School Chairs for Developing Countries: Designing for Strength and Durability, Simplicity, and Ease of Construction

By

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Introduction

In developing countries of the world, persistent shortages of school furniture pose serious educational problems (7, 10). Shortages exist because furniture is one of the most expensive components of education (7), it has a low priority in limited school budgets, and frequent replacements are needed owing to the short service life of the furniture – often as short as 1 to 3 years.

Initial research has shown that strong durable school furniture can be produced with simple tools and production processes (4, 8, 9). Thus, the opportunity exists to solve school furniture problems by participatory cottage industry at the local level as well as by larger manufacturers at the regional or country level. To do so, however, it is necessary to have designs that inherently ensure long maintenance-free service life, using parts that are easy to manufacture and constructions that are easy to assemble.

The objective of this project was to develop a design for school chairs, based on proven round mortise and tenon construction, that not only would be strong and durable, but also easy to assemble and manufacture.

Design Criteria – Overall Design Considerations

In general, the chair was to be designed for children in the 9 to 10 year old age group, but the design was to be of such a type that it could be scaled to size for essentially all school grades from kindergarten through high school. Construction was to be simple, and equipment requirements limited to a table saw and drill press. In so far as possible, the chair was to be constructed of small parts – parts that in many cases could be machined from sawmill waste. The desired simplicity of design and manufacture dictated that the chair have either a straight or straight slanted back. Furthermore, assuming a bandsaw is not available to cut curved surfaces, the back slats would necessarily be straight. Since a slanted back would allow for a slight back slope, it became the preferred design. It was recognized, however, that in many areas, practical considerations would dictate the use of straight rather than slanted back posts. Thus, a design was needed that would allow the use of both. Comfort considerations also dictate that the seat should have a slight front to back slope and that the seat should cover the tops of the front posts. Finally, strength, durability, ease of parts manufacture and chair assembly mandated that round mortise and tenon joints be used in construction of the chair.

The front and side view of a chair that satisfies the above criteria in most essentials is shown in Figure 1. Height of the seat is 14 inches – which makes it suitable for children in the 9 to 10 year age group (6). The chair has three side stretchers, which ensures high front to back strength and durability. It also has a front stretcher and front rail, which ensures satisfactory sidesway strength of the front frame. Finally, the chair has a back stretcher and top and bottom back seat rails, a top rail, and back slat, all of which provide sidesway strength to the back frame and also help to reinforce the front frame.

The front edges of the back posts are slanted in order to provide a small amount of slope to the backrest. These posts measure 1-1/2 by 2-1/4 inches in cross section, whereas the front posts measure 1-1/2 inches square. All of the other members are constructed of 7/8-inch stock, except the front seat rail which is constructed of 1-inch thick material to accommodate the recess holes for the seat bolts. The seat is supported only by the front and back seat rails and has a half-inch slope to the rear.

Round Mortise and Tenon Joints

Round mortise and tenon joints were chosen for construction of the chair because round tenons are simple to cut with deep hole saws (plug cutters will also work) and mortises are simple to machine with conventional wood bits. Also, it is relatively easy to obtain a close fit between the round tenon and the mortise into which it fits by matching the drill bit used to machine the mortises to the hole saw used to cut the tenons. This ability to match the diameter of the tenon to the diameter of the hole without the need for strict quality control procedures and thereby obtain a tight force fit provides the key to the construction of uniformly durable furniture. Additionally, "shrink and swell fit" construction (1) may be used to augment "force fit" construction.

After the tenons are cut, excess material surrounding the tenons must be removed. This is done in such a way that a "shoulder" is formed at the point where the tenon emerges from the part. Subsequently, when the chair is assembled, the tenon is pressed into the mortise until the "shoulder" of the tenon presses against the side of the part into which the tenon is inserted. In constructions with non-slanting legs, this practice assures the dimensional accuracy of the construction without resorting to gages and other measuring devices – assuming that the desired shoulder to shoulder distance is maintained.

Strength Requirements

Universal strength requirements for school furniture of the type described here have not been established, but useful estimates can be obtained from work published on the performance of library chairs, particularly, the work on front to back and side thrust load tests (Eckelman, 1997, 1995(2, 3). Both tests are described below in the section dealing with performance tests. In the case of front to back load tests, acceptance levels of 250, 350, and 450 pounds are defined for categories of light, medium, and heavy duty. Experience indicates that if chairs in university libraries do not have a front to back strength of at least 250 pounds, a significant number will fail during the first two years of service. Few chairs with a front to back strength of 350 pounds ever fail, however. Comparable values for side load tests are 200, 250, and 300 pounds. The higher values tend to reflect the strength of chairs produced (and tested), however, rather than strength needed to survive in service. Thus, as a first estimate, it appears reasonable that if chairs designed for lower grades meet the lower requirements and chairs for upper grades the higher requirements, both designs should have sufficient strength and durability to survive in service.

Structural Considerations

As a close approximation, for chair side frames in which the front and back legs are large in cross section compared to the stretchers, and the stretchers are of identical cross section, the external bending force acting on a side frame is equally distributed to each stretcher (and to its accompanying tenons). Thus, for a front to back force applied to the top edge of the front post of a side frame, Figure 2, the internal bending force acting on each tenon is given by the expression

$$f_4 = F_2 \times \frac{h}{n} \ \textit{in-lb}$$

where f_4 is the bending force acting on the end of the stretcher, F_2 is the force applied to the side frame in a front to back direction*,* h is the vertical distance to the load point, and n is the number of tenons. This expression indicates that for a given external front to back force acting on a side frame, the greater the number of stretchers, the smaller the internal bending force acting on each tenon. Hence, strength and durability are obtained by using sufficient stretchers to ensure that the bending force acting on each joint does not exceed the strength of the corresponding tenon.

The stress generated in a round tenon is given by the expression

$$S_4 = \frac{32 f_4}{\pi D^3}$$

where f_4 refers to the bending force, S_4 refers to the corresponding bending stress, and π is equal to 3.14.

Previous tests indicate that under cyclic loading conditions, round tenons fail at stress levels at least equal to the modulus of rupture (MOR) of the material. The resistance of a side frame to front to back loads, therefore, can be estimated by setting S_4 equal to MOR in the above expression, rearranging terms, and then solving for F_2 in terms of S_4, i.e.,

$$F_2 = \frac{\pi D^3 S_4}{32} \times \frac{n}{h} = \frac{\pi D^3 \cdot MOR}{32} \times \frac{n}{h}$$

In the case of yellow-poplar, for example, the MOR at 12 percent moisture content is about 10,100 psi. A side frame with three stretchers constructed with 3/4-inch diameter tenons and a front post height of 13-1/4 inches, therefore, would be expected to have an ultimate resistance to front to back forces applied to the top of the front post of

$$F_2 = \frac{10{,}100 \times 3.14 \times (0.75)^3}{32} \times \frac{6}{13.25} = 189 \ lb.$$

The complete chair (with two side frames), therefore, would be expected to have an ultimate resistance to front to back cyclic loads of 2 x 189, or 378 *lb*.

Had the chair been constructed with 5/8-inch diameter tenons, the expected front to back strength would be $(0.625)^3/(0.75)^3$, or, 58 percent as great, i.e., it would be expected to have a front to back strength of 0.58 x 378, or 219 *lb*.

Similarly, as a first approximation, the front frame of the chair, with seat rail and one stretcher, might be expected have about two-thirds of the strength of one side frame, i.e., about 2/3 x 189, or, 126 *lb* for 3/4-inch diameter tenons, and 84 *lb* for 5/8-inch tenons. Including the strength of the back frame, the resistance of the chair as a whole to side sway forces would be at least double these values.

It should be noted that these values apply to one of the "weaker" woods. Had sugar maple (Acer sacharum) been used, for example, with an MOR of 15,800 psi at 12 percent mc (11), these values would be increased by 15,800/10,100, or, 56 percent. For northern red oak (Quercus rubra), the corresponding increase would be 14,300/10,100, or 42 percent.

These preliminary calculations tend to indicate that a chair constructed from even a relatively low strength wood species with nominal 3/4-inch diameter tenons should have sufficient strength to satisfy medium strength requirements as defined by the American Library Association (2, 3). Chairs constructed from "stronger" species would be expected to satisfy heavy-duty requirements.

Cross Mortises in Legs

Pilot studies (5) have quantified the loss of strength that occurs when holes or mortises intersect at right angles in chair and table legs and similar parts. In tests carried out with legs 1-3/8 inches square with intersecting 3/4-inch diameter mortises, the strength of the leg was reduced to 31 percent of solid wood strength. With 5/8-inch diameter holes, strength was reduced to 40 percent.

Furthermore, as the separation between the crossed mortises increased, leg strength increased substantially. In the case of 3/4-inch tenons, maximum strength values were obtained with crossed axes separations of as little as 1-1/2 inches, namely 50 percent of solid strength. At this point, the residual external bending strength, F_4, could be calculated by means of the conventional bending stress expression for beams on the basis of net remaining section, i.e.,

$$F_4 = \frac{(t-d)(w^2)}{6} \times S_4$$

where t refers to the thickness and w to the width of the member, inches; d refers to the diameter of the tenon, inches; and S_4 retains its previous meaning, MOR.

Given the above results, the maximum possible practical distance was maintained between mortises for side rails and the mortises for front and back rails in the chair shown in Figure 1 – in most instances, a spacing of 1-3/8 inches.

In the case of 1-1/2 thick by 2-inch wide yellow poplar back legs with this mortise spacing, the above expression indicates that the ultimate carrying capacity of a back leg with a 3/4-inch diameter mortise should be about 5,050 *in-lb*. Since even a 500-pound front to back load applied to the front of the seat would produce a bending force acting on each back leg at the lower side stretcher joint of only $(500/2) \times 5.5 = 1375$ *in-lb*, these legs would be expected to carry far larger loads than what might reasonably be expected in service. From a practical viewpoint, however, this over-design provides some measure of protection against the use of wood with knots or other defects in this area.

Front to back loads acting against the backrest must also be considered. For an extreme case in which the load is applied to the top edge of a 16-inch high back rest, each backrest would be able to resist a front to back load of 5,050 *in-lb*/16 in, or, 316 *lb* for a total back load of 632 *lb*, which would satisfy ALA requirements for medium back strength.

Seat Construction and Attachment

Several seat constructions are possible with this chair. The simplest is the one-piece seat constructed of 3/4-inch MDF shown in Figure 1. This seat has enough bending strength that it need be supported only by the front and back seat rails. Considered as a simple beam in bending, for a material bending strength of 2,400 psi, this seat should be able to support a concentrated load at midspan of 1,100 pounds. The comparable value for a 3/8-inch thick seat would be 286 pounds. Since impact must be considered, the latter thickness would not be expected to be satisfactory for all applications.

To use thinner seat material, it is necessary to add seat support rails as shown in Figure 3. Addition of the rails makes construction more labor intensive, but assuming the rails are cut from waste material, this practice may result in sufficient composite board savings to justify the practice.

Edge-glued solid wood seats could also be used when they are available and cost effective. Seats may also be constructed of narrow, often scrap, boards as shown in Figure 4 without edge-gluing the slats together. Fabrication of these seats is labor intensive but is justified when low cost labor is plentiful. The seat itself consists of a front edge piece, or lip, and several seat slats – usually, at least 4. Half-inch diameter tenons are cut on the front edge of the seat slats. Corresponding round mortises are cut into the back edge of the lip. A notch is cut into the rear edge of each slat. This notch prevents the seat slat from sliding rearward beneath the back upper seat rail. The seat slats should be sufficiently long to allow about 1/4 inch of the front edges to rest on top of the front rail. This allows the seat loads to be transferred directly to the front rail rather than to the tenons. A rabbet is cut on the top of the seat along the back edge. The shoulder of the rabbet butts up against the upper back seat rail and prevents the seat slats from sliding to the rear. The seat rail must be repositioned downward 1/8-inch from its normal position to engage the shoulders of the slats. The lip of the seat is attached to the front rail with two carriage bolts, whereas the rear ends of the slats are allowed to "float" between the upper and lower back seat rails. Notches cut into the rear end of the outer two seat rails prevent the rear of the seat from sliding sideways.

Top Rails and Back Slats

Ideally, the top rails and back slats used in the backrests should be curved to provide maximum comfort to the user. It is common practice, however, to use straight rails. A curve can be cut on the inside face of these members with a bandsaw in order to obtain some relief as is shown in Figure 1.

Separate top and back rails are normally used. With wide top rails, there is the chance of the end joints loosening with time so that the top rail rotates. A solution to this problem was devised as shown in Figure 5. In this construction, a wide top rail is used that has two 3/4-inch diameter tenons on each end. Use of two tenons provides significant strength to the top rail, prevents it from rotating in service, and allows the slant of the top rail to be altered by changing the location of the holes for the tenons in a front to back direction.

In constructing this top rail, the material between the two tenons is removed by first cutting a 3-inch diameter hole in the flat plane of the rail at each end with centers located 1-1/2 inches from the end and edge of the rail. Tenons are then cut on the protruding stubs.

An alternative slatted backrest construction was devised as shown in Figure 6. This backrest makes use of small pieces of material, but the fabrication process is labor intensive. The complete backrest consists of the top rail, the backrest rail, and, in this case, three backrest slats. Somewhat wide slats are shown in the figure – narrower, or even square, slats could be used instead. Half-inch diameter tenons are cut on the ends of the backrest slats. These fit into corresponding round mortises cut into the bottom edge of the top rail and the top edge of the bottom rail. Three-quarter inch diameter tenons cut on the ends of the top rail and backrest rail fit into corresponding mortises cut in the sides of the backrest posts. Use of this construction eliminates the need for careful spacing of the top rail and backrest tenons to match the corresponding mortises in the back posts as is necessary with the construction shown in Figure 5.

Parts Manufacture

Parts first are cut to rectangular shape. Mortises are then cut in them with the aid of the jigs shown in Figure 7. These jigs are placed on the bed of a drill press and clamped in such a position that with the backstop properly adjusted, holes are located in the desired position with respect to the width of the leg. Position of the mortises along the length of the leg is governed by the dowel pin stops that may be extended or retracted as desired. Toggle clamps may be used to hold parts in place while the mortises are being drilled. Use of the jigs significantly speeds the mortising process and ensures the proper location of the mortises.

The tapers on the back post are then cut with the jigs also shown in Figure 7. Use of these jigs significantly simplifies the cutting of the tapers on the back posts and also ensures the accuracy of the cuts.

Frame Assembly

Side frames are constructed first. These frames are assembled by inserting the stretcher tenons into their corresponding mortises and then pulling the assembly together with bar clamps. The clamps are tightened until the shoulders of the tenons press against the sides of the front and back legs. Thus, shoulders must be cut at points on the ends of the rails that result in the desired leg to leg spacing and thereby ensure that the assembly, when clamped together, is dimensionally accurate. The tenons on the ends of the cross stretchers, rails, and slats are then inserted into their corresponding mortises in the side frames. Again, the assembly is pulled together with bar clamps until the shoulders on the tenons press against the inside surfaces of the legs and backrest. This assembly procedure is inherently simple and produces frames that are both dimensionally accurate and square without the use of jigs or other types of clamps.

The walls of the mortises are coated liberally with a polyvinyl adhesive before the tenons are inserted. Excess glue pushed out the end of through-mortises is wiped off immediately. Before the adhesive dries, an adjustable wrench may be used to rotate any misaligned members into alignment.

Attachment of Seats

The rear edge of the seat is inserted in the slot between the top and bottom back seat rails, Figure 1. With the chair standing in an upright position, #10 round head carriage bolts are then inserted through the holes near the front edge of the seat and into the corresponding pilot holes in the front rail. A hex serrated flange-head nut is then inserted in the open end of a deep socket wrench with the socket held in the vertical position. The socket with nut is then inserted in the recess hole for the nut (drilled vertically in the underside of the front rail) and the nut screwed onto the end of the carriage bolt, Figure 1. Use of hex serrated flange-head nuts greatly simplifies the threading of the nuts on the bolts and is greatly preferred over the use of a two-part nut and washer combination.

Chair Construction

Essential details of the basic chair developed in the study with seat height of 14 inches is shown in Figure 1. This chair can be scaled up or down in 2-inch increments to produce chairs with 12 inch or 16 inch seat heights. Aside from differences in the lengths of the members, the only major difference between chairs is that the small chair is constructed with two side stretchers rather than three. These are positioned at points 6-

1/4 and 9 inches above the floor, whereas in the case of chairs with a 16-inch seat, the side rails are positioned at heights of 5-1/2, 9-1/4, and 13 inches. These chairs are suitable for children in kindergarten and beginning grades, middle grades, and upper grades and some adults, respectively. The cross sectional areas of comparable members are the same in all three chairs.

Two chairs of each seat height were constructed of yellow-poplar (Liriodendron tulipifera) and two of red oak (Quercus rubra) for a total of 12 chairs. An additional four chairs were constructed with a seat height of 14 inches from material salvaged from scrap loblolly pine (Pinus taeda) 2 x 4"s. These chairs were included in the tests because school furniture may be constructed from scraps of structural timber left over from construction of school buildings, and it was thought worthwhile to determine the performance of chairs fabricated of this material. Tenons were cut with a 3/4-inch diameter hole saw that produced nominal 0.725-inch diameter tenons. Mortises were drilled with a 46/64-inch diameter twist drill. Before assembly, walls of the mortises were coated liberally with an aliphatic resin adhesive.

Performance Tests - Front to Back Load Test and Side Load Test on Seats

The front to back load test on seats as defined in the performance test method for library chairs developed by the American Library Association (3) was used to evaluate the strength and durability of the chairs in the critical front to back direction. This performance test method was selected initially because of the similarity of the service conditions in schools and libraries. In addition, the tests provide a straightforward procedure for relating field performance to laboratory test results based on historical data. Finally, this method of test maximizes the amount of useful engineering data obtained.

The test itself consists of pushing from front to back on the seat of a chair (or on the front rail). This action produces internal resisting forces in the side frame of the chair similar to those caused by the action of someone tilting backward. The chair is mounted for testing as shown in Figure 8. Reaction brackets are placed behind each of the back legs to prevent the chair from sliding backwards. A strap is then passed over the seat from front to back and attached to a small clevis connected to the rod end of an air cylinder that applies loads to the chair. The other end of the belt is dropped over the front edge of the seat, allowed to hang vertically, and attached to a crossbar located directly below the front edge of the seat. As the seat is pulled to the rear, the chair tends to tip over backward. As it begins to tilt slightly, however, its motion is resisted by that portion of the strap that hangs vertically from the front edge of the seat and is anchored below – in effect, the vertical portion of the strap always provides the exact force needed to keep the chair from overturning.

Horizontal loads are applied to the chair seat in a front to back direction at a rate of 20 cycles per minute. Tests were conducted until a chair suffered disabling damage.

The horizontal side load test on seats is identical to the front to back load test except that the load is applied to the seat in a sideways direction, and reaction brackets are placed on one side of the chair rather than behind the chair.

Results and Discussion

Results of the tests are presented in Table 1. Estimated and failing strengths for the front to back load tests are given in Table 2.

The loblolly pine chairs were tested first. Owing to uncertainty concerning their expected performance, tests were started at the 50 pound load level and increased in increments of 25 pounds. As a result of the of the use of these low conservative starting loads and load increments, the loblolly pine chairs were subjected to a much larger number of load cycles than the remaining chairs. In the front to back tests, these chairs failed at 475 and 450 pounds respectively. In the side load tests, the chairs failed at 375 and 350 pounds, respectively.

All remaining tests were started at the 150 pound load level and increased in increments of 50 pounds In the case of the chairs with 12-inch seat height, the red oak chairs failed at 450 and 400 pounds, respectively in the front to back load and the side load tests. Comparable values for the yellow-poplar chairs were 350 pounds and 350 pounds, respectively. As expected, the red oak chairs performed better than the yellow-poplar chairs.

In the case of the chairs with 14-inch seat height, the red oak chairs failed at 700 and 450 pounds, respectively in the front to back load and the side load tests. Comparable values for the yellow-poplar chairs were 550 pounds and 300 pounds, respectively. In the case of the chairs with a 16-inch seat height, the red oak chairs failed at 450 pounds in both the front to back load and the side load tests. Comparable values for the yellow-poplar chairs were 350 pounds in both tests

Conclusions

Results of the study indicate that strong durable school chairs can be produced from only a few configurations of simple parts that are easy to manufacture and assemble into finished furniture. Round mortise and tenon joint construction produces tight-fitting, strong, durable joints with minimum quality control requirements. Furthermore, dimensionally accurate tenons may be machined with simple equipment and mortises cut with conventional drill bits. Simple jigs ensure the accurate placement of the mortises and speed up part production. Shoulders machined at the root of the tenons allow rails and legs to be assembled into dimensionally accurate frames without the use of special jigs. Use of an upper and lower back seat rail provides a simple fool-proof means of anchoring the rear of the seat. Attachment of the front of the seat to the front seat rail with two #10 carriage bolts provides an unobtrusive yet positive means of anchoring the front of the seat to the chair frame. Use of hex serrated flange-head nuts allows the nuts to be rapidly threaded onto the bolts, even in the deeply recessed access holes.

Results of the tests indicate, therefore, that all of the chairs met either the medium or high acceptance levels for front to back load tests specified by the ALA. Furthermore, all of the chairs met the high acceptance levels for side load tests. To put these results into perspective, it must be realized that adult library reading rooms (especially those located at universities) represent a severe use environment and acceptance levels, accordingly, are set high relative to other use environments. Chairs that meet only the “low” ALA acceptance level, for example, have given good service in fast food restaurants. Furthermore, chairs intended for home use often fall considerably short of satisfying the “low” ALA acceptance level. Thus, a very high level of strength has been achieved in the test chairs, which, presumably, can be attributed both to their design and method of construction.

References

1. Boggs, Brian. 2001. Post-and-Rung Stool. Fine Woodworking July/August(150):70-75.
2. Eckelman, C.A. 1977. Evaluating the Strength of Library Chairs and Tables. Monograph. Library Technology Reports 23(4):341-433. American Library Association. Chicago.
3. Eckelman, Carl A. 1995. Library Chairs: An Overview of the Library Technology Reports Test Method with Test Reports on 30 Chairs. Library Technology Reports 31(2):117-214. American Library Association. Chicago.
4. Eckelman, C., Haviarova, E., and Y. Erdil. 2001. Considerations in the Design and Development of School Furniture for Developing Regions Based on Local Resources. Forest Prod. J. 51(6):56-63.
5. Eckelman, C., Y. Erdil, and E. Haviarova. Effect of Cross Holes on the Bending Strength of Chair and Table Legs Unpublished pilot study. Wood Res. Lab. Purdue U.
6. Garcia, C., R. Moraga, A. Page, L. Tortosa, and V. Verde. Guia de Recomendaciones para el Diseño de Mobilario Ergonomico. Instituto de Biomecanica de Valencia. Spain.
7. Haviarova, E. 2000. Design and Construction of Wooden School Furniture for children in Developing Countries. Ph.D. Thesis. Purdue U. W. Lafayette, Ind. 201 pp.
8. Haviarova, E., C. Eckelman, and Y. Erdil. 2001a. Design and Testing of Environmentally Friendly Wood School Chairs for Developing Countries. Forest Prod. J. 51(3):58-64.
9. Haviarova, E., C. Eckelman, and Y. Erdil. 2001b. Design and Testing of Wood Desk Frames Suitable for Production by Low Technology Methods from Waste Residues. Forest Prod. J. 51(5):79-88.
10. Quesada, Henry Y. 2001. Design of a Manufacturing System for the Construction of Wood Furniture. MS Thesis, Purdue Univ., W. Lafayette, Ind. 158 pp.
11. USDA Forest Products Laboratory. 1999. Wood Handbook: Wood as an Engineering Material. Gen. Tech. Rept FPL-GTR-113. USDA Forest Serv., Forest Prod. Lab., Madison, Wis.

Table1. Results of front to back and side thrust load tests on chair frames.

Chair No.	Seat Height (in)	Wood Species	MC %	Type of Test	Initial Load	Load Step	Ultimate Load	Cycles at Ultimate Load	Total Cycles Completed
1	12	red oak	9.07	Front to Back	150	50	450	3040	153,040
2	12	red oak	9.13	Side Load	150	50	400	23,200	148,200
3	12	y-pop	9.82	Front to Back	150	50	350	17,400	117,400
4	12	y-pop	9.51	Side Load	150	50	350	21,300	121,300
5	14	red oak	7.11	Front to Back	150	50	700	4,543	254,543
6	14	red oak	7.53	Side Load	150	50	450	5,063	155,063
7	14	y-pop	9.83	Front to Back	150	50	550	5,102	205,102
8	14	y-pop	8.90	Side Load	150	50	300	10,341	85,341
9	14	lob. pine	7.96	Front to Back	50	25	475	16,532	241,532
10	14	lob. pine	do	Side Load	50	25	375	3,130	328,130
11	14	lob. pine	do	Front to Back	50	25	450	23,100	423,100
12	14	lob. pine	do	Side Load	50	25	350	2,350	302,350
13	16	red oak	9.36	Front to Back	150	50	450	11,300	161,300
14	16	red oak	9.51	Side Load	150	50	450	2,360	152,360
15	16	y-pop	9.45	Front to Back	150	50	350	20	100,020
16	16	y-pop	9.13	Side Load	150	50	350	75	100,075

Table 2. Comparison of estimated and failing load values in front to back load tests.

Chair No.	Wood Species	Moisture Content (%)	Seat Height (inches)	Front Post Height (inches)	Modulus of Rupture (psi)	Est. Failing Load (lbs)	Actual Failing Load (lbs)	Actual/ Est. (%)
1	Red oak	9.07	12	11.25	15,976	416	450	107.4
3	Y-pop	9.82	12	11.25	10,981	286	350	122.4
5	Red oak	7.11	14	13.25	17,098	567	700	123.5
7	Y-pop	8.9	14	13.25	11,352	377	550	145.9
9	Lob Pine	7.96	14	13.25	14,868	493	475	96.35
11	Lob Pine	7.96	14	13.25	14,868	493	450	91.3
13	Red oak	9.36	16	15.25	15,810	456	450	98.7
15	Y-pop	9.45	16	15.25	15,444	321	350	109.0

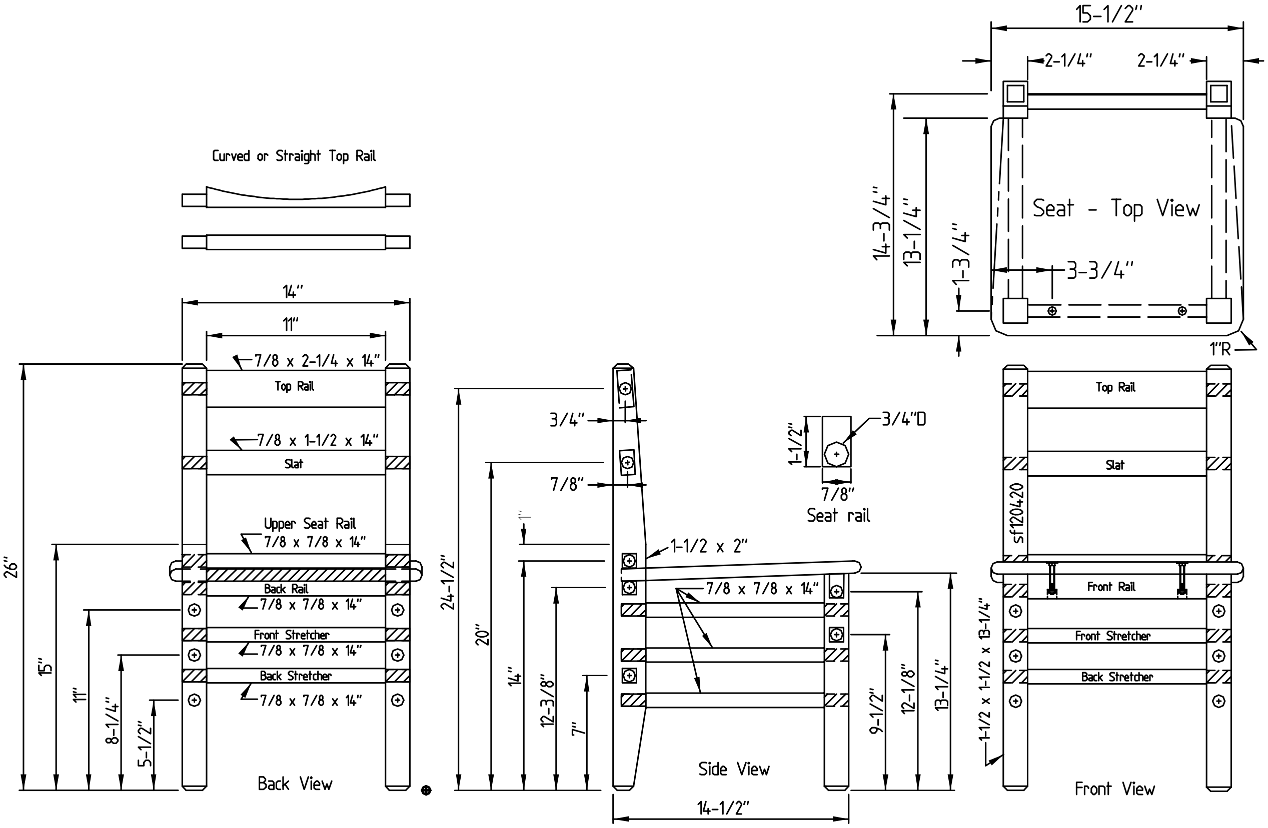

Figure 1. Chair with 14-inch seat height developed for classroom use.

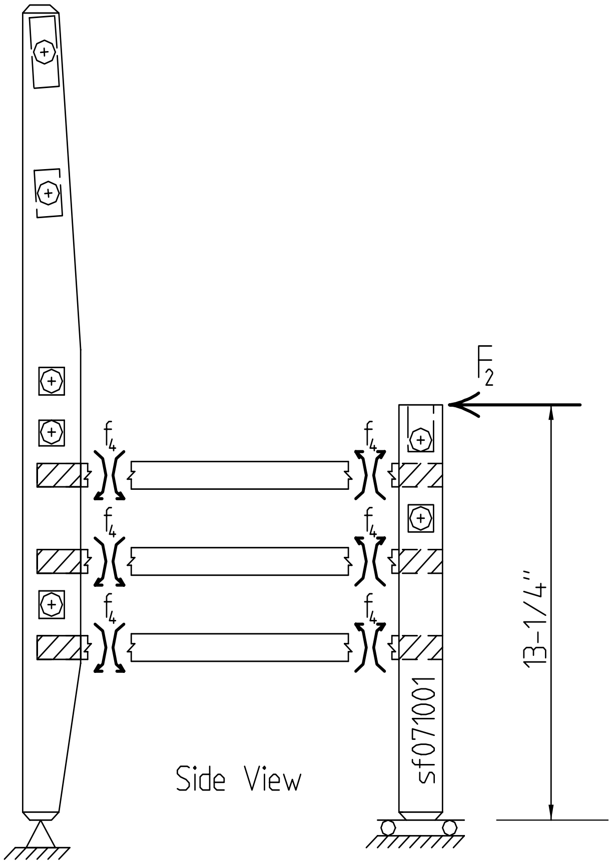

Figure 2. Diagram showing distribution of internal bending forces acting on ends of stretchers.

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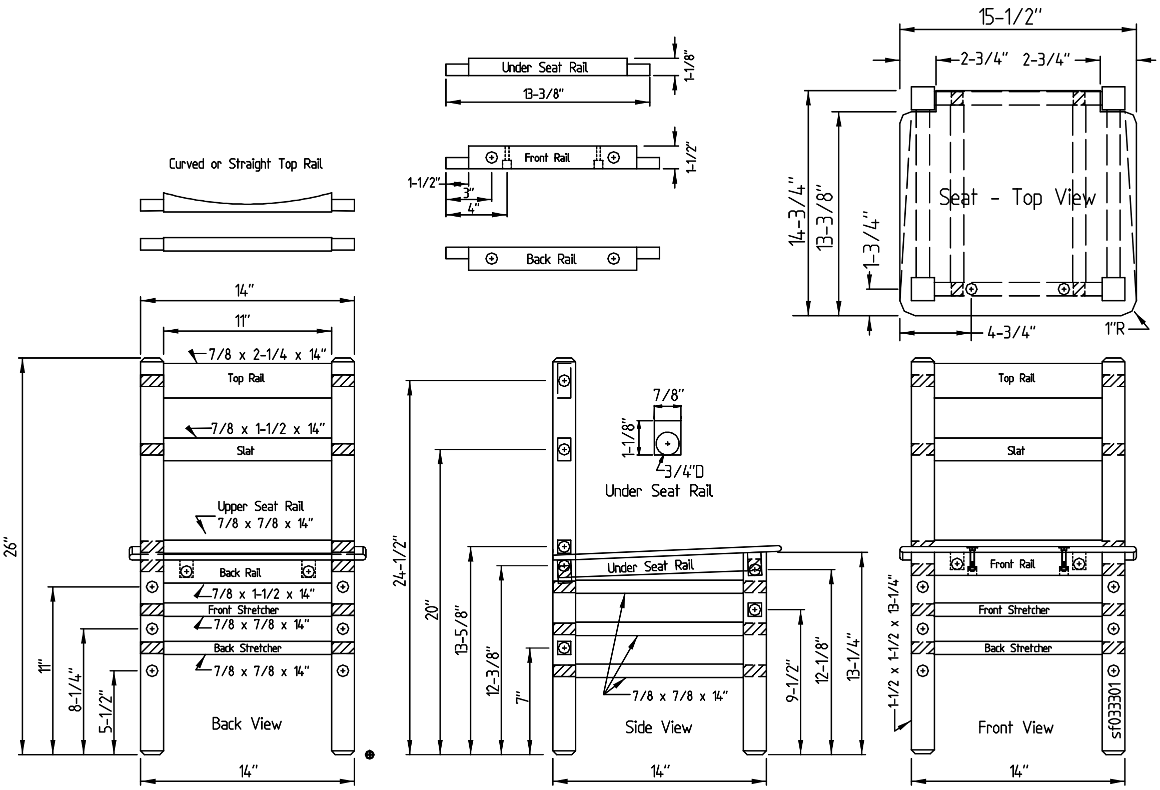

Figure 3. Under-seat rails have been added to the basic chair frame to support "thinner" seats.

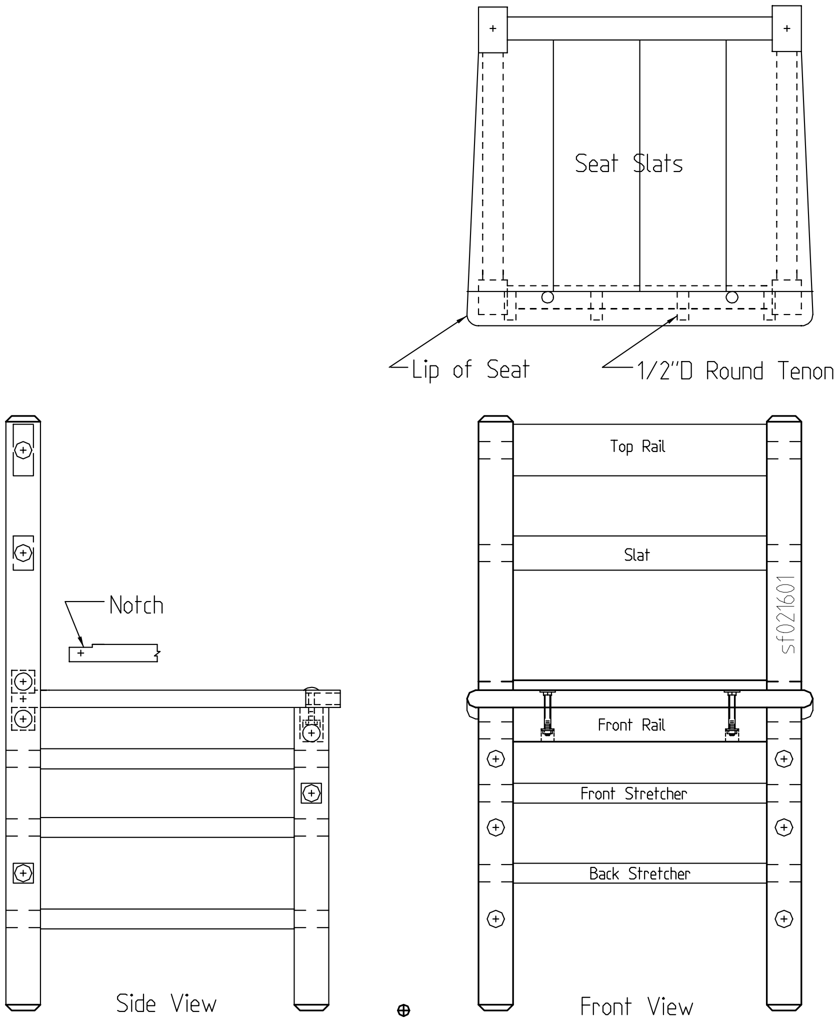
Seat Slats
Lip of Seat
1/2"D Round Tenon
Notch
Top Rail
Slat
sf021601
Front Rail
Front Stretcher
Back Stretcher
Side View
Front View

Figure 4.

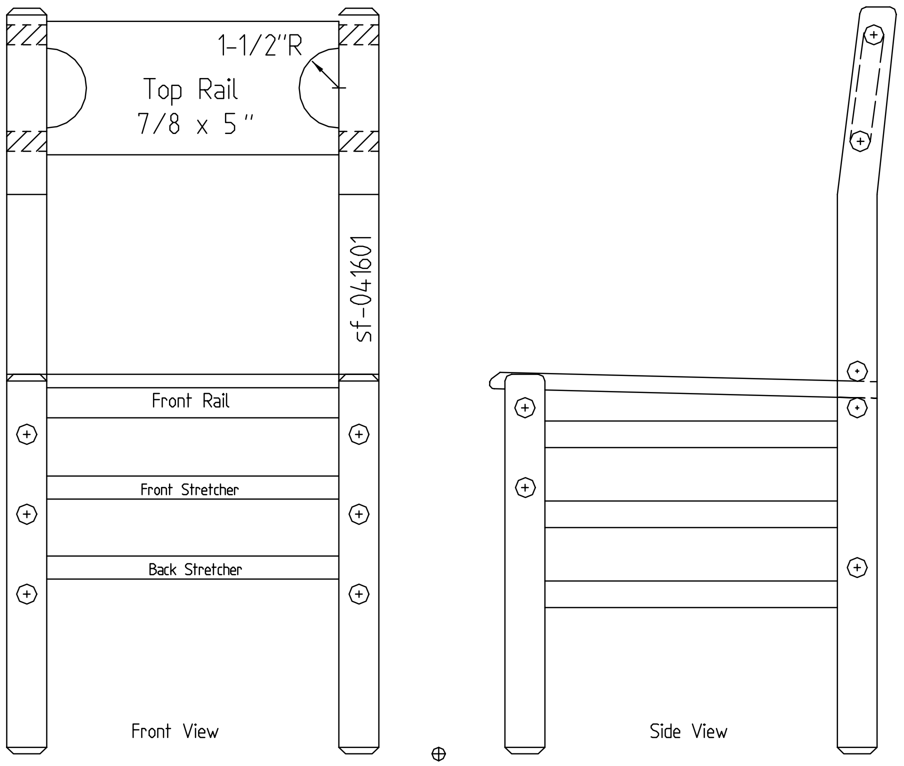
1-1/2"R
Top Rail
7/8 x 5"
sf-041601
Front Rail
Front Stretcher
Back Stretcher
Front View
Side View

Figure 5.

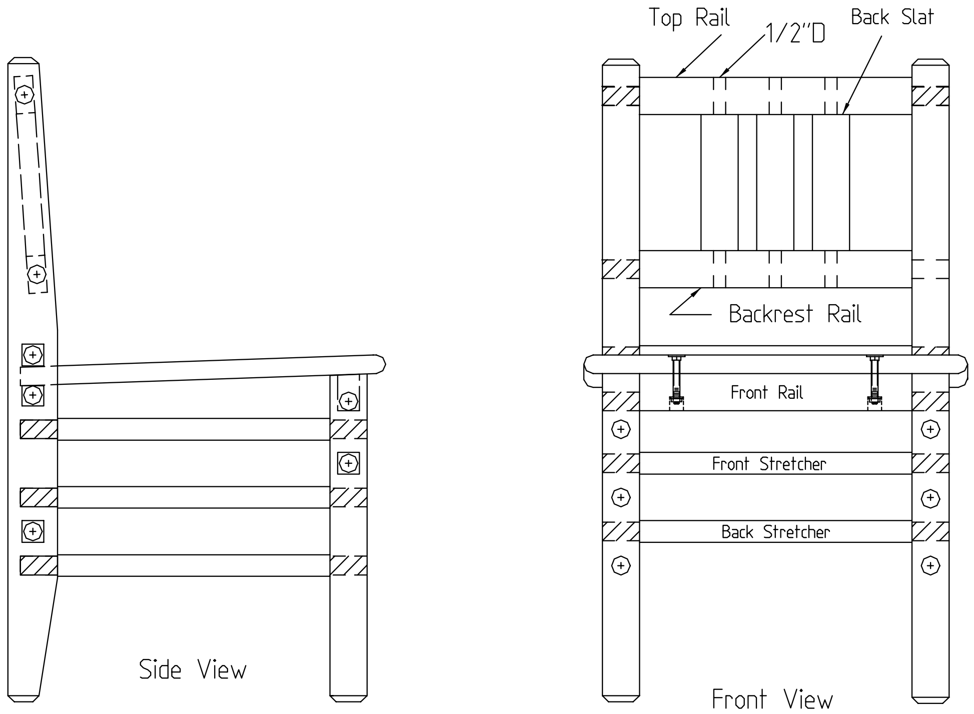
Top Rail
1/2"D
Back Slat
Backrest Rail
Front Rail
Front Stretcher
Back Stretcher
Side View
Front View

Figure 6.

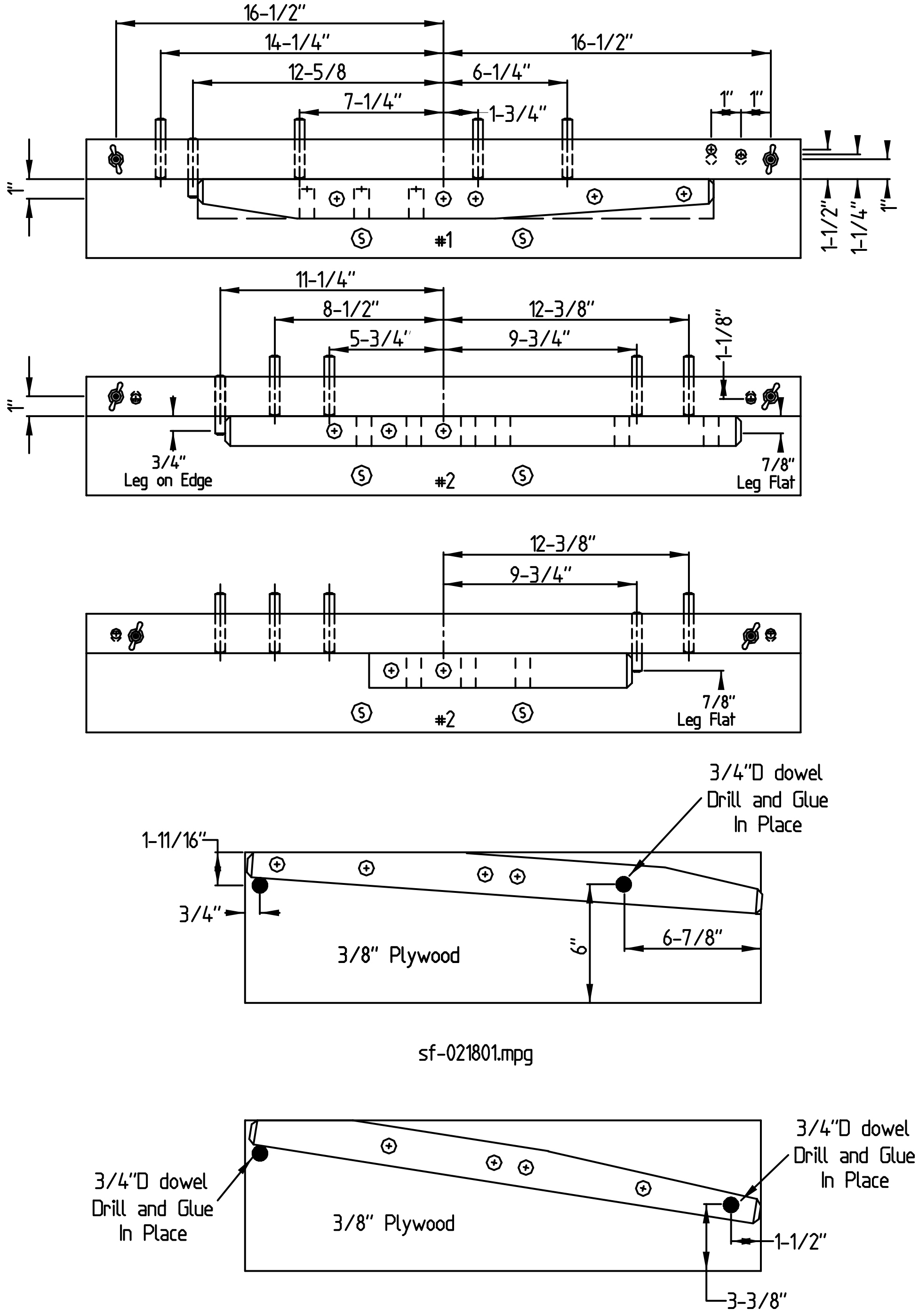
16-1/2"
14-1/4"
12-5/8
7-1/4"
16-1/2"
6-1/4"
1-3/4"
1"
1"
1"
1-1/2"
1-1/4"
1"
#1
11-1/4"
8-1/2"
5-3/4"
12-3/8"
9-3/4"
1-1/8"
1"
3/4"
Leg on Edge
#2
7/8"
Leg Flat
12-3/8"
9-3/4"
#2
7/8"
Leg Flat
3/4"D dowel
Drill and Glue
In Place
1-11/16"
3/4"
3/8" Plywood
6"
6-7/8"
sf-021801.mpg
3/4"D dowel
Drill and Glue
In Place
3/8" Plywood
3/4"D dowel
Drill and Glue
In Place
1-1/2"
3-3/8"

Figure 7.

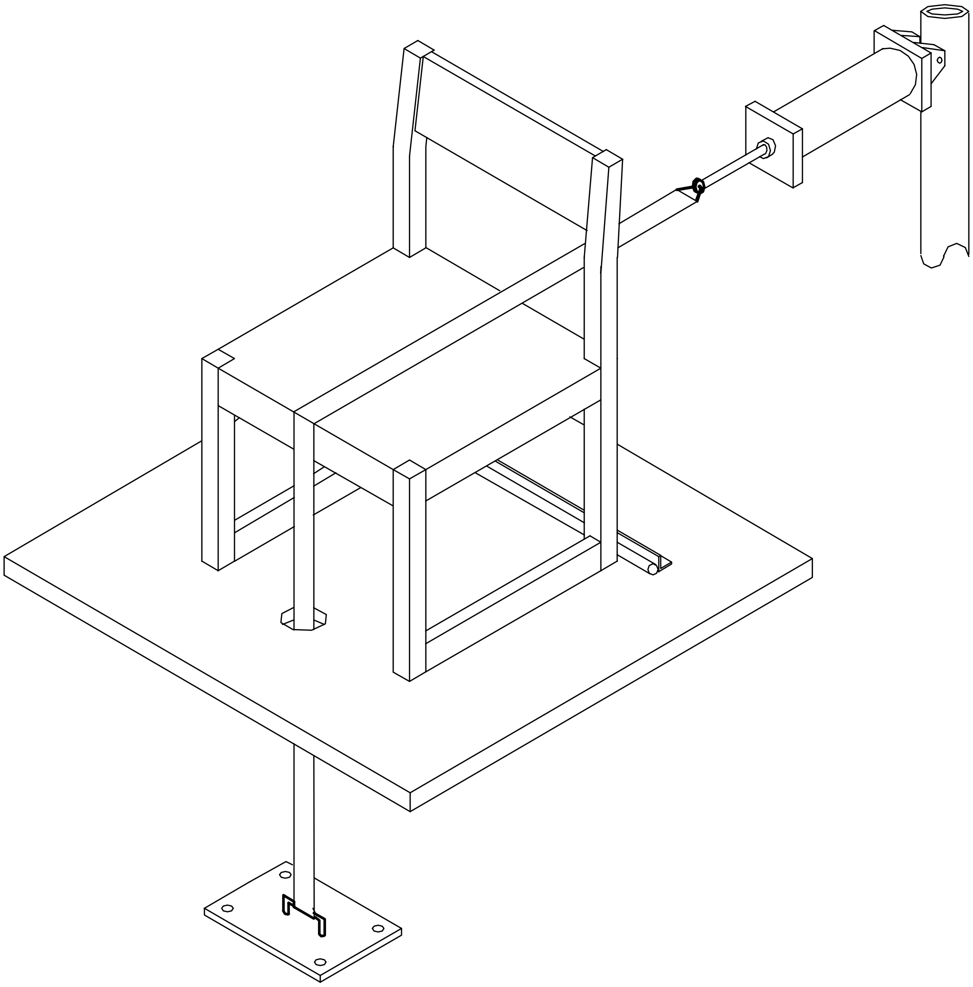

Figure 8. Front to back load test on seats.

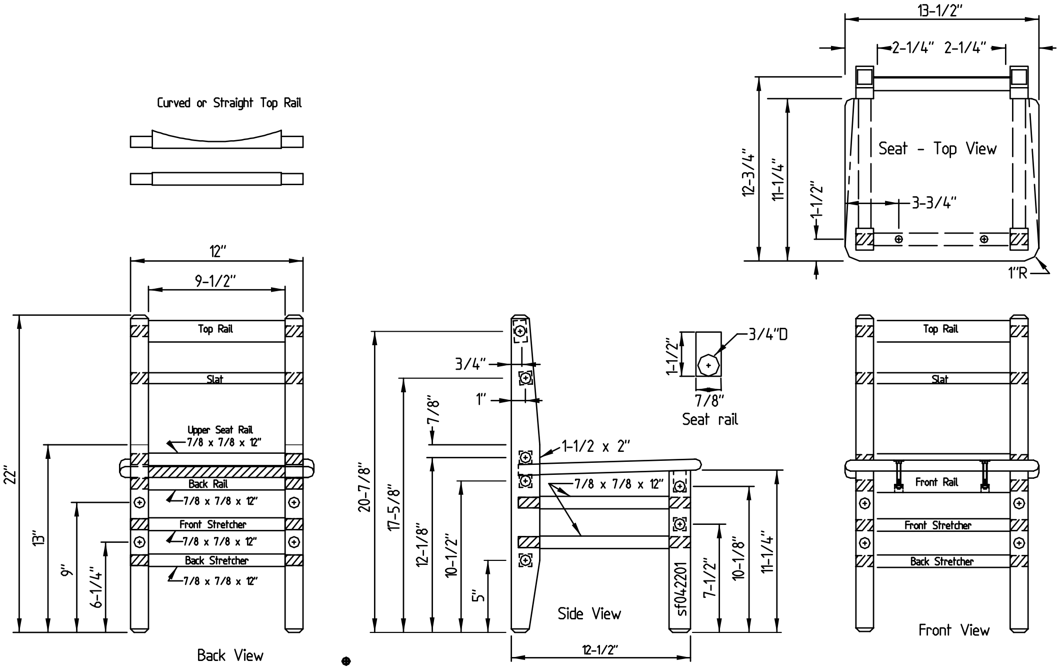

Figure 8 (sf-042201). Kindergarten version of chair.

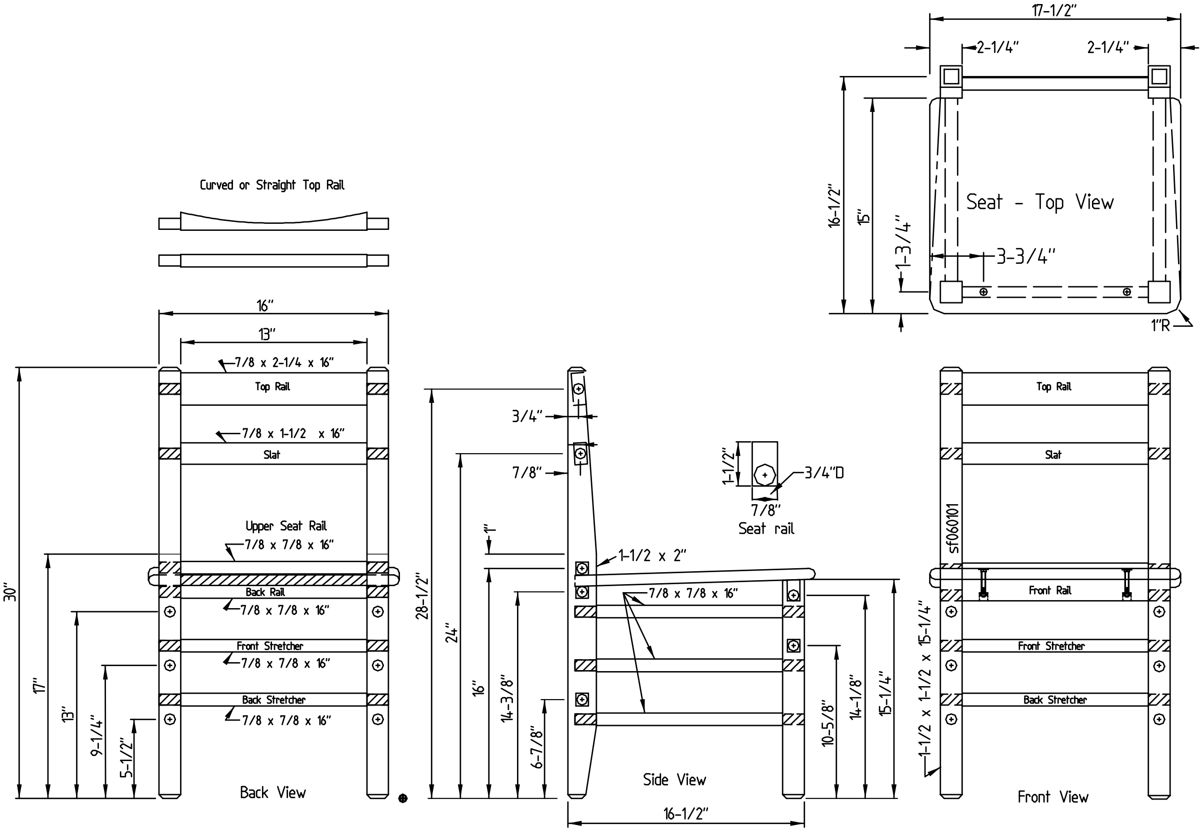

Figure 9 (sf-060101).