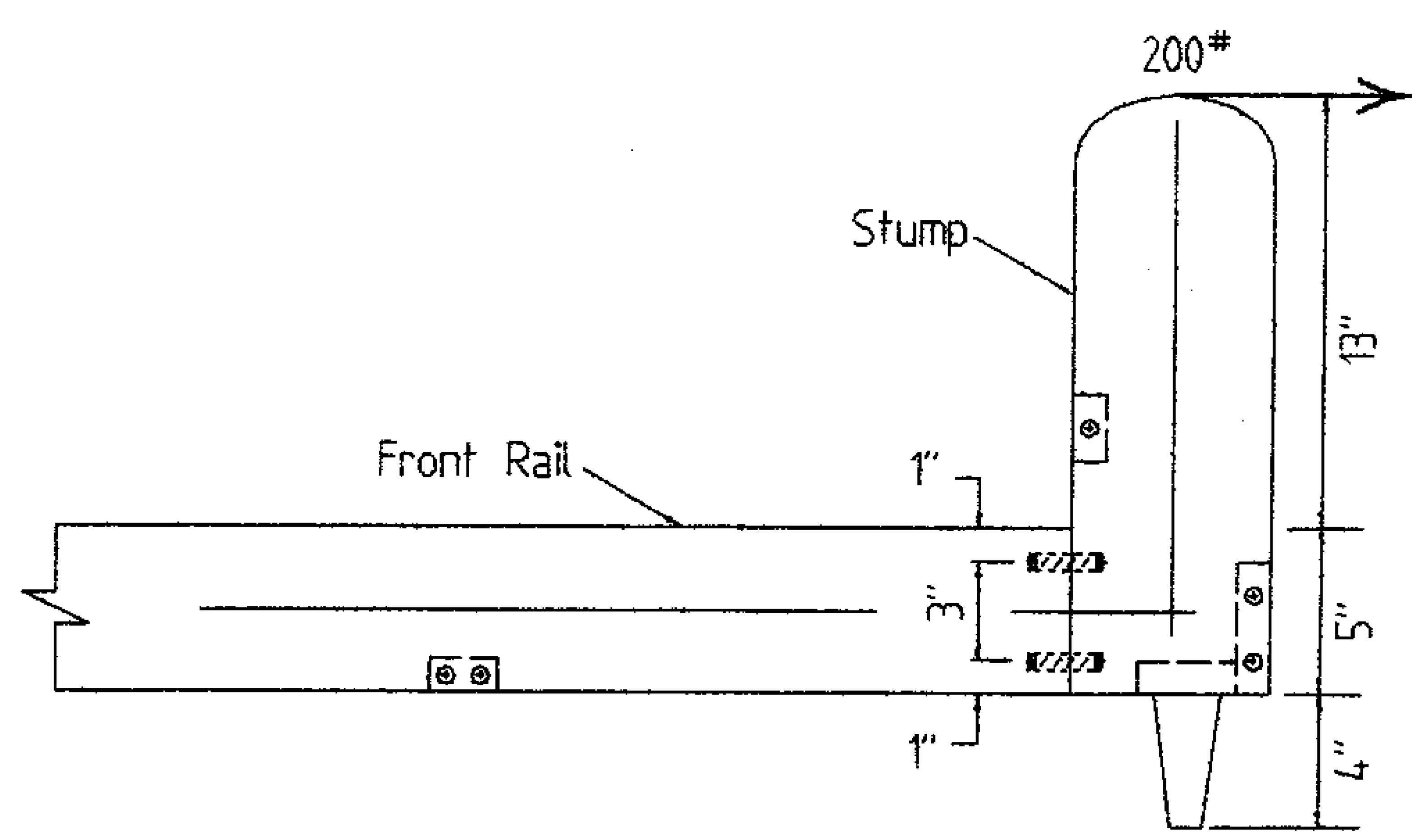

Figure 5. Design of two-pin moment-resisting front rail to stump dowel joint

It should be noted that the above calculations hold only if adequate glue is used in construction of the joints. Use of less than adequate glue will result in joints with only a fraction of the strength shown above.

To further illustrate the design of two-pin moment-resisting joints, the strength of the front rail to stump connection shown in Figure 6 will be determined. Assume that the frame members are con-structed of Southern yellow pine plywood that has a density of 36 pcf. Further assume that the dowels are 3/8 inches in diameter, are constructed of yellow birch, and are embedded 1 inch in the edge of the stump. Also assume that excess glue was used in construction of the joint.

The withdrawal strength of the dowels may be estimated by means of the appropriate expression given in Table 2, i.e.,

$$F_2 = 75.5DW = 75.5(0.375)(36) = 1019 \text{ lbs.}$$

The bending strength of the joint may be found by means of the expression

$$F_4 = F_2(d_1 + d_2/2) = 1019(2+1/2) = 2548 \text{ in-lb.}$$

In terms of the outward sidethrust loads on arms, the bending force transmitted to the joint by an outward sidethrust load is equal to the magnitude of the load multiplied times the vertical distance from the line of action of the load to the joint center, i.e., F_h x (14 + 4/2) = 16 x F_h. The bending force imposed on the joint by a 200-pound load, which is specified in the GSA specification for heavy duty service, would be 200 lbs. x 16 in, or, 3200 in-lb. Hence, this construction does not meet the criteria for heavy duty institutional service. The bending force imposed on the joint by a 75-pound load, which is specified for light duty institutional service, would be 75 lbs x 16 in, or, 1200 in-lb. If the cyclic strength of the joint is taken as 50 percent of the static strength, i.e., cyclic strength = 0.5 x 2548 = 1274 in-lb, it is seen that the joint meets the requirement for light duty institutional service. Requirements for domestic service have never been formally established, but as previously discussed, the light duty GSA acceptance level is also likely satisfactory for domestic service.

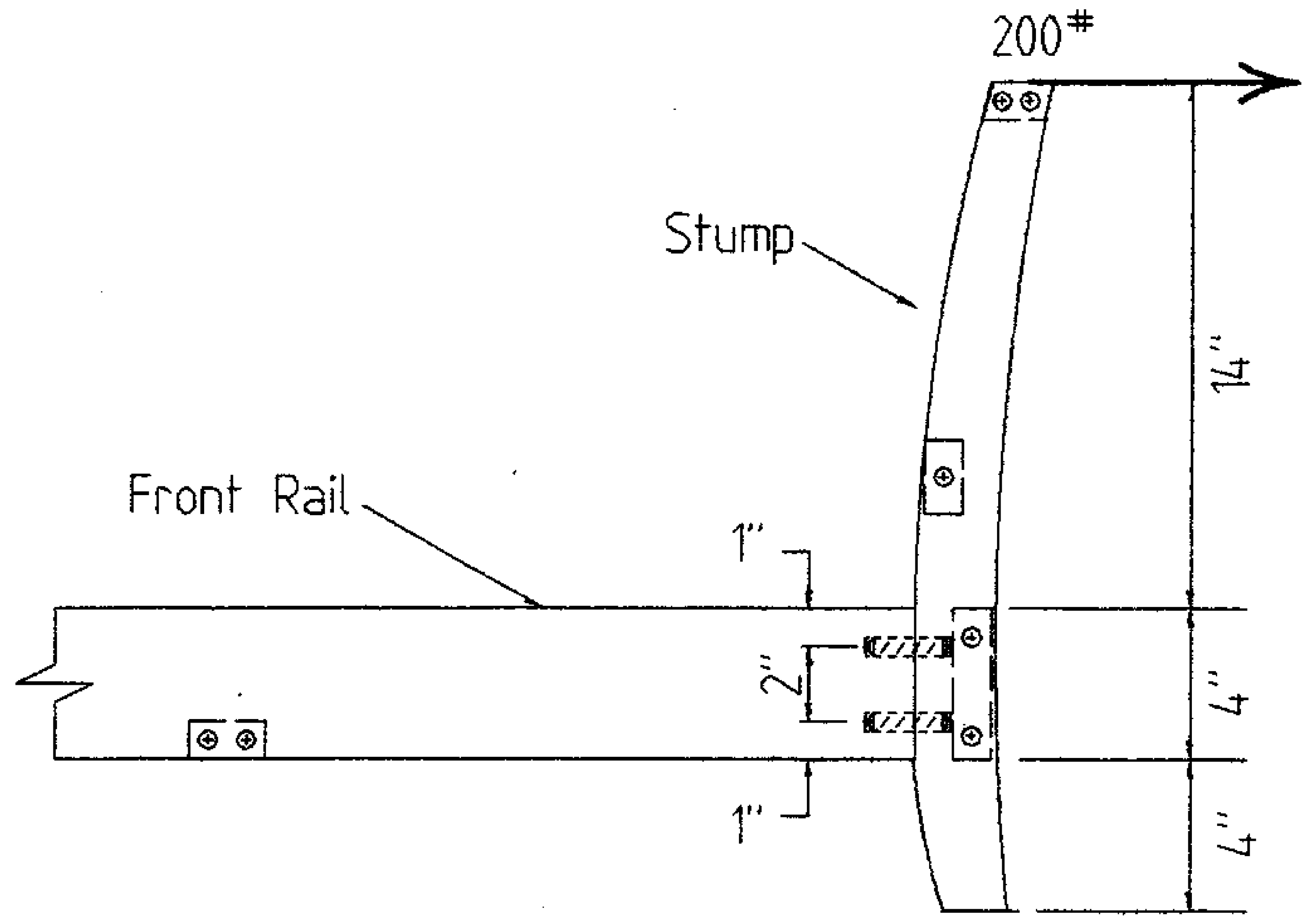

Figure 6. Design of two-pin moment-resisting front rail to front post dowel joint.

Lateral Holding

The lateral strength of dowel joints constructed of plywood and oriented strand board is an important consideration in the design of frames constructed of these materials since several of the joints in such frames are relatively heavily loaded in lateral shear. These joints include, among others, the front rail to stump joints, the top rail to back post joints, stretcher to rail joints arm to front and back post joints.

Intuitively, the lateral holding strength of dowels would be expected to be related to such factors as internal bond strength, rail width, rail orientation (edge or flat), and so on. Lateral holding strength of dowels in composites has been found to be quite variable and not clearly functionally related to the parameters listed above. As a result, predictive expressions have not been developed to estimate their strength. Strength values have been published, however, which provide sufficient information concerning the lateral holding strengths of dowels to allow the rational design of frame joints subjected to lateral loads.

Two types of lateral holding must be considered, lateral edge holding strength, Figure 7a, and lateral face holding strength, Figure 7b. The lateral face- and edge-holding strength of dowels in a number of different plywood and oriented strand boards are given in Table 5. These data clearly illustrate the variation in strength that must be expected among the boards produced. In general, good design practice dictates that joints must be designed on the basis of the least strengths shown unless the specific lateral strength characteristics of a specific board have been determined by test.

To illustrate the design of joints to resist lateral face loading, consider the top rail to back post joint shown in Figure 8. The GSA specification calls for a backframe load of 100 pounds in order to meet light duty requirements. Under this condition, the total back load amounts to 300 pounds. Half of this load is transmitted to each joint so that the lateral shear force acting on each joint is 150 pounds. If it is assumed that each dowel in the joint carries half this load, then the lateral shear force acting on each dowel is 75 pounds. If the loads are doubled in order to account for cyclic loading, the load on each dowel would be 150 pounds.

Referring to the values given for lateral face-holding dowel strength in Table 5, it is seen that all of the materials satisfy this requirement except for the oriented strand board designated OSB-2. Thus, joints constructed with most of the materials would satisfy the GSA requirements for light duty service.

The GSA specification for heavy duty service, however, calls for loads of 150 pounds rather than 100 pounds at each position. Under this condition, a lateral force of 225 pounds is transmitted to each joint and 112.5 pounds to each dowel. Doubling this latter value to account for cyclic loading gives a lateral load per dowel of 225 pounds. Thus, all of the materials except for the two oriented strand boards listed as OSB-1 and OSB-2 would again satisfy GSA requirements.

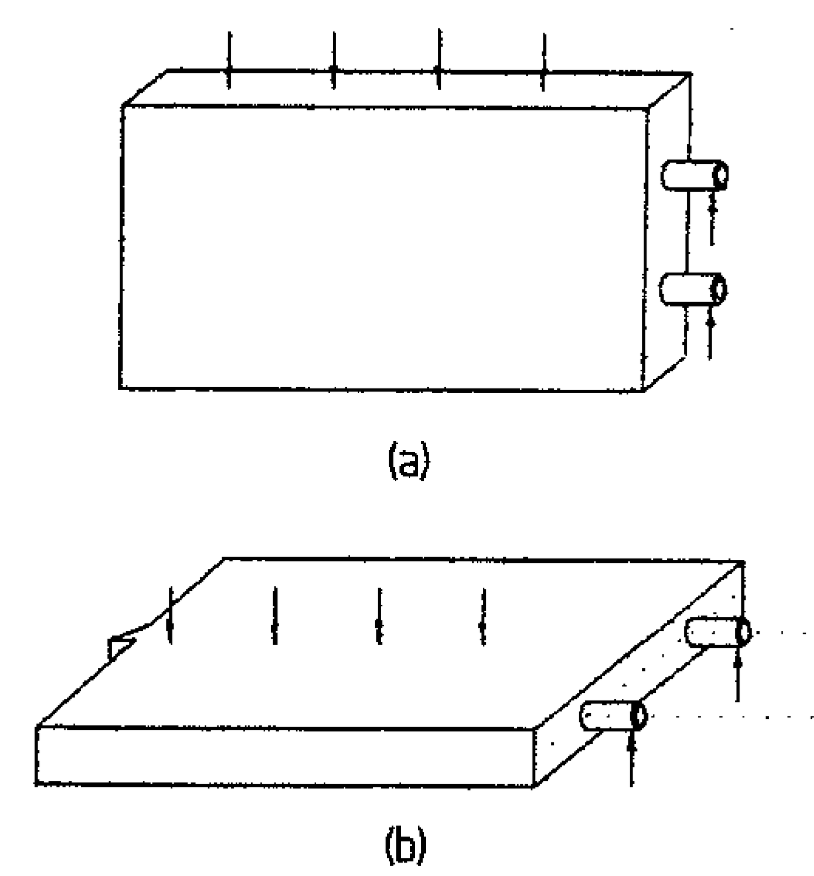

Figure 7. Lateral edge loading, (a); lateral face loading, (b).

These results tend to indicate that whereas joints constructed with some boards might be expected to give satisfactory service, joints constructed with other boards might not. Good design procedures, therefore, dictate that either the joints be reinforced with other fasteners or constructions to increase their strength, or a control program be implemented to ensure that only board with high lateral dowel holding strength be used in construction of the frames.

The front rail to stump joint provides an example of dowels subjected to lateral edge loading. The GSA specification calls for the front rail construction to be able to resist 2/3 of the seat load shown in Table 1. The light duty acceptance level, for example, calls for the use of three 200 pound vertical loads applied at the points shown in Figure 8. Half of the total load of 600 pounds, or, 300 pounds is transmitted to the joints at each end of the rail. For a joint constructed with 2 dowels, each dowel presumably carries a lateral edge force of 150 pounds. For cyclic loading, this force is doubled to 300 pounds. Referring to Table 5, it is seen that joints constructed with all of the materials would be expected to have sufficient strength to carry the 300 pound load.

The GSA specification for heavy use calls for a loading which amounts to 2/3 x 412.5, or, 275 pounds per position. Half of the total load of 825 pounds, or, 412.5 pounds is transmitted to the joints at each end of the rail so that each dowel carries a lateral edge force of 206 pounds. For cyclic loading, this value is again doubled to 412.5 pounds. Referring to the values shown in Table 5, it is seen that joints constructed with most but not all of the materials could carry the specified load. Again, good design procedure dictates that either the joint be reinforced with other fasteners or constructions to carry the load, or else a control program be implemented to ensure that only board with high lateral dowel edge-holding strength be used in construction of the frames.

Front rail to stump joints are also subjected to lateral face loads that result from the front to back forces applied to the tops of front rails by sinusoidal type springs, Figure 9. The magnitudes of these forces have not been well-documented, but work carried out by the author indicates that they may reach values as high as 150 pounds. Another factor to be considered is the number of springs used in the support system. No specific standard exists, but the author often uses a design convention of 15 springs with spring loads of 100 pounds each.

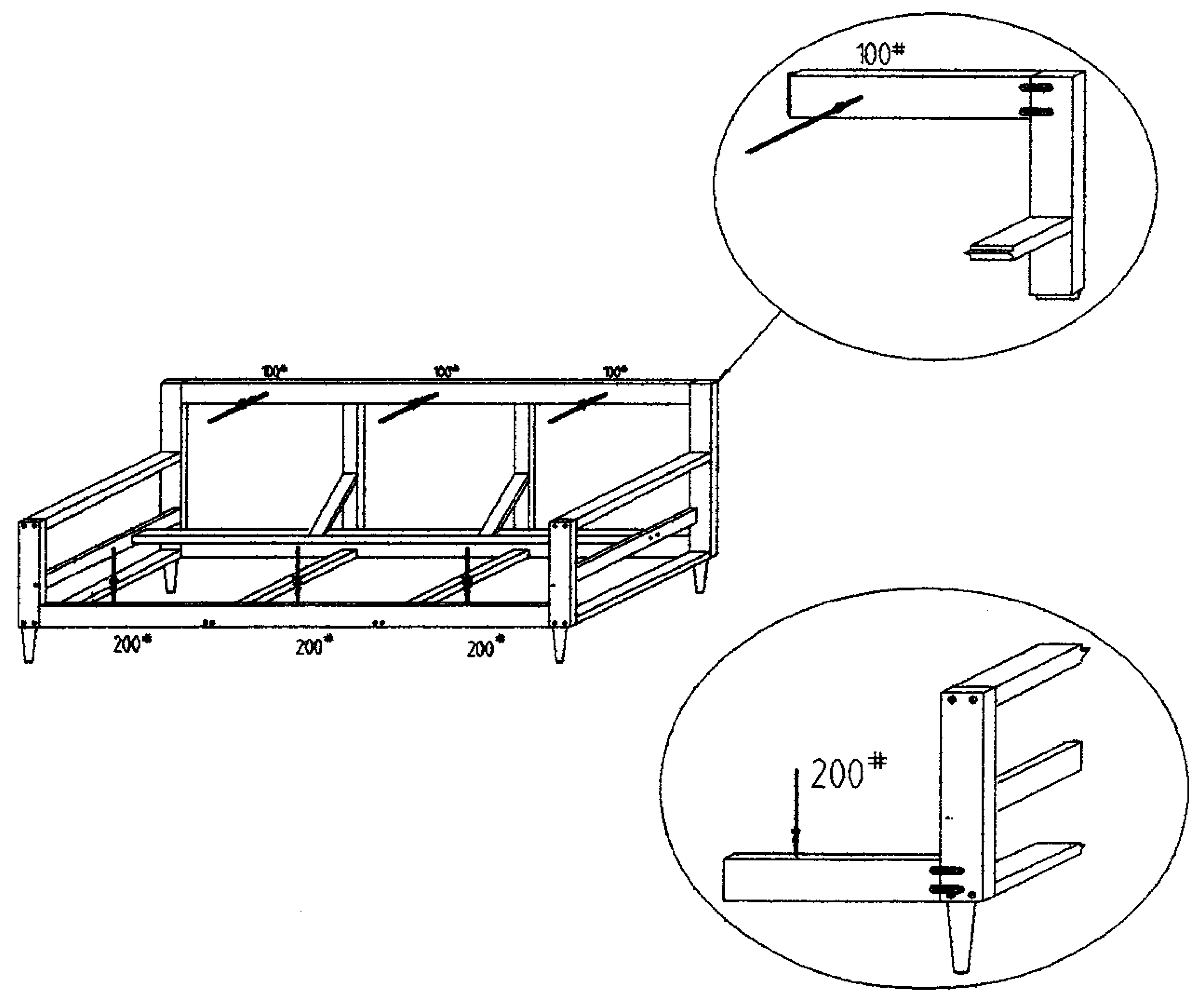

Figure 8. Design of the top rail to back post joint against lateral face loads and the front rail to stump joint against lateral edge loads.

In designing the rail to stump joint, the loads transmitted to the joint at each end of the rail must first be computed. If it is assumed that two stretchers are used in construction of the frame and that the stretcher to rail joints are effectively blocked, then each stretcher carries one-third of the front to back spring loads, whereas the rail to stump joints each carry one-sixth of the spring loads. Thus, each stump to rail joint carries 100 x 15/6, or, 250 pounds. It must be remembered, however, that to the extent that the stretchers and stretcher joints are ineffective in resisting the front to back forces, correspondingly greater forces will be exerted on the rail to stump joints.

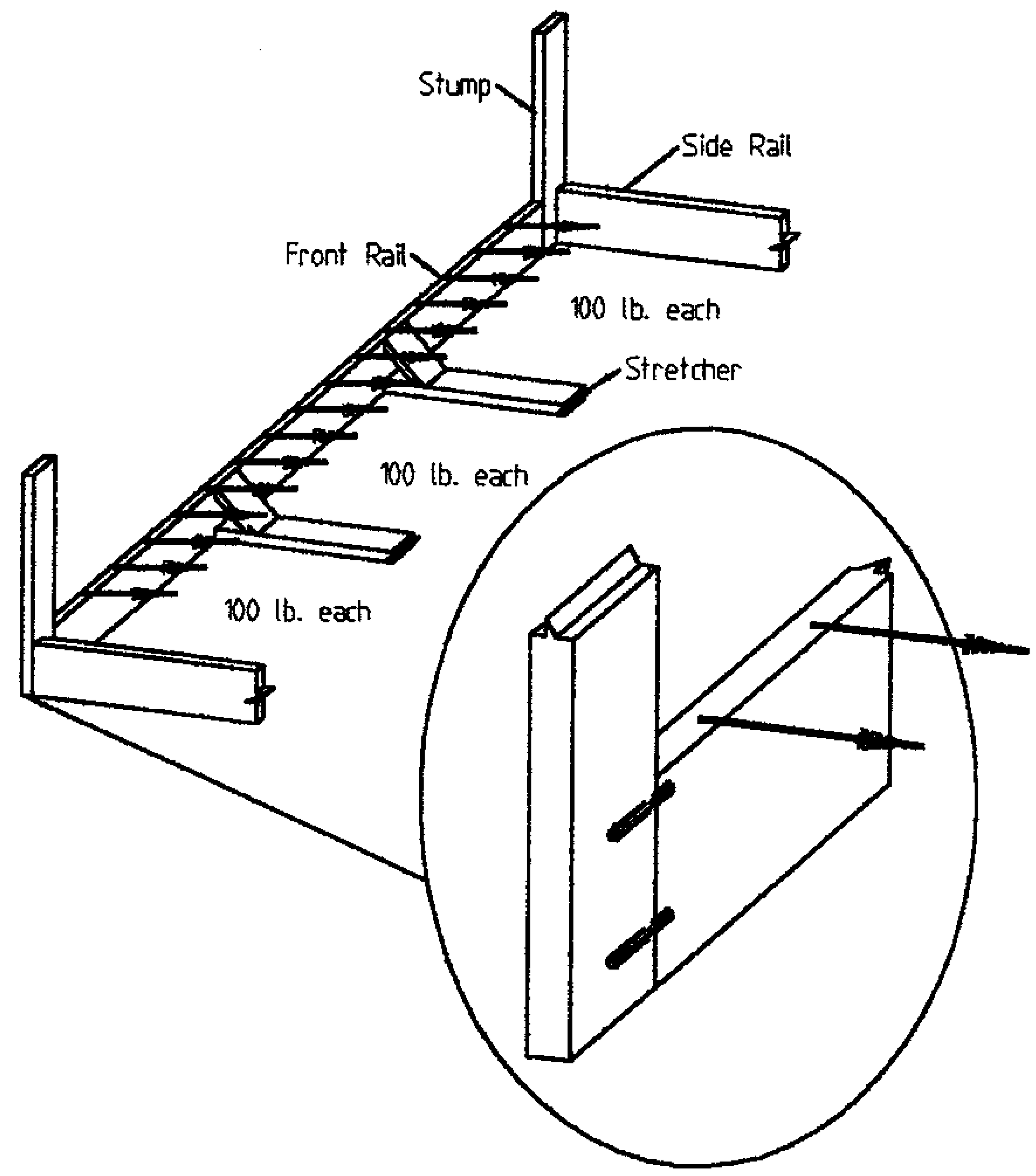

Figure 9. Design of the front rail to stump joint against lateral face loads.

Because the spring forces act on the top edge of the rail whereas the dowels are located some distance below the top edge, Figure 10, the forces exerted on the dowel will be somewhat greater than the force transmitted to the joint. The magnitude of the lateral force acting on the dowel may be found by summing forces about the latter dowel. Let us assume in this example that the width of the rail is 6 inches and that the longitudinal axes of the dowels are located 1 inch from the edge of the rails.

The magnitude of the lateral force F_1 may be found by summing forces about the longitudinal axis of the lower dowel or by proportion, i.e., F_1 = 250 x5/4, or 312.5 pounds. Referring to Table 5, it is seen that only a few of the materials provide the required lateral strength. If the load is doubled to 625 pounds to meet cyclic loading requirements, however, none of the materials provide the required lateral strength. Hence, these calculations indicate that dowels, used alone, do not provide the required strength. Thus, the joint must be reinforced with other fasteners or other constructions such as a glued plywood gusset plate or toothed metal plate, or, the rail must be braced on its back side.

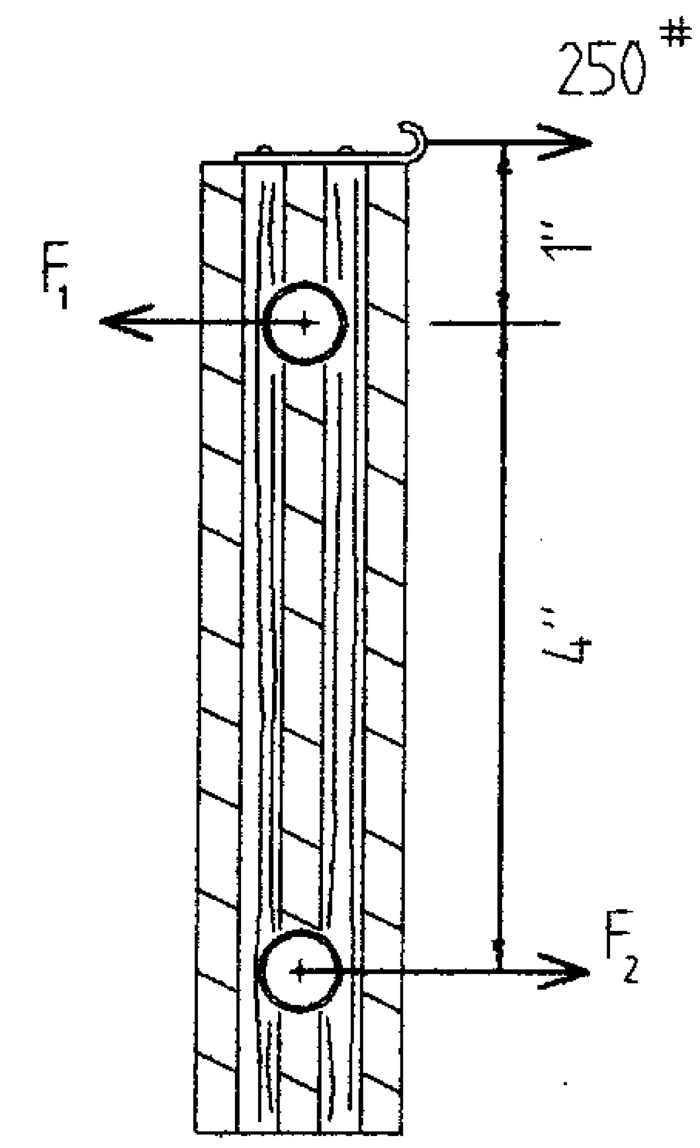

Figure 10. Calculation of lateral shear force, F_1, resulting from spring load.

Torsion

The torsional strength of dowel joints is an important consideration in the design of furniture frames constructed of plywood and oriented strand board since several members, but especially the seat rails of sofa frames, may be subjected to substantial torsional forces. In T-front sofas, for example, side rails are loaded in torsion when inward or outward forces are, in effect, applied to the tops of the arm stumps which in turn are attached to the sides of the side rails. When legs are anchored to the side rails, twisting forces are applied to the rails when a sofa is moved sideways.

In general, the torsional strength of dowel joints is low relative to that of other dowel joints. Torsional strength values for rails in which the dowels were spaced one inch from the edge in rails 4 inches wide and wider are given in Table 6. These values provide an indication of the joint strengths that can be expected in torsion. It should also be noted that torsional joint strengths can also be calculated form the previous information given concerning the lateral face strength of dowels.

Table 5. Lateral edge- and face-holding strength of dowels in plywood and oriented strand board. Ultimate loads are listed over standard deviation in pounds. All loads are pounds per dowel.

	Rail Position -- Edge			Rail Position -- Flat		
	Rail Width - Inches			Rail Width - Inches		
	3	3	4	2	3	4
	Dowels per Joint			Dowels per Joint		
Material	2	2	2	1	2	2
Identifier	Dowel Spacing -Inches			Dowel Spacing -Inches		
	1	1.5	2	0	1	2
OSB-1	350		532	149		163
	66		47	17		8
OSB-2	318		376	134		127
	38		44	14		7
OSB-3		400	414	373	365	
		20	37	46	24	
OSB-4		407	446	331	240	
		37	51	35	24	
OSB-5		374	423	306	244	
		46	9	25	18	
SPLY-1	450		471	238		230
	25		30	18		24
SPLY-2	479		526	269		225
	28		29	36		29
SPLY-3	448		456	219		230
	37		56	22		36
HPLY-1	633		697	255		220
	24		36	24		30
HPLY-2	697		713	563		362
	31		87	55		27
WSPLY-3/4	554		656	216		240
	74		29	10		21

To illustrate the torsional design of dowel joints in upholstered furniture frames, consider the design of the frame shown in Figure 11 to meet the GSA requirements for sidethrust load on arms. As shown in Table 1, this test requires that the arm and stump be able to resist a sidethrust force applied in the outward direction at the most forward portion of the arm and side rail to stump and back post joint shown in Figure 11. Acceptance levels for light, medium, and heavy duty institutional service are 75, 150, and 200 pounds, respectively. Because this type of construction is commonly used in furniture intended for the home, let us begin the design process at the 75 pound load level.

In this construction, the sidethrust force applied to the arm is transmitted to the side rail as a torsional force that acts around its longitudinal axis. The magnitude of the torsional force is equal to 75 lb. x 12.5 in, or, 900 in-lb. By proportions, the amount of this force carried by the side rail to front rail joint is equal to 900 x 25/30, or, 750 in-lb, whereas the amount carried by the side rail to back post joint is equal to 900 x 5/30, or, 150 in-lb.

Referring to Table 6, it can be seen that 4-inch wide rails with 2-inch dowel spacings have torsional strengths ranging from about 500 to 700 in-lb. These values may be used to estimate the strengths of rails of other widths provide a 1-inch dowel to edge distance is maintained, i.e., the

Table 6. Torsional strength per joint , 2 multi-groove dowels, symmetrically spaced 1" from edge of rails, i.e., all rails 2" wider than dowel spacing.

Material	Rail Position	Rail Width (inch)	Dowel Spacing (inch)	Torsional Force (inch-lbs.)	Std. Dev. (inch-lbs)	COV (%)	Maximum Shear Force per Dowel (Lbs)
SPLY-1	flat	4	2	608	133	22	334
SPLY-2	flat	4	2	616	17	3	339
SPLY-3	flat	4	2	530	25	5	292
HPLY-1	flat	4	2	718	131	18	395
WSPLY	flat	4	2	480	30		264
		6	4	832	138		250
		8	6	1022	60		222
WSPLY	edge	4	2	561	26		281
		6	4	1004	79		251
		8	6	1570	93		262
OSB-1	flat	4	2	518	146	28	285
OSB-2	flat	4	2	406	64	16	223
OSB-4	edge	4	2	477	38	8	239
OSB-5	edge	4	2	516	57	11	258

strength of the new rail will be in proportion to the ratio of the dowel spacings for the two rails. In the case of a 3-inch wide side rail with a 1-inch dowel to edge distance, the spacing between dowels would be 1 inch. The torsional strength of the side rail to front rail joint, therefore, would be expected to be 1/2 as great as that of a 4-inch wide rail. Applying this result to the values listed above, the estimated torsional strength of the side rail would be 250 to 350 in-lb. In addition, if the design load is doubled to take cyclic loading into account, the joints clearly cannot withstand the load. This particular design problem relates primarily to the inherent strength of the design. Whether constructed of solid wood or plywood, it is difficult to meet GSA acceptance levels with this type of arm construction. Hence, it is necessary to reinforce the side rail to stump joint with a solid wood corner block. Ideally, this block should be glued and screwed in place, Figure 12. In addition, the screws should pass through the plywood and into the corner block rather than vice versa. This practice should be followed whenever possible with plywood or other composite construction. In short, mechanical fasteners should be used in such a way that they tend to pull compress the laminates of composite parts together rather than pull them apart. The torsional forces exerted on the rail, particularly by the back leg which is attached solely to the side rail, must also be considered in the design of the side rail to front and back rail joints. GSA specifications require the legs to resist total sidethrust forces of 200, 250, and 350 pounds, respectively, for light, medium, and heavy duty acceptance levels. Assuming that half of the load is carried by the front and half by the back leg, the light duty acceptance level would require that the back leg resist a sidethrust force of 100 pounds, as shown in Figure 13.

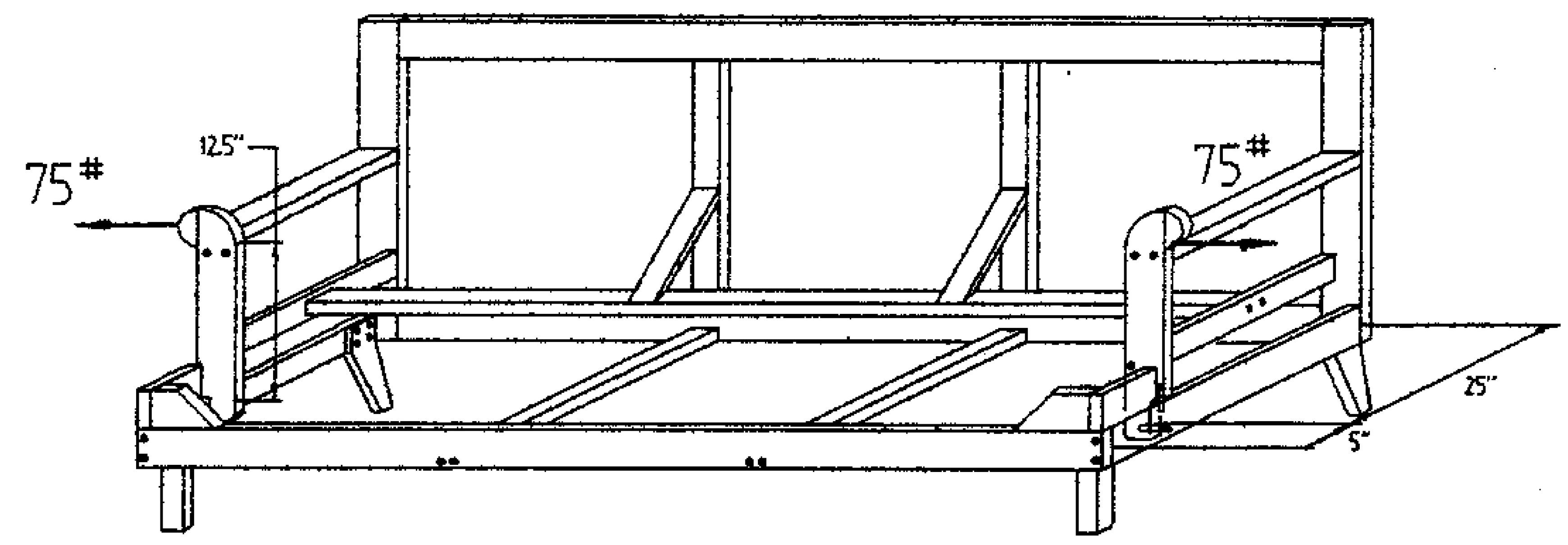

Figure 11. Design of the side rail to front rail and back rail joints to resist torsion.

Assuming that the vertical distance from the floor to the longitudinal axis of the side rail is 6 inches, then the torsional force acting on the rail is 100 x 6 = 600 in-lb. Since the leg is located very near the rear end of the rail, it must be assumed that the rail to back post joint would carry essentially all of the torsional force of 600 in-lb. Referring to Table 6, it is seen that even a 4-inch wide rail might barely carry the load. Furthermore, if the load is doubled in order to account for cyclic loading, the torsional force acting on the rail increases to 1200 in-lb so that clearly, the joint would be unable to carry the load. Thus, it is necessary to reinforce the joint as described in the previous example.

Design of the side rail to front rail is of similar concern. In this case, however, the leg can be rigidly joined to the front rail so that essentially no forces are transferred to the side rail. A leg of this type should be securely joined to both the front rail and the side rail, however, so that the front rail is able to resist sidethrust forces applied to the leg whereas the side rail is able to resist front to back forces.

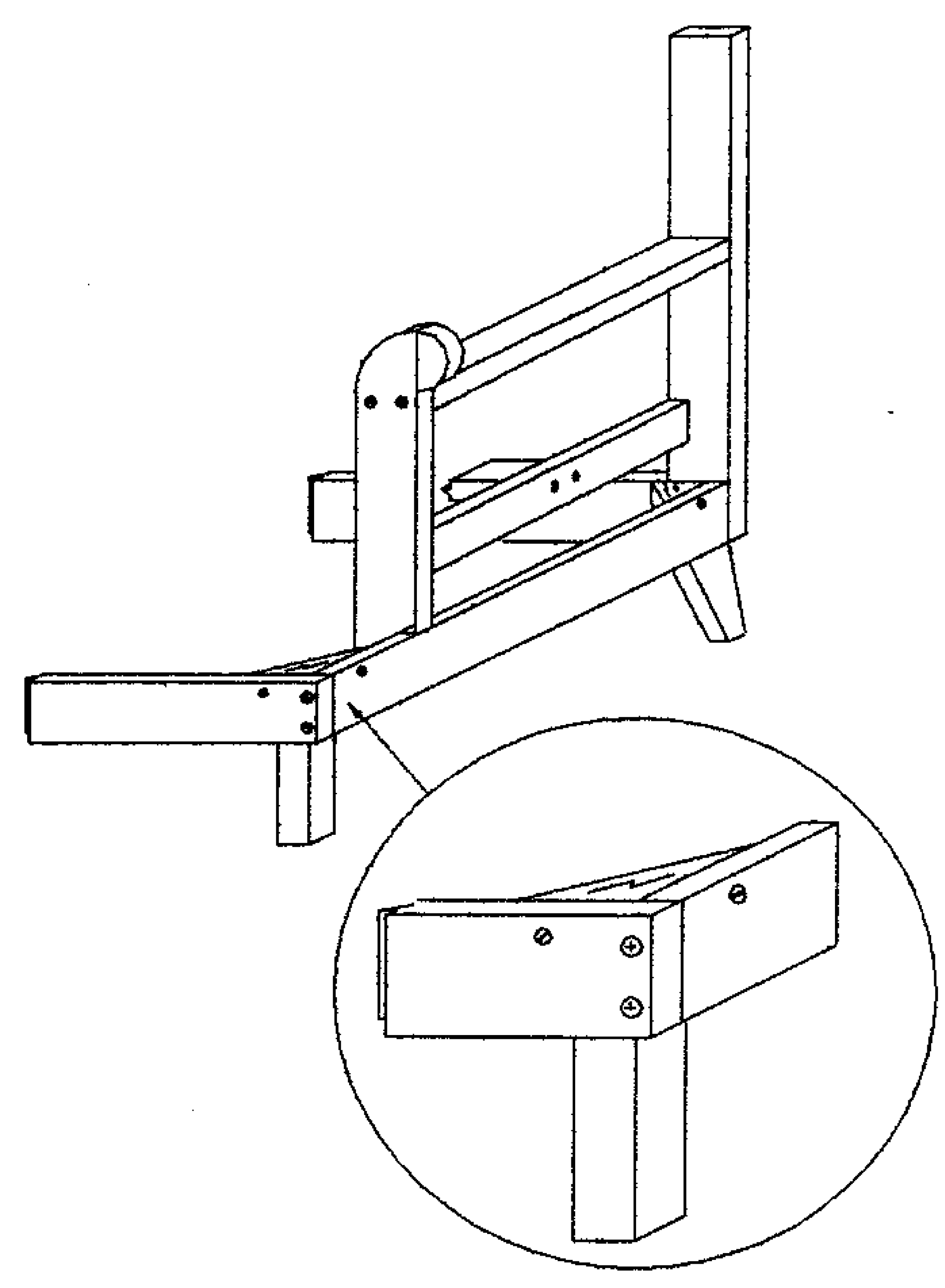

Figure 12. Reinforcement of the side rail to front rail joint with a solid wood corner block.

Finally, it should also be pointed out that a rather narrow side rail was used for illustrative purposes. A practical design might require a wider rail.

Screws

Withdrawal Strength

Screws are widely used in furniture frame construction, primarily to reinforce other constructions or to attach parts such as glue blocks. Screws have some advantage over adhesive joints in that the strength of the joint is not dependent on the amount of adhesive used. On the negative side, there is no simple method of determining whether over-size pilot holes have been used that greatly weaken holding strength or whether the screws have been "stripped" when they were inserted. It is important, therefore, that effective quality control practices be followed.

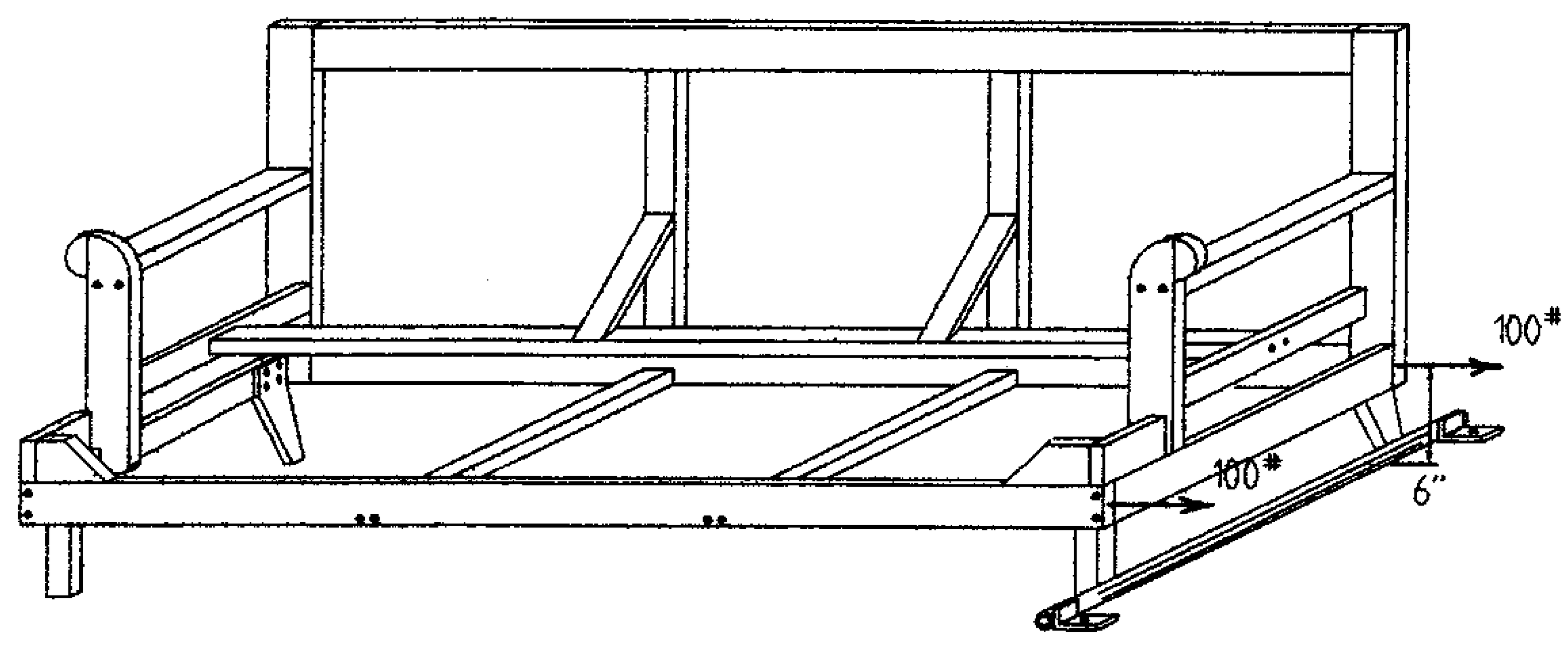

Figure 13. Frame subjected to GSA side load test on legs.

Furthermore, although numerous types of screws are available, research indicates that holding strengths among screws of different configurations may not differ greatly. Hence, it is worthwhile to conduct test both to determine which screws offer the best cost/performance ratios and also to find those screws best suited for production purposes.

The diameter of various screw sizes along with other geometric data are given in Table 7. Recommended pilot hole sizes are also included. These values should be used as first estimates that should be adjusted in keeping with the specific characteristics of a given board. In the case of edge withdrawal, a pilot hole size often must be used which is sufficiently large to prevent edge splitting or delamination of the boards.

Expressions that may be used to estimate both the face and edge holding strengths of screws in plywood and oriented strand board are given in Table 8. Average test values for face and edge withdrawal in several plywood and oriented strand boards are given in Tables 9 and 10.

Screws are most often used to reinforce constructions or add parts to frames rather than as primary connectors although they may also be used in any non-blind connection. They are of particular value for attaching parts such as corner blocks to the main frame.

A typical corner block reinforcement is shown in Figure 14. It should be noted that the screws were driven through the rails into the corner block which is the preferred method of construction since it holds the laminates together. From a production point of view, however, this construction usually requires that matching holes be pre-drilled both in the rails and the corner block. The benefit is that it produces a very robust construction.

Table 7. Outside diameter, root diameter, and other related geometric data for various screw sizes along with suggested pilot hole diameters.

				Pilot Hole Diameters			
	Screw	Root	Screw	Face		Edge	
Screw	Diameter	Diameter	Diameter	Plywood	OSB	Plywood	OSB
Gage	(inch)	(inch)	(mm)	(inch)	(inch)	(inch)	(inch)
6	0.138	.102	3.5	1/16	6/64	1/16	1/16
8	0.164	.119	4.2	5/64	7/64	6/64	6/64
10	0.190	.138	4.8	5/64	7/64	6/64	6/64
12	0.216	.161	5.5	7/64	7/64	8/64	8/64
14	0.242	.178	6.1	8/64	8/64	8/64	8/64

Another common use of screws is shown in Figure 15 where screws are used to attach the center rail braces to the center rail and the interior uprights. Although the axial forces exerted on these screws are relatively light, they frequently loosen in service because they are subjected to bending as well as axial forces. The principal problem is that the entire construction is actually quite flexible in many constructions, particularly those in which the top rail is turned on edge. As the users lean backward in the sofa, the top rail may deflect a significant amount. This action causes the center rail to be pulled upward and backward with an accompanying change in the angle between the brace and the interior upright and the center rail. As a result, the screws not only pull loose but may also fracture owing to fatigue in bending. An effective method of reinforcing these joints and producing a more robust construction is to reinforce the brace to interior upright joint with a corner block as shown in Figure 16.

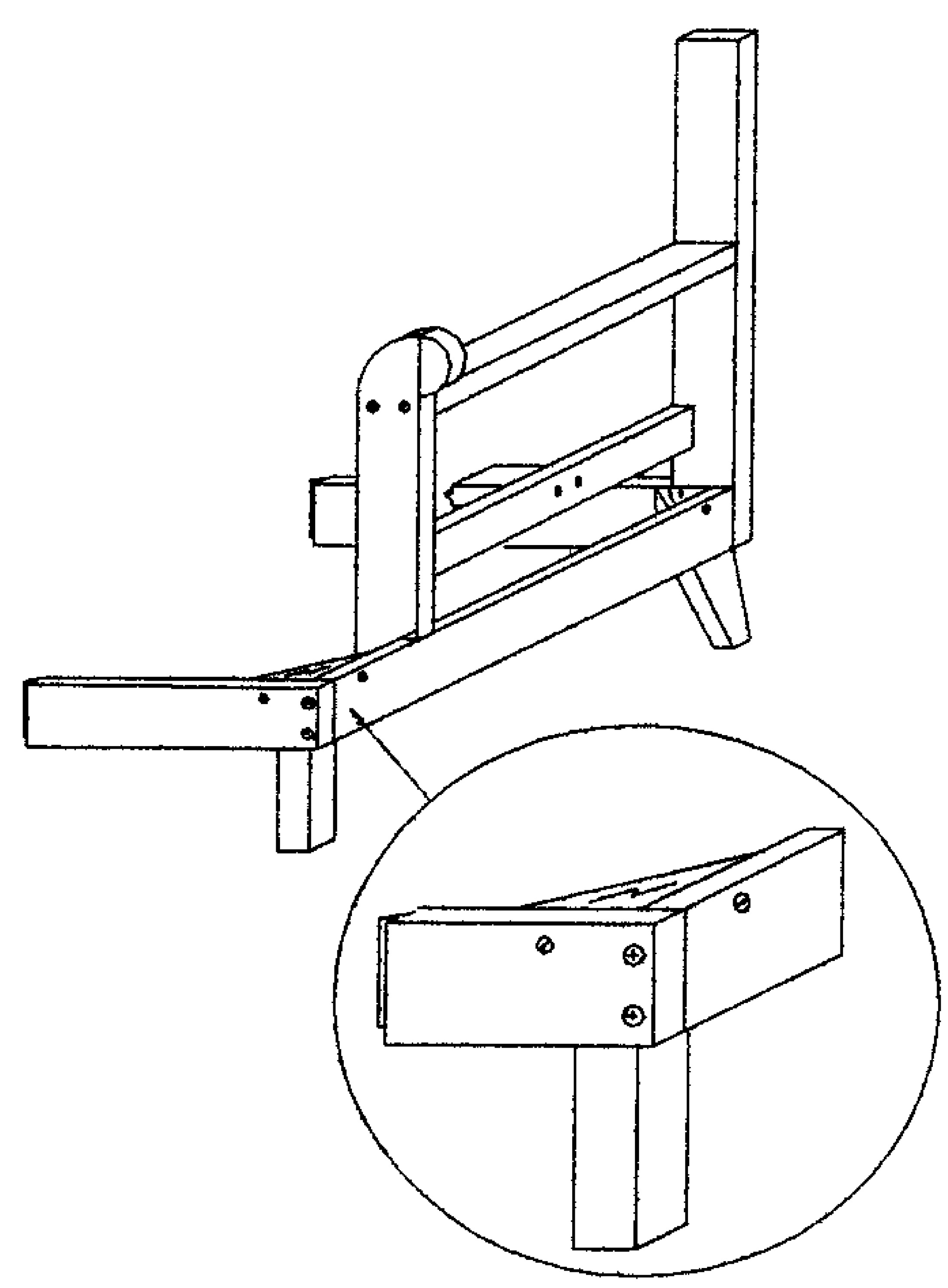

Figure 14. Reinforcement of side rail to front rail connection with solid wood corner block and screws. Note that screws are driven through the rails into the corner block.

A closely related application is the connection of the center rail to side slat with screws as shown in Figure 16. Number 10 screws, at least 1-1/2 inches long, are used in this application. Two screws are shown in Figure 16, but a single screw is often used in practice, particularly when a mortise is cut into the side of the slat to receive the end of the rail.

Screws are also used to attach stretchers to front and back rails as shown in Figure 17 and also to attach the corner blocks used to reinforce these joints. Number 10 screws, from 1-1/2 to 2 inches long are used in these constructions. The conventional method of fastening the corner block is shown in the left hand side of Figure 17.

Table 8. Expressions for estimating the holding strength of screws in plywood and oriented strand board

Material	Predictive Expression	Correlation Coefficient	Under-Predict %	Over-Predict %	Std. Dev. of Diff. %
	Face Withdrawal				
Plywood	$y=8.7D^{0.5}(L-D)W^{1.5}$	0.776	79	42	24
Oriented Strand Board	$y=0.87D^{0.5}(L-2D/3)W^{1.5}$	0.654	38	36	16
	Edge Withdrawal				
Plywood	$y=6.8D^{0.5}(L-D)W^{1.5}$	0.603	108	69	27
Oriented Strand Board	$y=0.66D^{0.5}W^{2}$	0.571	45	39	20
	[1] $y=0.76D^{0.5}(1-2D/3)W^{2}$	0.563	51	44	20
	[1]This expression takes tip effect into account				

A more robust, though more difficult, method of fastening corner blocks is shown in the right hand side. These constructions are very important in furniture that uses sinusoidal type springs since the glue blocks or corner braces must resist very substantial loads. If, as discussed in a previous example, 15 spring loads of 100 pounds each are applied to the top of the front rail, then the corner block/stretcher construction must resist half the loads applied to the rail on either side of it, i.e., 250 pounds from the rail section to the left and 250 pounds from the section to the right, or, 500 pounds total.

Screws may also be used as the principal connectors as shown in Figure 18. The forces acting on the screws may be determined by means of an analysis of a line drawing of the side frame as shown in Figure 18. The GSA test for upholstered furniture calls for the application of 3 front to back loads to the top rail. Acceptance levels range from 100 pounds each for light duty to 150 pounds each for heavy duty. Assuming this frame is to be designed to meet the light duty institutional acceptance level, the back system would be subjected to total front to back forces of 300 pounds. Each back post in turn would be subjected to half this load, or 150 pounds. Summing moments about the side rail to back post joint as shown in Figure 18, it is seen that the axial force acting along the

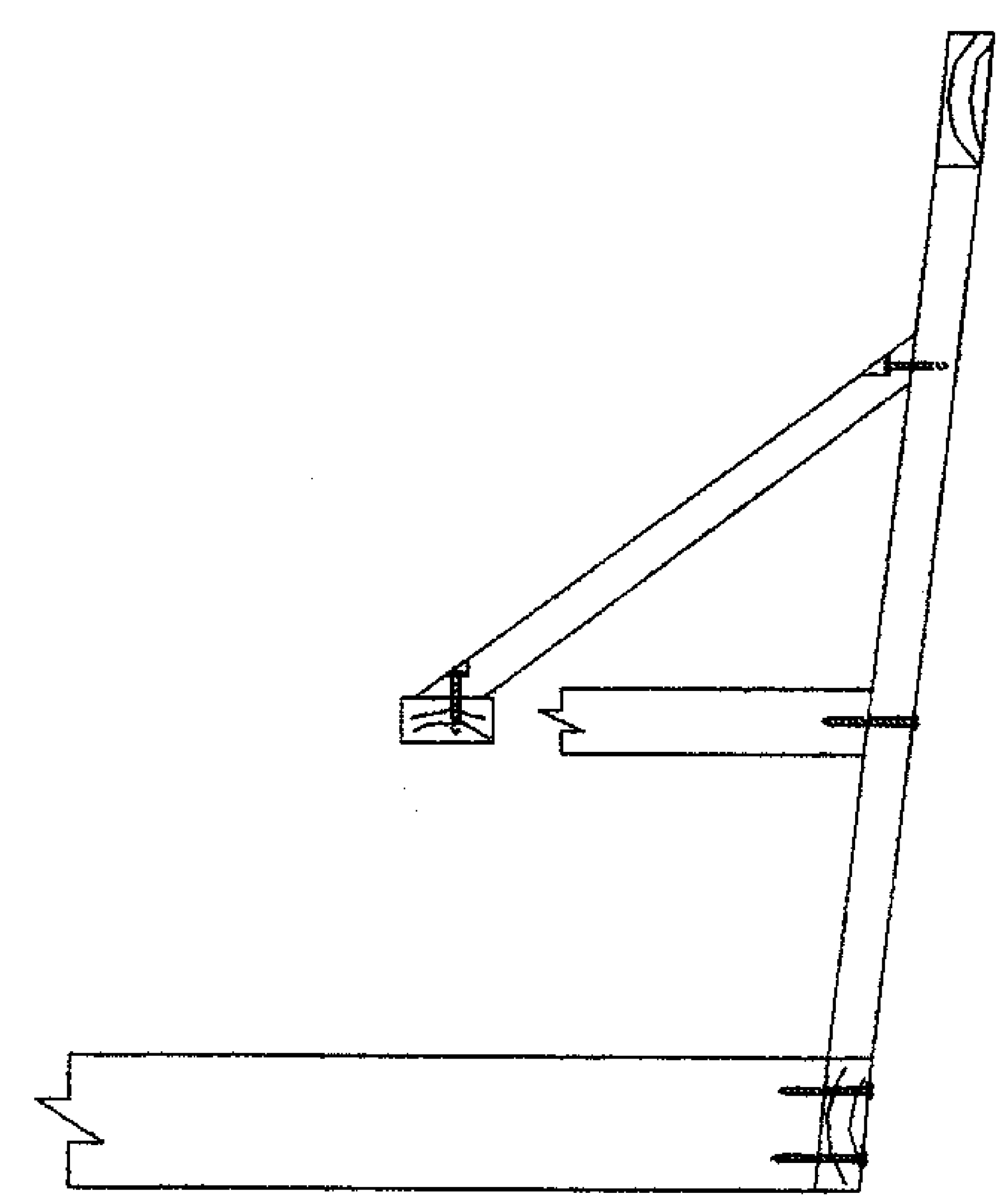

Figure 15. Attachment of center rail braces to center rail and interior uprights with screws.

longitudinal axis of the arm amounts to 243 pounds. As shown in Table 10, the withdrawal strength of a number 10 screw embedded 1 inch in the end of the arm would be expected to be about 519 pounds. Thus, one screw would have sufficient strength to carry the load. If the load is doubled to account for cyclic loading, however, the axial force should be doubled for design purposes. Again, a single screw has almost enough strength to satisfy the design requirements. Good design practice calls for the use of 2 screws however, both to insure reliability and to increase the robustness of the design.

Table 9. Face withdrawal strength of screws in plywood and oriented strand board. Board thickness was 0.75 inches; density was 36 pcf.

Material	Screw Size	Tip	Withdrawal Force - lbs
Plywood	6	not exposed	427
	8	"	446
	10	"	459
	12	"	466
	14	"	470
	6	exposed	524
	8	"	571
	10	"	614
	12	"	655
	14	"	693
OSB		not exposed	
	6	"	276
	8	"	293
	10	"	306
	12	"	318
	14	"	327
	6	exposed	314
	8	"	342
	10	"	369
	12	"	393
	14	"	416

A corner brace is used between the stump and the side rail in this design in order to provide resistance to front to back loads acting on the side frame. Use of this brace - though a desirable practice - causes large axial forces to act on the screws used to connect the stump to the side rail. Summing moments about the brace to stump joint, it is seen that the axial force acting on the screws used to attach the stump to the side rail amounts to 508 pounds. If we utilize the appropriate expression listed in Table 8 for estimating edge withdrawal strength of screws in plywood, namely,

$$y = 6.8D^{0.5}(L - D)W^{1.5}$$

we find that a number 10 screw embedded 1 inch in the edge of a plywood part with a density of 36 pcf has an estimated withdrawal strength of

$$y = 6.8(0.190)^{0.5}(1 - .190)(36)^{1.5} = 519 \text{ lb.}$$

Thus, a single screw would have just enough strength to resist this force. If cyclic loading is taken into account, however, the load would be doubled so that the two screws would be needed to connect the stump to the end of the side rail in order to meet design requirements. Certainly, good design practice calls for

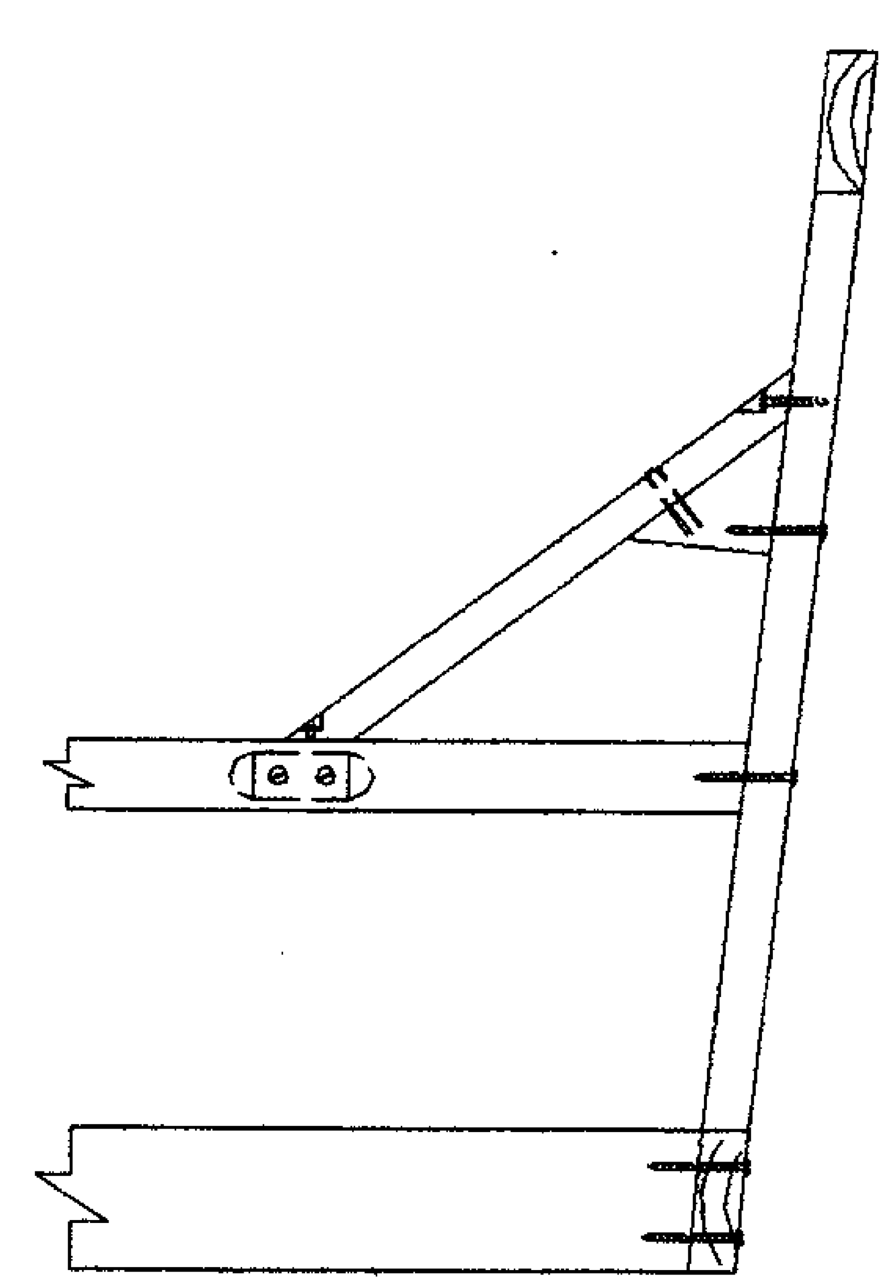

Figure 16. Drawing showing reinforcement of the center rail brace to interior upright connection.

the use of two screws, both to meet structural requirements and provide structural redundancy and also to locate and fix the part in place.

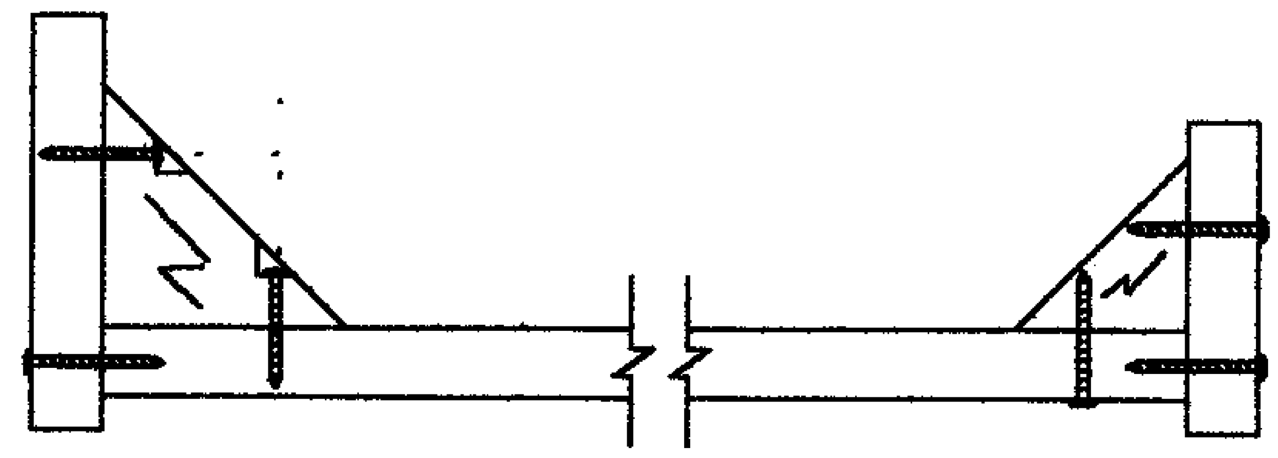

Figure 17. Diagram showing two methods of joining stretcher to rails with screws.

Through Bolt with Dowel Nuts

Through-bolts with dowel-nuts are commonly used in furniture construction, both as primary connectors and also to reinforce weaker joints. Through-bolt construction itself is not new. Bed bolts, which are one form of through-bolts, have been used for many years to attach bed rails to bed posts in order to allow transportation of bulky bed frames, particularly in pioneer days. Modern steel dowel-nut construction, Figure 19a, differs from earlier constructions in that the nut itself is a steel dowel pin turned crossways to the axis of the bolt, Figure 19b, rather than a conventional

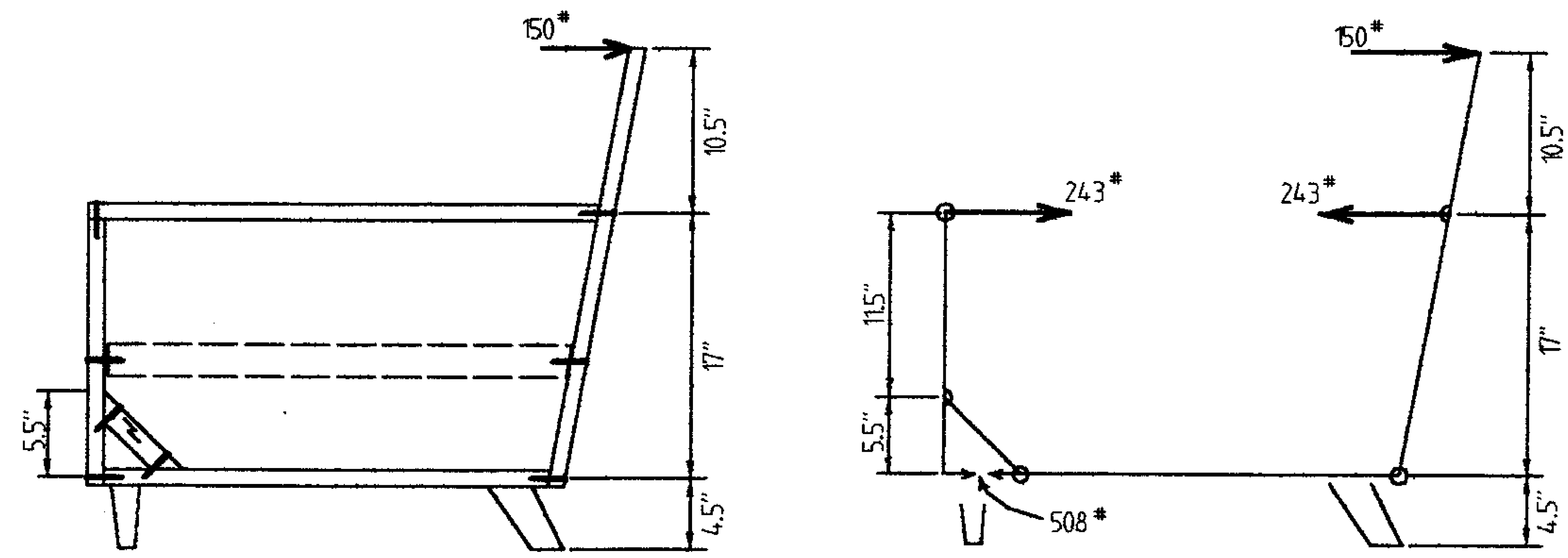

Figure 18. Design of sofa side frame constructed with screws as primary connectors (left); internal forces acting along longitudinal axes of arm and side rail (right)

square or hexagonal nut. Furthermore, the through-bolt screws into the side of the cross dowel rather than into the end.

Aside from their use in constructions which must be assembled and disassembled on site, through-bolt with dowel-nut construction is of particular interest because of its high strength and reliability (Eckelman, 1989; Eckelman and Senft, 1995). Through-bolts with dowel-nuts are often used in chair construction, for example, to reinforce the critical seat side rail to back post joints. They are also widely used in furniture that because of its bulkiness must be shipped in a partially disassembled condition such as tables where they are used to attach the ends of legs to steel mounting plates which, in turn, are attached to the underside of table tops (Eckelman, 1977). These fasteners also have significant potential value in upholstered furniture frame construction in similar situations where strength and reliability are essential. An obvious use is the attachment of an arm to a back post where reliability is essential. Other, though less obvious, uses abound where through-bolt construction could be used to form the base construction in key critical joints that obtain robust frame strength overall.

The bending strengths of a number of T-shaped joints constructed with dowel nuts are given in Table 11. In addition, the holding strengths of 3/8-inch diameter dowel nuts in the ends of rails are given in Table 12. Values are given for nuts placed 1, 1.5, and 2 inches from the end of the rail. The bending strengths of joints with configurations other than those covered in Table 1 may be estimated by means of the expression

Table 10. Edge withdrawal strength of screws in plywood and oriented strand board. Depth of embedment was 1 inch; density was 36 pcf. "Corrected" values computed are computed.

Material	Screw Size	Tip Effect	Withdrawal Force -lbs
Plywood	6	corrected	470
	8	"	497
	10	"	519
	12	"	535
	14	"	548
OSB	6	uncorrected	321
	8	"	350
	10	"	376
	12	"	401
	14	"	425
	6	corrected	332
	8	"	355
	10	"	375
	12	"	392
	14	"	406

$$F_4 = F_2(d_1 + d_2 - 0.25)$$

where F_2 refers to the holding strength of the dowel nut in the end of the rail, Table 12; d_1 refers to the spacing between the longitudinal axes of the through bolts, Figure 20; d_2 refers to the distance from the longitudinal axis of the lower through bolt to the edge of the rail; and 0.25 is a constant that locates the position of the compression force vector. When only one through bolt with dowel nut is used, the above expression reduces to the form

$$y = F_2(d_1 - 0.25)$$

where d_1 refers to the distance from the longitudinal axis of the through bolt to the edge of the rail. Often, a single through bolt is located along the centerline axis of the rail so that d_1 is often equal to half the width of the rail.

To illustrate the design of joints constructed with these fasteners, consider the front rail to stump joint shown in Figure 21a. Let us say that this joint is to be designed to resist sidethrust loads on arms. As can be seen in the figure, a 1 pound sidethrust applied to the arm causes a bending force of 1 lb x 10.5 in, or, 10.5 in-lb to act of the front rail to stump joint. Thus, if the rail were to satisfy the GSA requirement for heavy duty institutional furni-

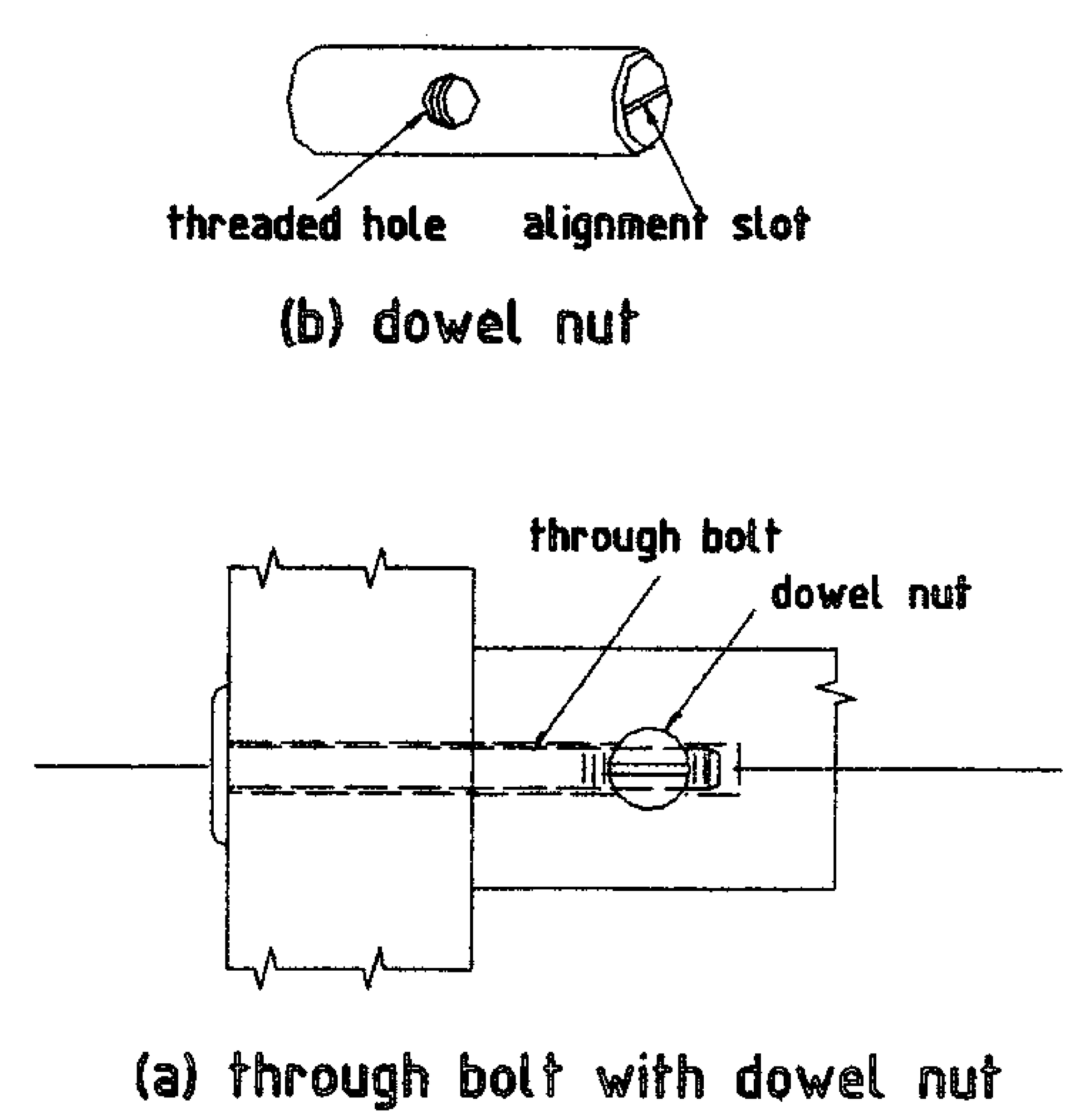

Figure 19. Through-bolt with dowel-nut construction.

ture, the joint would be required to resist a bending force of 200 lb x 10.5 in, or, 2100 in-lb. doubling this value to account for cyclic loading, gives a value of 4200 in-lb.

Let us say that the 4-inch deep front rail is constructed of hardwood plywood and that the edge placement distance of the dowel nut is 2 inches. Referring to Table 12, it is seen that the holding strength in the end of the rail is 1580 pounds. Substituting value this along with the appropriate geometric values into the expression given above for estimating the strength of through bolt with dowel nut constructions gives

$$F_4 = 1580(2+1-0.25) = 4350 \text{ in-lb.}$$

Dividing this value by the length of the moment arm, 10.5 in, it is seen that this joint could resist a sidethrust load on arms of 4350 in-lb/10.5 in, or, 414 lbs. Thus, this connection would be expected to satisfy the GSA requirement for heavy duty institutional furniture.

Next, consider the design of the side frame shown in Figure 21b. The side rail is connected to the back rail with two through bolts with dowel nuts and one dowel. In general, the strength of these fasteners is not additive. Normally, the dowel joint must fail before the through bolt begins to carry load. Let us assume for design purposes that the dowel in this joint is used as a locator only and determine the strength of the through bolts as though they alone carried load. Let us also assume that the arm is effective in reinforcing the back post so that the side rail to front post joint carries a substantial .part of the back load.

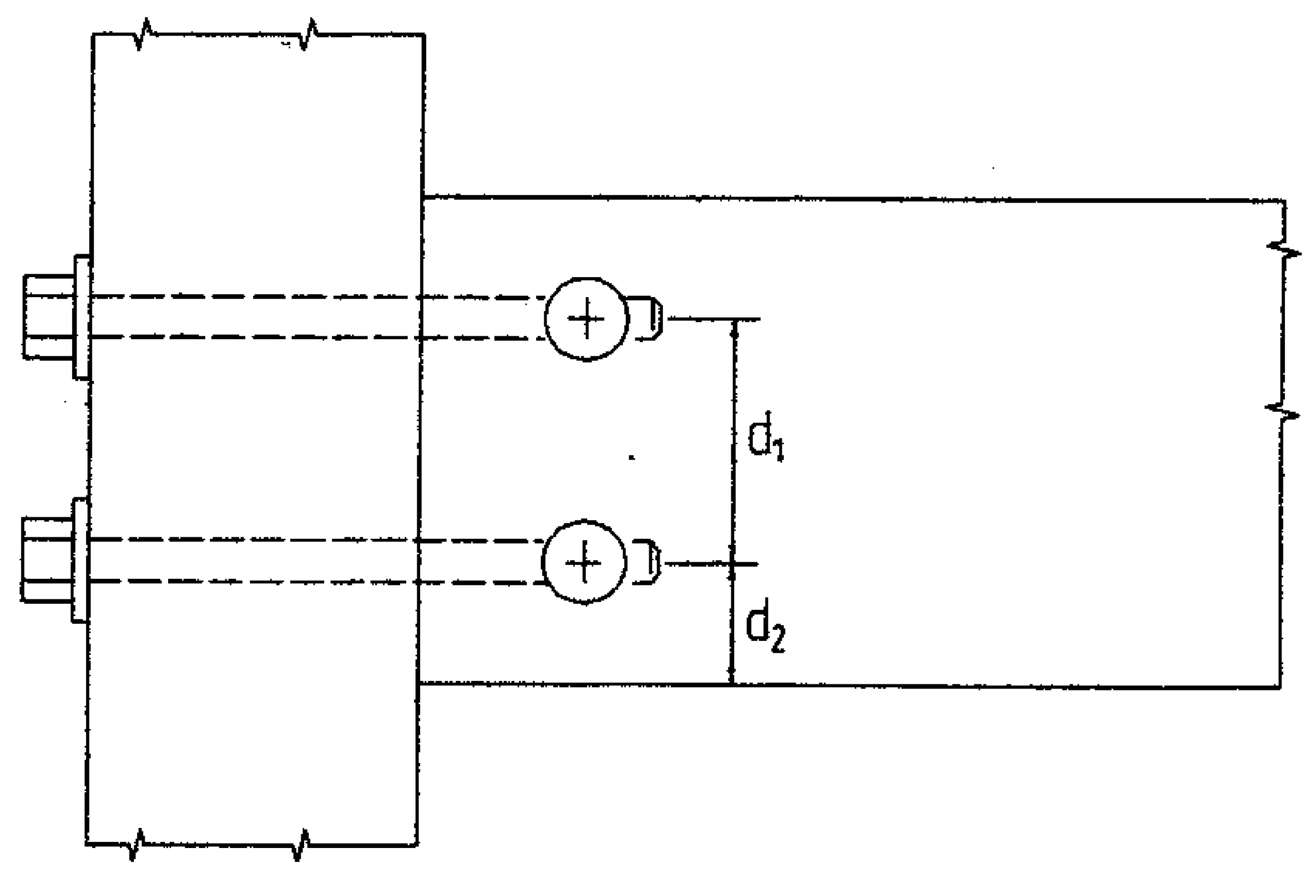

Figure 20. Moment-resisting through-bolt construction illustrating position of internal moment arm.

In general, the stiffness of the side rail to back post joint would be greater than that of the side rail to front post joint so that, strictly speaking, the back post joint would carry a disproportionate amount of the load. Through bolt with dowel nut joints are relatively flexible, however, so that it is reasonable to assume that both joints act together in resisting the back load. Thus, as a first estimate, it is reasonable to simply add the strengths of the two joints together in computing the strength of the side frame.

The bending strength of the side rail to back post joint may be computed as

$$F_4 = 1580(2+1-0.25) = 4350 \text{ in-lb.}$$

Likewise, the strength of the side rail to front post joint may be computed as

$$F_4 = 1580(2-0.25) = 2765 \text{ in-lb.}$$

Thus, the combined strength of the two joints is 4350 + 2765, or, 7115 in-lb.

Let us now determine how large a back load the side frame is able to resist. Ignoring the reinforcement provided by the arm, a 1 lb load applied as shown will produce a bending force of 1 lb. x 15.5 in + 1 lb x 14 in = 29.5 in-lb acting on the side rail to back post joint. Dividing the combined strength of the side frame, 7115 in-lb, by this moment arm gives a back strength of 7115 in-lb/29.5 in, or, 241 lbs.

GSA requirements for light duty institutional furniture requires that the top rail resist three front to back loads of 100 pounds each (or, three loads applied no higher than 16 inches above the seat). Half of the combined load of 300 pounds will be shared by each back post so that each back post must carry 150 pounds. Doubling this load to account for cyclic loading, gives 300 pounds. As can be seen, under cyclic loading conditions, this joint will not satisfy GSA requirements. To do so, it will be nec-

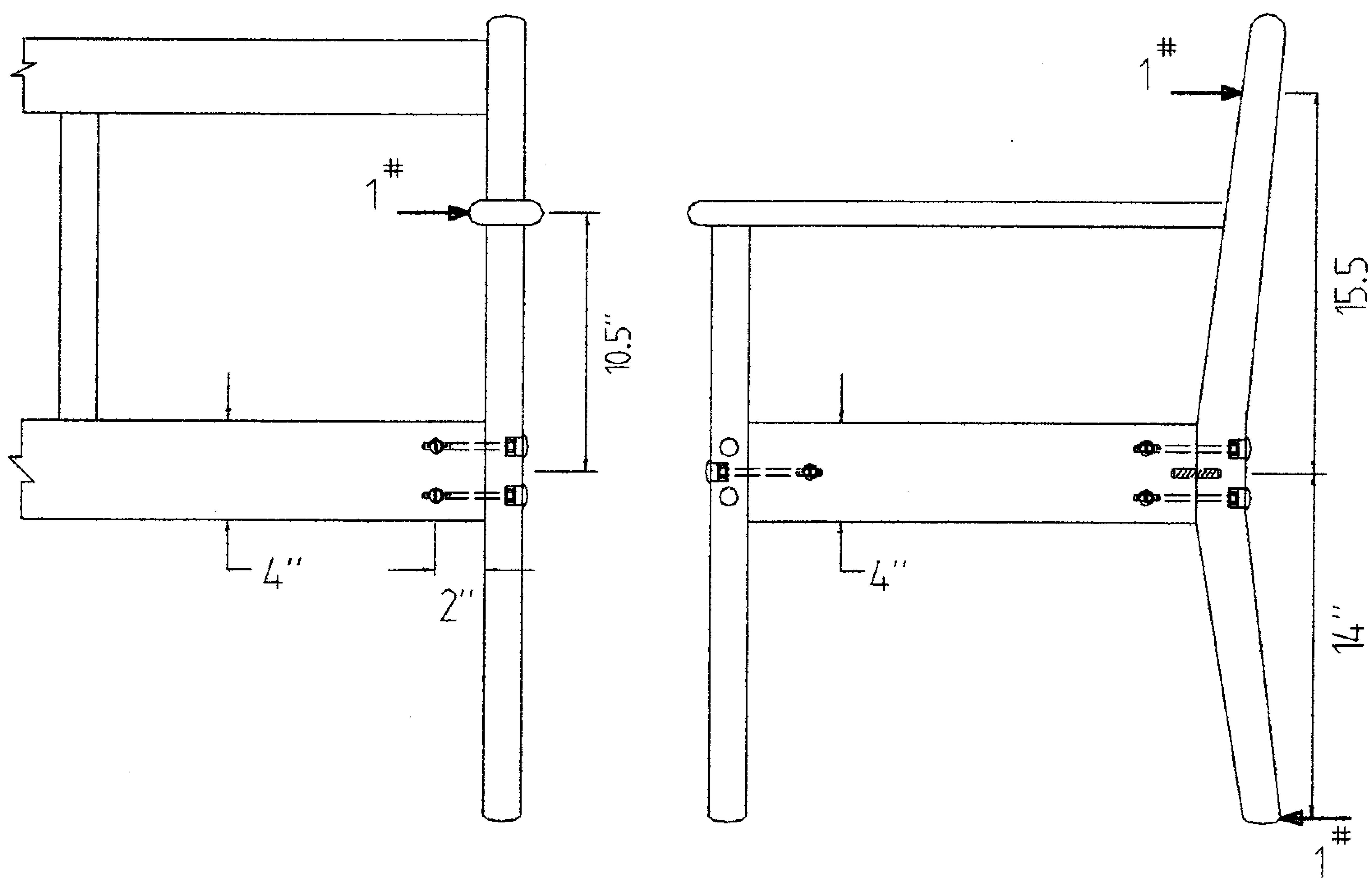

Figure 21. Diagram illustrating the use of through bolt with dowel nut construction in a front post to front rail joint (left) and a side rail to back post joint (right)

essary to redesign the side rail to front post joint. Referring to Figure 21b, it is seen that the through bolt may be offset to a position 2-3/4 inches above the lower edge of the side rail.

The strength of this connection may be estimated as

$$F_4 = 1580(2.75 - .25) = 3950 \text{ lb in.}$$

Thus, the combined strength of the two side frame joints amounts to 4350 + 3950, or, 8300 in-lb. The GSA loading calls for the joint to resist a loading of 300 lb x 29.5 in, or, 8850 in-lb. Thus, this construction nearly satisfies the GSA requirement Since the arm to stump joint and the arm to back post joint would also develop internal resisting bending force, this design may be satisfactory so that the design should likely be tested to determine its actual cyclic strength.

It is also worthwhile to determine if this construction is able to meet the GSA requirement for front to back loads on legs. The GSA specification requires that a back leg be able to withstand a front to back force applied to a side frame (with the back leg blocked) of 150, 200, and 300 pounds, respectively, to satisfy light, medium, and heavy duty institutional acceptance levels. A front to back load of 300 pounds would cause a bending force of 300 lb x 14 in, or 4200 lb in to act on the side frame. Doubling this value to account for cyclic loading gives a value of 8400 in-lb. Since it was shown above that the side frame is able to resist a loading of 8300 in-lb, it appears that the leg construction could satisfy the GSA acceptance levels for heavy duty institutional service.

Table 11. Bending strength of moment resisting through-bolt with dowel-nut joints.

		Rail Width - Inches		
		2	4	6
		No. of Nuts		
Material		1	2	2
Code	Statistic	Bending Force In-Lb		
OSB-1	avg.	1075	2630	6200
	std dev	266	262	549
OSB-2	avg.	675	2375	4840
	std dev	126	299	726
OSB-3	avg.		6390	9175
	std dev		497	932
OSB-4	avg.		3943	8158
	std dev		402	1157
OSB-5	avg.		4631	7037
	std dev		385	1219
SPLY-1	avg.	805	2663	4738
	std dev	10	450	193
SPLY-2	avg.	1023	3523	6038
	std dev	78	207	862
SPLY-3	avg.	1038	3038	5375
	std dev	85	328	753
Hply	avg.	1150	4358	7840
	std dev	48	315	1203

Toothed Metal Connector Plates

One fastener used to a limited extent in upholstered furniture frame construction is the metal tooth connector plate. Typical applications of this connector include the back post to side seat rail joints in recliner type chairs and in the front rail to stump (or front post) joints sofa frames. Both of these joints are highly stressed and thus require high strength joints -- which metal tooth plates can provide. Metal tooth plates also provide a quality control advantage in that they can be inspected visually to determine if they have been properly installed. Those that have been properly installed, based on visual inspection alone, may be expected to develop full anticipated levels of strength.

The bending strengths of several plate geometry by rail geometry and material combinations are given in Table 13. As can be seen, very high strengths may be achieved with wider plates, particularly when they are used on both sides of the joint.

To illustrate the design of joints constructed with this connector, consider the design of the stump to front rail joint shown in Figure 22. GSA acceptance require that the arm be able to resist an outward sidethrust force of 200 pounds applied as shown in Figure 22. Assuming that a plate will be placed symmetrically along the centerline of the front rail, the moment arms amounts to 14 +2, or, 16 inches. Thus, the bending force applied to the joint is 200 lb x 16 in, or 3200 in-lb. Doubling this value to account for cyclic loading gives 6400 in-lb. Referring to Table 13, it can be seen that this requirement can be met by applying a 3-inch wide by 4.5-inch long plate to both sides of the rail. Alternatively, 2-inch wide plates would be expected to provide a little less than 6000 in-lb of resistance and would be satisfactory for GSA medium duty construction.

A back post to side rail construction commonly use in recliner chair construction is shown in Figure 23. Strength requirements for this type of furniture are also defined in the GSA test specification for upholstered furniture since these chairs must satisfy the same requirements as upholstered furniture frames. Because there is only one seat position, the back must carry only a single load of 75, 100, or 150 pounds corresponding to the light, medium, and heavy duty acceptance levels, respectively. Doubling these values to allow for cyclic loading yields values of 150, 200, and 300 pounds. Only half of a back load is transferred to the side frame, or, 150 pounds in the case of the heavy duty loading. This loading produces a bending force of 2400 in-lb on the side rail to back post joint. Referring to Table 13, it is seen that a 2-inch wide by 4.5 inch long plate applied on one side of the frame has a strength of about 4000 in-lb. Thus,

Table 12. Holding strength of dowel-nuts in relation to end distance.

		Edge Distance		
Material		1"	1.5"	2"
OSB-1	avg.	1320	1440	1270
	std dev	310	260	270
OSB-2	avg.	940	1030	910
	std dev	90	70	130
OSB-3	avg.	1540	1690	1700
	std dev	270	220	230
OSB-4	avg.	1420	1490	1490
	std dev	270	200	220
OSB-5	avg.	1300	1350	1550
	std dev	130	200	190
Totals	avg.	1305	1400	1385
	std dev	225	240	310
SPLY-1	avg.	890	1100	1360
	std dev	220	140	70
SPLY-2	avg.	1130	1160	1680
	std dev	140	160	50
SPLY-3	avg.	1040	1130	1240
	std dev	80	100	160
HPLY-1	avg.	1040	1480	1580
	std dev	120	40	150
Totals	avg.	1025	1270	1465
	std dev	85	175	200

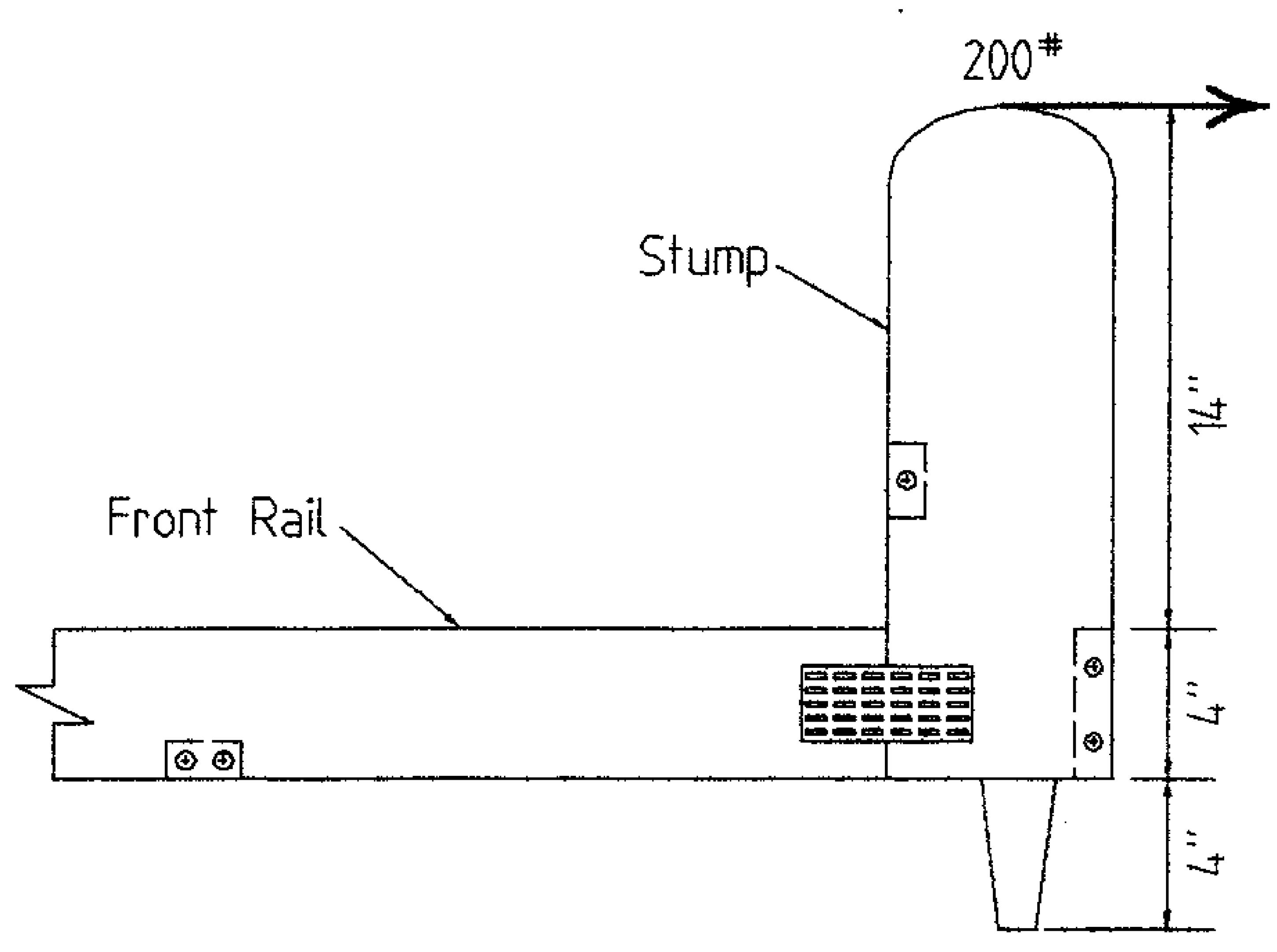

Figure 22. Design of front rail to stump joint using toothed metal connector plate.

this plate should provide a robust joint relative to the strength needed - which is an important consideration in the design of this critical joint.

Staple Withdrawal Strength

Staples are widely used in the construction of upholstered furniture. They are most commonly used for the attachment of fabric to the frame, but they are increasingly used for the construction of the frame itself. Taken individually, staples are generally acknowledged to have limited holding strength, There is a pervasive feeling, however, that the low holding strength of individual staples can be offset by their use in multiples. This idea holds in such applications as the attachment of plywood gussets to the sides of other members with staples -- the reinforcement of the side rail to back post joint with a plywood gusset in which the gusset is stapled to the sides of the rail and back post provides an excellent example. In this case, the staples are loaded in lateral shear rather than tension and sufficient staples may be used to develop the strength required.

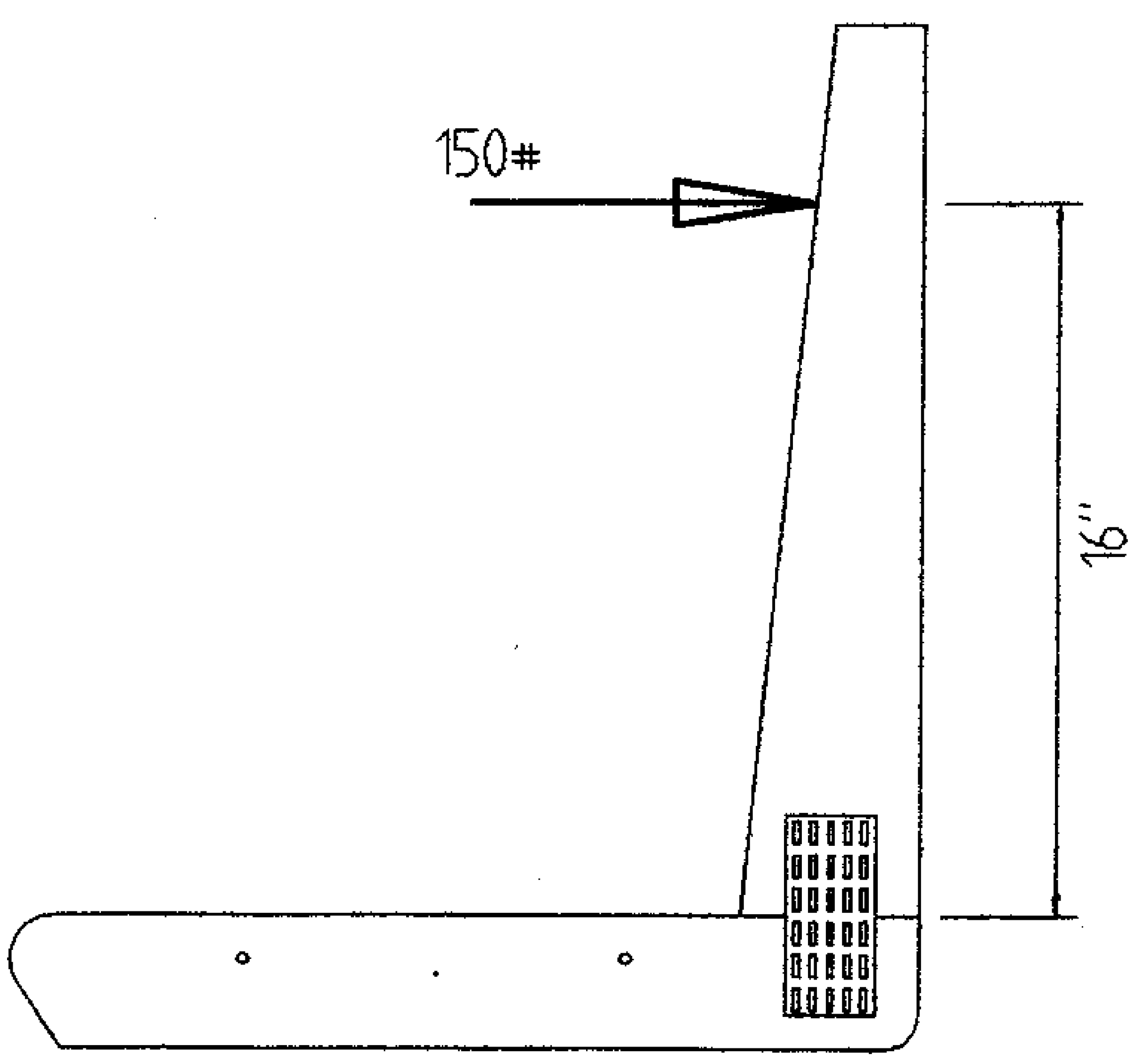

Figure 23. Design of back post to side railjoint in reclining chair using metal toothed connector plate.

It is also common practice to use staples to reinforce adhesive-based joints. The problem here is that the strengths of the mechanical fasteners used in the joints is usually not additive to the strength of the adhesive. An adhesive-based dowel joint, for example, is quite rigid, whereas a mechanical staple-based joint is flexible by comparison. As a result when staples are used to reinforce an adhesive-based dowel joint, the staples carry little load until the dowel construction fails, whereupon the staples carry all the load. Thus, the staples act as a "back-up" carrier, i.e., as a redundant construction (often a very important redundant construction), but they do not increase the initial strength of the joint.

The conclusion to be drawn is that the strength requirements of each joint in a sofa frame should be determined first and a rational procedure then followed to determine if a staple type joint can be used to provide the strength required. Alternatively, the frame and the joints must be designed so that staples can be used effectively as the primary fasteners in their construction. Sound furniture frames can be and have been constructed using staples as the sole load bearing fasteners when this practice has been followed.

Table 13. Bending strengths of moment-resiting toothed metal plate connector joints.

	Plate on One Face			Plate on Two Faces				
	Rail Width			Rail Width				
	3"	4"	6"	3"	4"	4"	6"	6"
	Plate Description -Inch			Plate Description - Inch				
Material	1.5 x 4.5	2x 4.5	(2)[1] - 1 x4.5	1.5 x 4.5	2 x 4.5	3 x 4.5	(2)[1] -1 x 4.5	(2/1)[2] - 1 x 4.5
Code	In-Lb.	In-Lb.	In-Lb.	In-Lb.	In-Lb.	In-Lb.	In-Lb.	In-Lb.
OSB-1	1860	3860	4687.5	2915	5365		8960	
	268	222	451	141	305		312	
OSB-2	1663	3213	4635	2820	4478		7778	
	98	282	775	130	67		1063	
OSB-3						10470		10640
						400		740
OSB-4						9250		7950
						960		310
OSB-5						8270		8540
						620		390
Avg. OSB	1762	3537	4662	2868	4922	9330	8369	9043
SPLY-1	1863	3710	5488	2810	5818		9148	
	162	248	912	232	467		396	
SPLY-2	1933	4628	5838	3293	6088		9585	
	211	717	146	204	295		469	
SPLY-3	1788	3973	5395	2933	5345		8750	
	139	246	483	272	379		487	
HPLY-	1963	3870	5400	3035	5328		8923	
	330	262	692	70	321		697	
Avg.PLY	1886	4045	5530	3018	5645		9102	
Avg. Comb.	1845	3876	5240	2968	5404	9330	8857	9043

(2)[1] Indicates that two 1-inch plates were used instead of a single plate

(2/1)[2] Indicates that two 1-inch plates were used instead of a single plate on one side of the joint and one 1-inch plate on the other side of the joint.

The withdrawal strengths of staples in the face and edge of various plywood and oriented strand boards are given in Table 14. Depths of embedment are also given for each case. These values are derived from tests in which specimens were constructed with both one and two staples. Hence, values are shown for both one and two staples.

As can be seen, the face withdrawal values tended to vary from 100 to 200 pounds per staple; edge withdrawal values were similar but more variable. The variability of the results indicate that considerable care should be used in designing joints in which staples will be loaded in withdrawal. Performance tests of frames in which staples, loaded in withdrawal, are used as the primary connectors are needed and should be used to validate the designs. Certainly, the location or spacing of staples and the number of staples to be used in these construction will need to be specified in order to ensure connections of uniform strength.

Staples can be quite useful in frame construction, however, when they are used to attach gussets to main frame members in order to reinforce joints. In such cases, the staples are loaded in lateral shear, and sufficient staples can be used to ensure adequate strength. Use of staples in this manner is shown in Figure 24 where a staple/glued gusset plate is used to reinforce the side rail to back post joint in a typical side frame. The strongest joints are obtained when staples and glue are both used. In such constructions, the staples are simply used to apply pressure to the plate until the glue dries. When adequate glue is used, these tend to be high strength joints. As a result, gussets are often small in size with the result that they may fail in rolling shear. Joints constructed without adhesive have lesser strength, but may still be effective in reinforcing a joint. In general, when adhesives are omitted, larger plates should be used and the number of staples increased. Gussets used without adhesive tend to fracture in bending, or, if too few staples, are used the staples tend to pull out of the substrate in a lateral direction.

The results of a brief study conducted to determine the bending strength of both staple and staple-glued gusset joints indicated that a 4-inch square staple glued 3/16-inch thick plate might be expected to have a bending strength of about 1900 in-lb. A comparable plate attached with a total six staples (3 each side) but no glue had a bending strength of only about 600 in-lb. In general, the results of the study clearly indicated the importance of using adhesive in a gussetted joint. In addition, the results indicated that the plates must be of sufficient thickness to develop desired levels of strength. The 3/16-inch thick by 4-inch wide plates used in the study, for example, could resist a moment of only about 2250 in-lb before fracturing. The thickness of the outer plies is especially important in thinner plates.

Use of staples to attach glued corner blocks to main frame members is also shown in Figure 24. Although this practice is widely followed, it should be clearly understood that the staples add little to the construction shown. Furthermore, when glue blocks are attached to the side of a plywood member, an outward load applied to the block may simply cause the member to delaminate. For that reason, the staples should be driven from the outside through the plywood rail and into the corner block since this method of construction tends to hold the plywood together and prevent delamination.

Another illustration of the use of gussets to reinforce joints is shown in Figure 25. Here, a gusset is used to reinforce the front rail to stump joint in order to resist sidethrust loads applied to the arm. In many constructions, this is the most practical reinforcement that can be used in order to obtain the strength needed to satisfy GSA acceptance levels in the sidethrust load test on arms. Again, use of adhesive provides the most reinforcement, but staples may also be used alone. In some constructions, it will be necessary to use a longer gusset than that shown so that the corner block may be attached to the side of the gusset. It is important in such cases that the corner block be attached by means of a fastener such as a screw that is driven through the front face of the stump into the glue block.

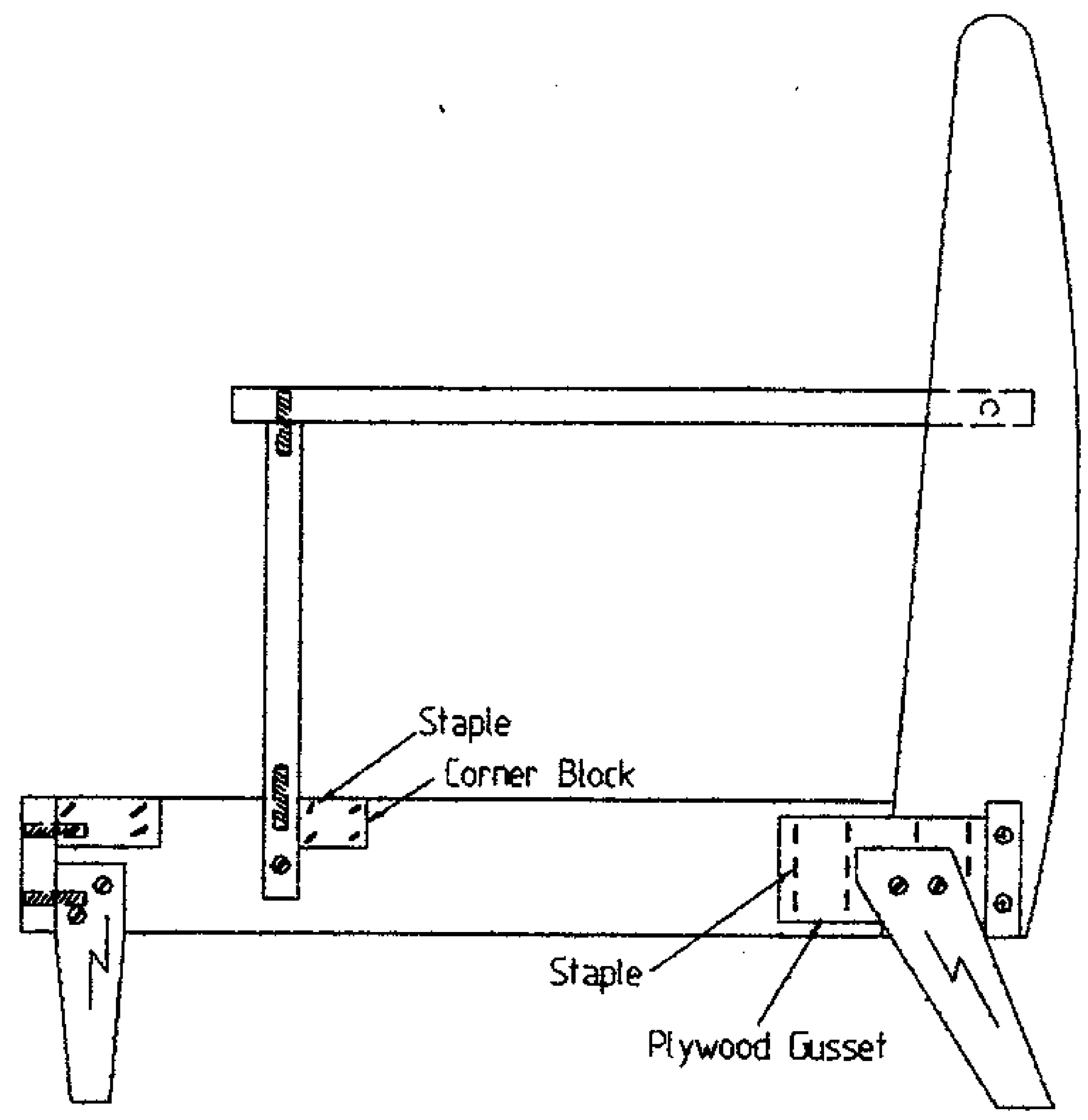

Figure 24. Reinforcement of side rail to back post joint with stapled gusset plate.

The use of CNC routers to cut furniture parts from plywood and OSB allows furniture parts to be easily "notched" so that in many cases traditional butt joints can be replaced with lap joints. The bottom rail to stump and back post joints of the side frame shown in Figure 26 provide an example of this type of joint. The side slat to stump and back post joints provide another example. The strength of these joints is not known; thus; frame designs based on this construction should be proven by test. Figure 26 also provides several other examples illustrating how staples are frequently used in frame construction.

A stapled gusset plate is used to reinforce the back rail to back post connection, for example. Staples are also used to attach corner blocks to the end of the stretchers, and the front and back rail, in turn, are stapled to the corner blocks. A one piece interior upright-center rail brace is shown attached to the back rail, to the top rail, and to the center rail with staples. This part provides an example of the construction simplifications made possible through the use of multi-function CNC-cut plywood parts.

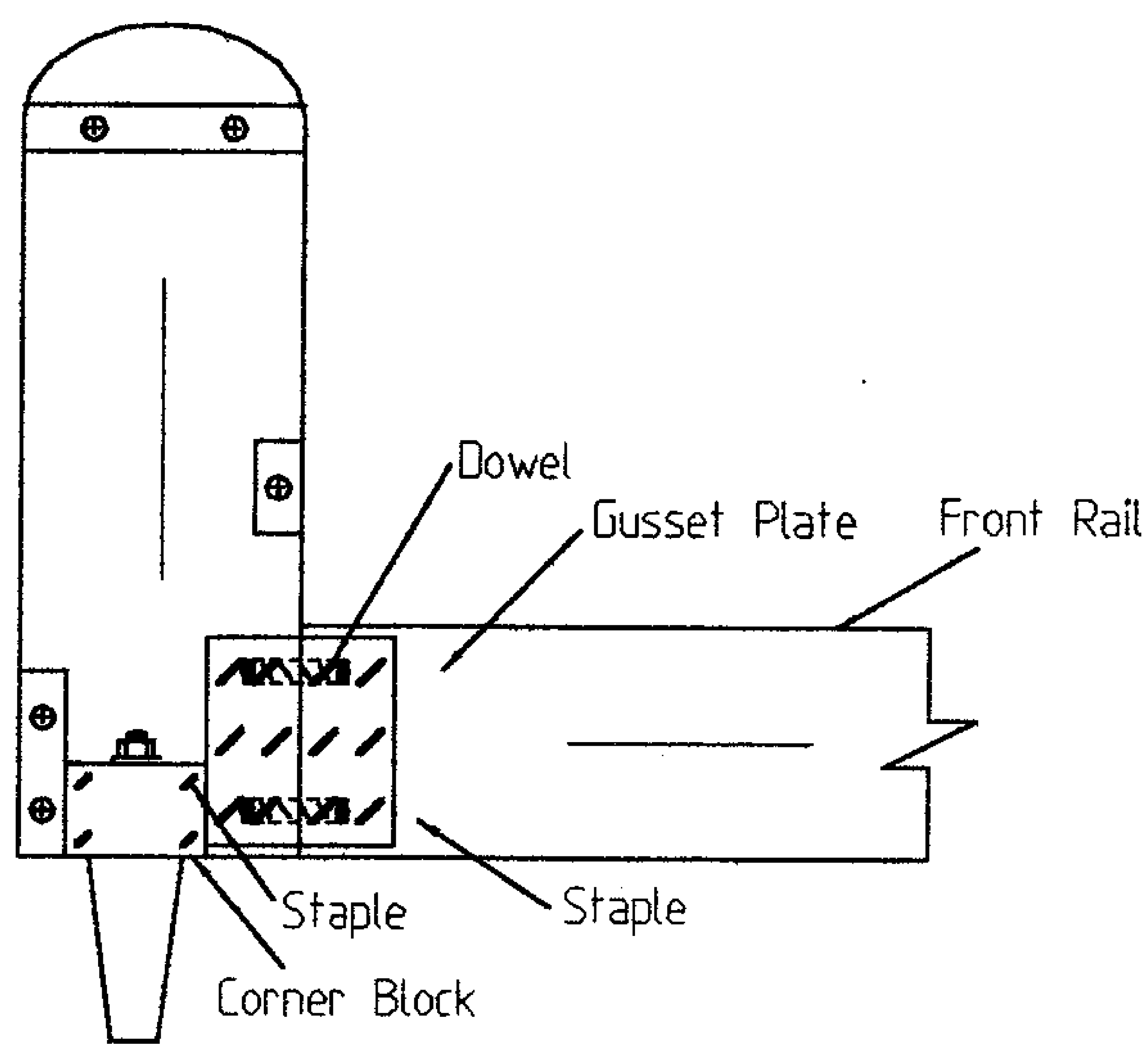

Figure 25. Use of plywood gusset to reinforce front rail to stump joint. Back side of construction is shown.

Other examples of commonly used staple construction are shown in Figure 27. Notched lap joint construction is again used to attach both the side rail and the side slat to the front post and the back post. In addition, the arm is attached to the top of the front post and to the front face of the back post with staples.

Good practice calls for the arm to back post joint to be reinforced with a corner block. Although not shown, staples could also be used to connect the stretchers and stretcher to rail corner blocks to the front and back rails. One important construction shown in the figure is the reinforcement of the top edge of the front rail with a ledger strip. This strip would be needed if the sofa were constructed with sinusoidal type springs because these springs exert very substantial front to back forces on the top edge of the rail. It should be firmly attached to the front rail with glue and staples, or with staples alone if sufficient staples are used. As shown in the drawing, this strip may also be used to reinforce the front rail to stump joint. If used for this pur-

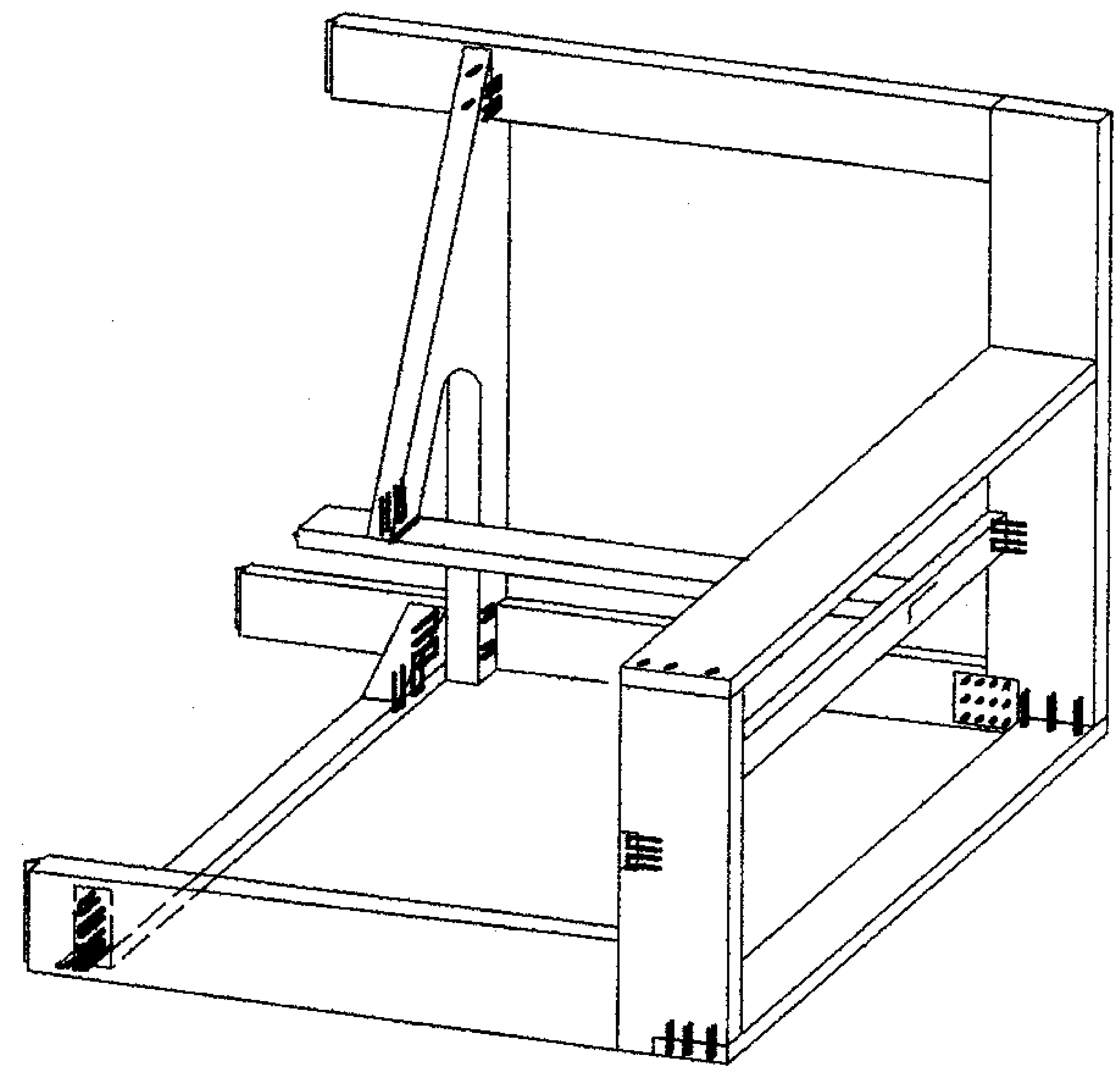

Figure 26. Diagram showing typical uses of staples in frame construction.

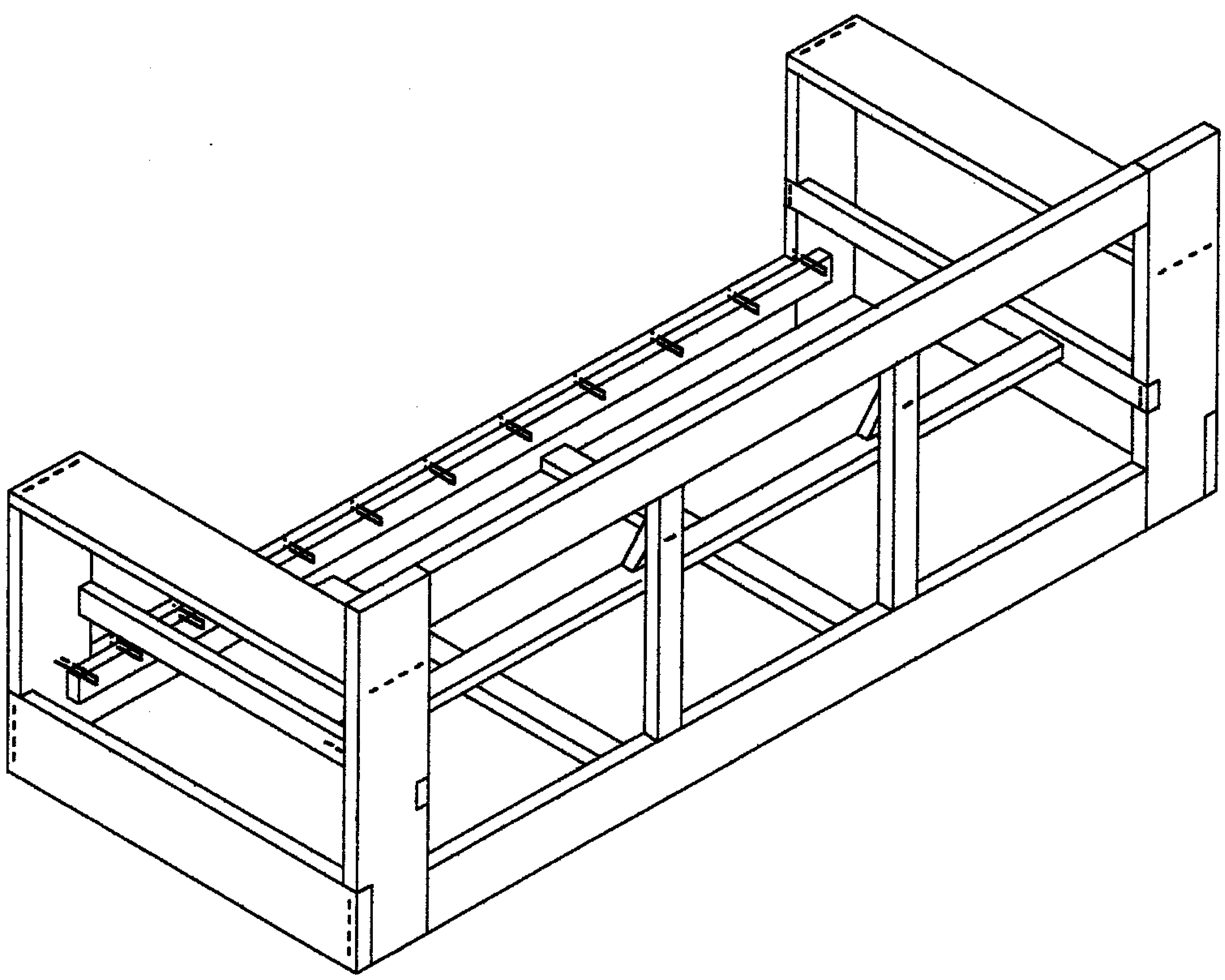

Figure 27. Diagram showing staples used to attach ledger strip to rear of the top edge of the front rail.

pose, the strip should be glued to the rail since the strip is too narrow to allow the required number of staples to be used. Again, it should be noted that the strengths of these joints cannot be calculated. Hence, the GSA tests should be used to determine the performance characteristics of these constructions and the fitness for use of the designs.

Table 14. Staple withdrawal strength from the face and edge of plywood and oriented strand board

		Withdrawal from Edge				Withdrawal from Face			
		No. of Staples				No. of Staples			
		1		2		1		2	
		DOP[1]	Force	DOP	Force	DOP	Force	DOP	Force
		(inch)	(lbs.)	(inch)	(lbs.)	(inch)	(lbs.)	(inch)	(lbs.)
OSB-1	avg.	.75	90	.75	195	.75	100	.75	255
	std dev		25		35		20		35
OSB-2	avg.	.75	25	.75	120	.75	105	.75	230
	std dev		5		25		30		50
OSB-3	avg.	.58	95			.56	180	.58	445
	std dev		20				40		45
OSB-4	avg.	1.0	100	1.0	145	.57	170	.57	280
	std dev		34		34		29		42
OSB-5	avg.	1.0	110	1.05	150	.70	200	.71	390
	std dev		26		31		40		59
SPLY-1	avg.	.78	125	.78	175	.78	145	.78	265
	std dev		31		31		47		51
SPLY-2	avg.	.78	40	.78	155	.78	160	.78	305
	std dev		15		15		35		55
SPLY-3	avg.	.78	165	.78	205	.78	230	.78	315
	std dev		50		95		35		40
HPLY-1	avg.	.75	220	.75	365	.75	185	.75	525
	std dev		30		35		45		45

[1]DOP refers to depth of penetration of tip.

Biscuit Joints

Biscuit, or plate joints are often used in the construction of corner joints in cases. Occasionally, they are also used in more demanding applications such as the side rail to back post joints in chairs. Presumably, plate joints could also be used in upholstered furniture frames constructed of plywood and oriented strand board. Potential applications include front rail to stump joints, side rail to back post joints, arm to stump joints, and top rail to back post joints, among others. Of these, the joints of most interest would be moment resisting joints such as the front rail to stump joint. Widespread experience with the use of these joints in upholstered furniture frame construction is lacking, however. Hence, constructions that rely on these fasteners for their structural integrity should be validated through performance tests until reliable methods of estimating the joint strength of these connectors have been developed.

The bending strengths of T-joints constructed with one and two biscuits per joint are given in Table 15. These joints are similar to the constructions that would be used in front rail to stump and similar joints. As can be seen, the strength of these joints are less than comparable joints constructed with dowels. Again, this comparison indicates that until greater experience is obtained with these connectors, they should be used with care, and the resulting constructions should be evaluated by means of performance tests to determine if the frames satisfy required levels of strength.

Table 15. Bending strength of moment resisting joints constructed with biscuits. Joints with 4-inch wide rails were constructed with one biscuit, whereas the joints with 6-inch wide rails were constructed with 2 biscuits.

		Rail Width	
		4-inch	6-inch
		No. of Wafers	
		1	2
Material		Bending Force	
Code No.	Statistic.	In-Lb.	In-Lb.
OSB-1	avg.	885	3143
	std dev	150	715
OSB-2	avg.	1005	2723
	std dev	91	292
SPLY-1	avg.	768	2285
	std dev	34	407
SPLY-2	avg.	803	2848
	std dev	225	630
SPLY-3	avg.	733	1920
	std dev	151	321
HPLY	avg.	883	2458
	std dev	173	329

Other Fasteners

There are many other fasteners and constructions which may be used in the construction of plywood and OSB furniture frames. T-nuts, for example, are useful in modular constructions where the arm and side frame are bolted to the seat frame. In general, these nuts have high strength. In hardwoods, T-nuts will develop the full strength of a 1/4-inch diameter bolt - about 2500 pounds. In plywood, they will produce somewhat less strength owing to compression of the wood beneath the flange of the nut.

Various types of threaded inserts may also be used, but their strength should be determined by test in the specific material to be used. Whatever fastener is used, cost is always a factor, the performance over cost ratio for any fastener used should be determined by test.

Conclusions

Strong reliable joints can be constructed with plywood and oriented strand board. Sufficient information exists to reliably estimate the strengths of several of these joints so that frame can be rationally designed. In addition, the GSA performance tests provide a reliable means for "proofing" furniture frame constructions.

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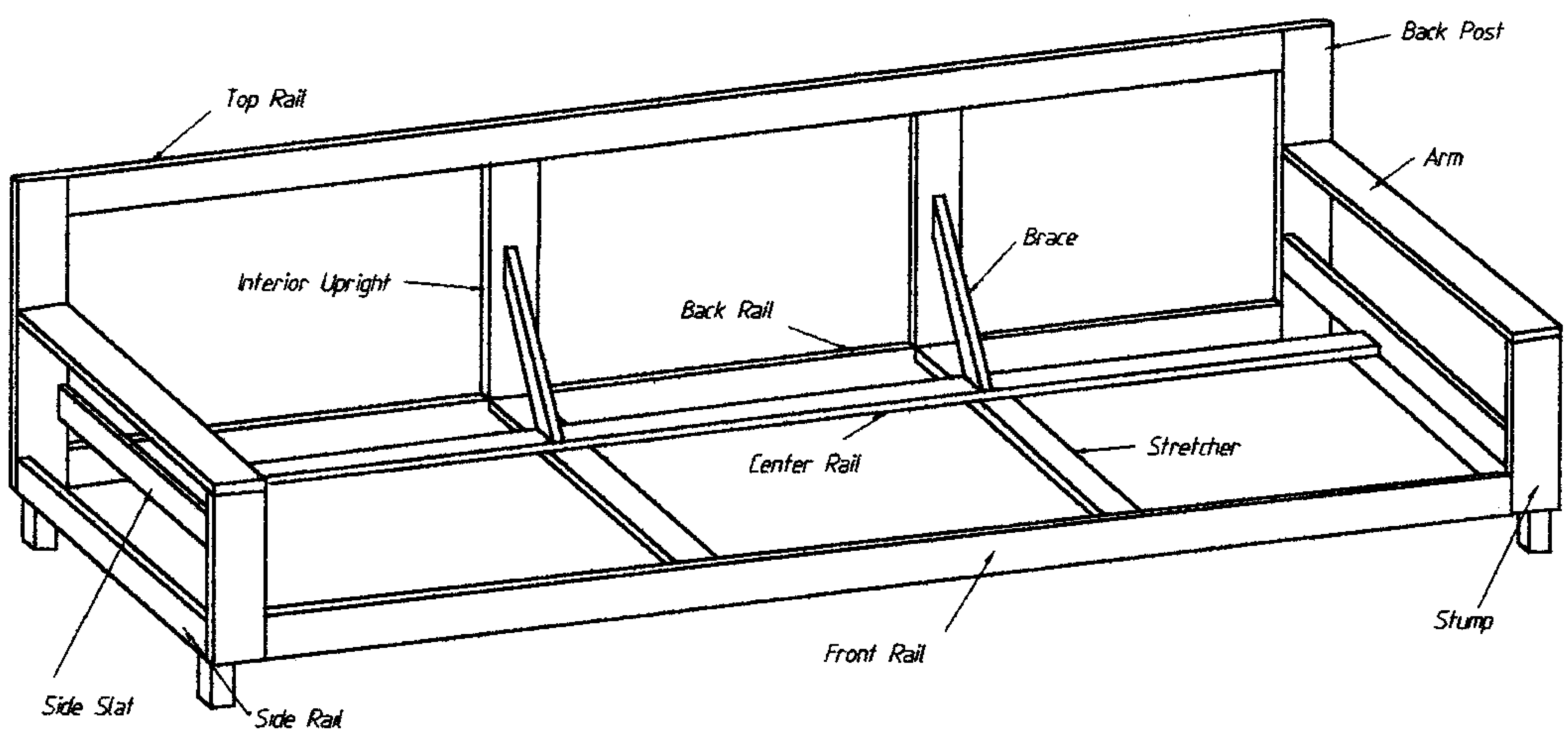

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