Demonstration of the Fastener Performance of the Wood of Western Juniper (*Juniperus occidentalis* Hook.)

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Edwin J. Burke
Missoula, Montana

Introduction

Concern about the structural integrity of juniper wood in use prompted initiation of a project designed to demonstrate the strength of mechanically-fastened joints. The concern came from reports of edge-glued panel breakage (3/4-inch thickness) during manufacturing trials. According to Burke (1994)[1], users reported that problems nearly always occurred where seasoning checks and, possibly, ring shake interrupted the panel surface. Needed information about the fundamental withdrawal resistance of such common fasteners as screws and nails was obtained.in this demonstration.

Methods and Materials

This demonstration was designed in two parts. Part 1: The evaluation of corner-joint strength using either wooden dowels or wooden plates[2], and Part 2: The evaluation of the withdrawal resistance of nails and wood screws, which used ASTM Standard #D 1761-88[3] to measure these properties.

Lumber used for the demonstration study was green-sawn and dried in two locations: Sycan Forest Products, Dairy, Oregon, late summer, 1993 (steam-kiln dried in Klamath Falls), and at the University of Montana School of Forestry's sawmill at the Lubrecht Experimental Forest in Missoula, MT., January, 1994 (air-dried in a heated laboratory, where the Sycan lumber was also stored, to approximately 10% moisture content prior to use).

The sawn trees came from two different lots:

1. The lumber sawn by Sycan was part of a short production run to test the marketability of

[1] Burke, Edwin J. 1994. In-Service Shrinking and Swelling Properties of Western Juniper, *Juniperus occidentalis* Hook. Report to Winema National Forest, Klamath Falls, OR.

[2] Methods used same as those in Burke, E. J. 1994. Bending Moment Resistance of Wood-Plate Corner Joints in Medium Density Particleboard and Lodgepole Pine Lumber. McIntire-Stennis Research Project # MONZ 94-11. Montana Forest and Conservation Experiment Station. Missoula, MT.

[3] American Society for Testing and Materials. 1993. Standard Test Methods for Mechanical Fasteners in Wood. Annual Book of Standards. Vol. 04-09-Wood.

the species and harvested southeast of Klamath Falls, Oregon, in the summer and early autumn of 1993. Tree were growing mixed with ponderosa pine (*Pinus ponderosa* Laws.) on what is anecdotally reported by land managers to be productive sites for western juniper. Trees varied in diameter-breast-height from 12 to 16 inches, and 40 to 60 feet tall.

2. The lumber sawn at the School of Forestry came from part of a collection of 39 trees from throughout the range of western juniper in California and Oregon that were to be used in a project to determine the mechanical properties of the species.

The principal criterion for lumber used in the demonstration study was that it be free of checks, shakes[4], warp and other drying-related defects. Lumber used for test samples exhibited ring counts of approximately 15 to 20 rings-per-inch, with lumber having exceptionally wide and narrow growth rings excluded. Pieces that were totally sapwood were difficult to obtain from the material available, so test samples were made up entirely of heartwood or mostly heartwood and a small amount of sapwood.

Unsound wood was generally not allowed in any of the samples, with any unsound wood, small knots wane or other defects located away from the fastener or joint center to not be factors affecting the evaluation. No distinction between the Sycan and Forestry School-produced lumber was made in the demonstration.

Corner Joint Strength

Two types of corner joints were evaluated for this project, the edge-grain joint and the end-grain joint. The edge-grain joint was made up with the plate's long axis parallel to the grain of the wood, and the joint connecting edge grain in both pieces (Figure 1a). The end-grain joint was arranged so the end grain of one leg was joined to the edge grain of the other leg (Figure 1b). Corner-joint face-member blanks (kerf cut in the face of the piece) measuring 6.250" wide by 6.000" long and edge-member blanks (kerf cut in the edge of the piece) 5.500" wide by 6.000" long were cut from 1-inch (nom.)-thick western juniper lumber (Fig. 1) resawn from the previously-described, 2-inch lumber. Kerfs were made in both legs of the joint using a DeWalt plate-joint kerfing tool, fixed with a 6-tooth, carbide-tipped, 4"-diameter blade. Lamello® brand, #20 compressed beechwood plates were used to complete the joint, after kerfs were cleaned with compressed air, and an amount of cross-linking polyvinyl acetate adhesive sufficient to cause adequate squeeze-out placed in the kerfs. Single-dowel joints were produced using the same size of lumber and 0.250"-diameter birch dowels and the same adhesive.

Fifteen replications of each joint-type were tested in tension applied as shown in Figure 2 using a Tinius-Olsen universal testing machine with a crosshead speed of 0.25 inches/minute. The test specimens rested on roller assemblies allowing the two joint members freedom to move relative to each other and the

[4] Ring shake is a separation of growth rings in the tangential direction (perpendicular to the radial), extending along the grain for indeterminate distances and sometimes encircling the pith.

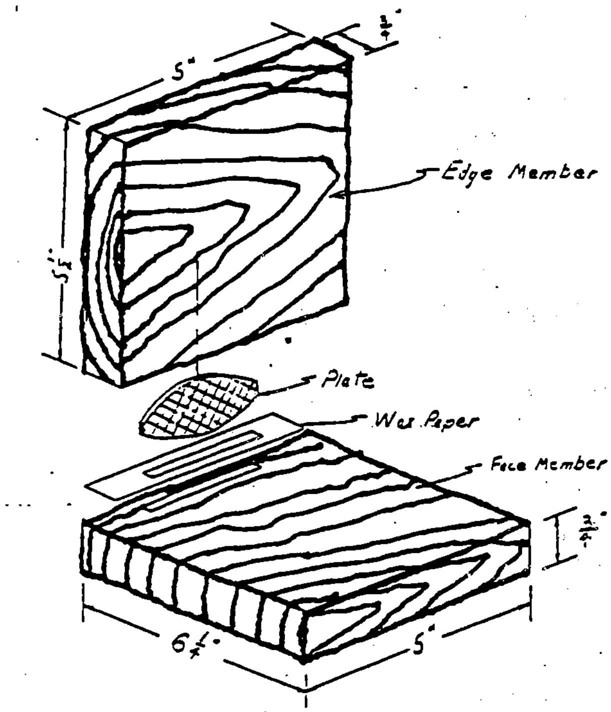


Figure 1a. Exploded view of the edge-grain corner plate-joint specimen. Dowel-joints were made in the same fashion, with a single birch dowel substituted for the plate.

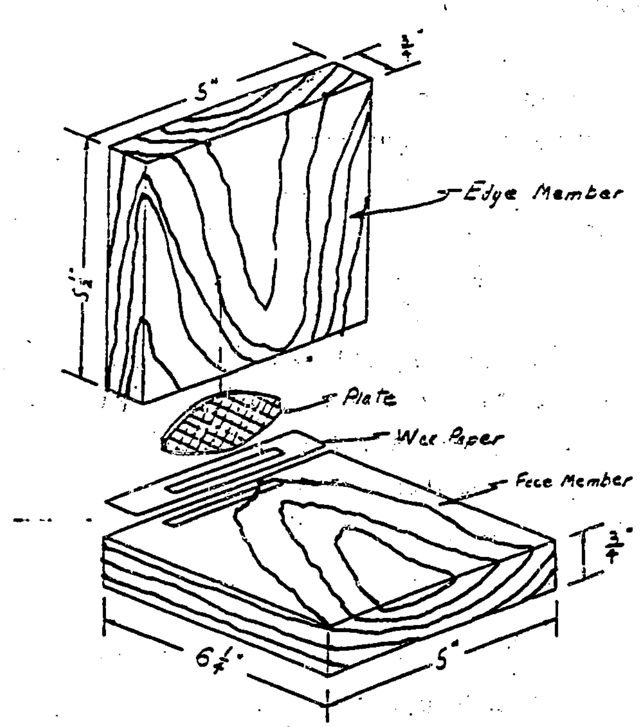


Figure 1b. Exploded view of the end-grain corner plate-joint specimen. Dowel-joints were made in the same fashion, with a single birch dowel substituted for the plate.

testing machine bed. Following joint breakage the mode of failure was recorded, specimens were extracted from each test joint, and the average moisture content and specific gravity at time of test determined for each test specimen.

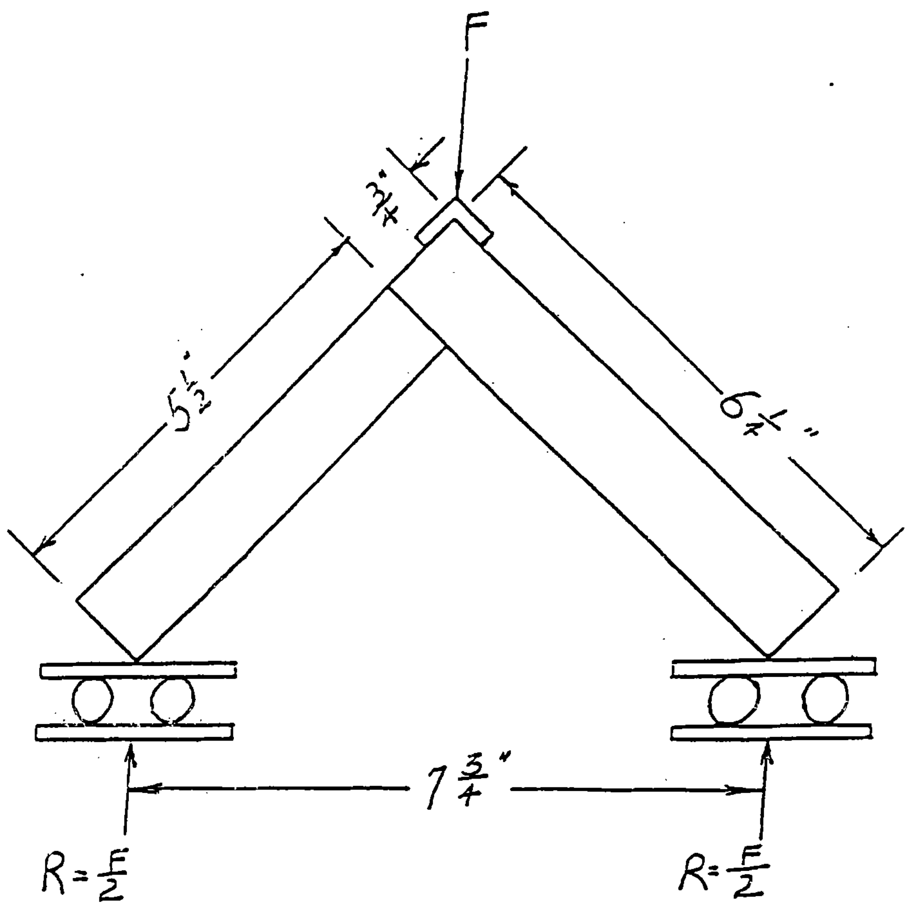


Figure 2. Diagram of tension loading of corner-joint specimen.

Withdrawal Resistance of Nails and Wood Screws.

Test prisms of clear wood, measuring 2" x 2" x 6" were cut from the previously-described lumber such that true radial, tangential and transverse faces were available for correct nail and screw insertion. Two, sixpenny-weight bright-finish common nails, measuring 0.113" in diameter, were inserted 1.250" into each anatomical face of the test prisms. Each specimen block (prism), therefore, had two nails inserted into a radial face, two nails inserted into a tangential face, and one nail inserted into each of the transverse faces. Testing of 15 prisms yielded 30 tangential, 30 radial and 30 transverse-face withdrawals, for a total of 90 nail withdrawals.

Screws used for direct withdrawal testing were 1.5"-long, zinc-plated, #10 flathead wood screws. They were inserted the length of the threaded portion of the screw, 0.855", using lead holes whose 0.098" diameters were the prescribed 0.7 x screw's root diameter (0.140"). Fifteen replications of each prism were tested in direct withdrawal using a Tinius-Olsen universal testing machine with a crosshead speed of 0.10 inches/minute. With two fasteners in each anatomical face, each prism had six fasteners applied for withdrawal, allowing for 30 tangential, 30 radial and 30 transverse-face withdrawals, for a total of 90 screw withdrawals.

Results

Dowel-Joint Strength

The first part of Appendix Ia. summarizes the results of the bending moment resistance of end-grain corner joints using wood plates. Mean resistive moment was 157.5 lb.-in. Bending stresses in the leg with the kerf in the face (side grain) causing longitudinal shear failure in the leg was the principal cause of joint failure. In three of the tests, radial longitudinal shear coupled with fracture of the wood plate were the causes of joint failure. Specific gravity (oven-dry weight and volume at test) of the prisms ranged from 0.38 to 0.46 and averaged 0.41. No relationship between specific gravity and joint strength was apparent.

The second part of Appendix Ia. summarizes the results of the bending moment resistance of side-grain corner joints using wood plates. Mean bending moment was 121.7 lb.-in. and specific gravity ranged from 0.36 to 0.47 and averaged 0.41. Ten of the fifteen joints tested failed in radial shear/cleavage at the joint, with the other five joints breaking in the center of one of the legs. As with the end-grain joints, specific gravity was not significantly correlated with joint strength. Five of the six lowest values corresponded to the joints where small seasoning checks caused the legs to break, rather than near the center of the joint where the highest stresses were located. This supports the theory that while small seasoning checks are an appearance issue for panel products, their presence should generate a concern for the structural integrity of western juniper products.

Plate-Joint Strength

The first part of Appendix Ib. summarizes the results of the bending moment resistance of end-grain corner joints using 0.250"-diameter birch dowels. Mean moment was 45.4 lb.-in. Bending stresses in the joint causing radial shear and dowel breakage was the principal cause of joint failure. In two of the tests, radial shear was the sole cause of joint failure. Specific gravity (oven-dry weight and volume at test) of the prisms ranged from 0.36 to 0.48 and averaged 0.42. No relationship between specific gravity and joint strength was apparent.

The second part of Appendix Ib. summarizes the results of the bending moment resistance of side-grain corner joints using 0.250"-diameter birch dowels. Mean bending moment was 59.4 lb.-in. and specific gravity ranged from 0.39 to 0.46 and averaged 0.42. Eleven of the fifteen joints tested failed in a combination of radial shear in the joint and subsequent breaking of the dowel when the stresses increased and were concentrated on the dowel. Two of the specimens showed radial shear failures in the wood surrounding the dowel while the two remaining joints broke in the center of one of the legs (as seen in the plate joints with minute seasoning checks). As with the end-grain joints, specific gravity was not significantly correlated with joint strength.

Withdrawal Resistance of Nails

Appendix II summarizes the results of the nail withdrawal demonstration. Each prism has two values for each face, a withdrawal load in lbs. and the specific gravity. Mean value for straight withdrawal was 194.9 lbs. tangentially, 199.2 lbs. radially and 134.1 lbs. for the transverse face. The "sidegrain" (the average of the mean tangential and radial values) was 197.1 lbs. The Wood Handbook[5] gives the following formula to estimate the sidegrain withdrawal resistance (**p**) of a smooth-shanked nail as follows:

$$p_{nail} = 7{,}850\ G^{5/2} DL \qquad [1]$$

where:

p_{nail} = maximum withdrawal resistance (lbs.)
G = specific gravity of the wood member
D = diameter of the nail (in.)
L = penetration into the member (in.)

Given the average specific gravity for all samples of 0.42, a nail diameter of 0.113 and a depth of penetration of 1.300", the mean sidegrain withdrawal load of 194.9 lbs. is 1.49 times greater than the load predicted by Equation [1], 131.8 lbs. The reason for this difference has not been determined, but a relatively small sample size may be a factor. A comparison of nail withdrawal resistance of western junipers and other western species is also provided in Appendix II.

The ratio of the mean end-grain withdrawal resistance, $p_{transverse}$ to the combination of radial and tangential or sidegrain resistance, $p_{sidegrain}$ is equal to 0.69. This value is approximately equal to that obtained by using the Wood Handbook estimation of endgrain withdrawal resistance of approximately 0.75 $p_{sidegrain}$

The ratio of the p_{radial} to $p_{tangential}$ is listed in Table 2, with the mean value for p_{radial} approximately 1% higher than the mean value for $p_{tangential}$. Due to the relatively small sample and inherently large variance, this difference is most likely not statistically significant. For all practical purposes, the two values are the same.

[5] U.S. Dept. Agric. 1989. Wood Handbook. Agric. Hndbk. #72. p. 7-2.

Appendix II also lists the value of the ratio of the experimentally-derived sidegrain value for **p** and the estimated value obtained from use of Equation [1]. The ratio of the mean value for all tests, 1.49, indicates that western juniper has unusually high nail withdrawal resistance when compared to the calculated values for other Pacific Northwest species. This comparison is shown in Figure 2. Further study is needed to determine the extent of this enhanced strength and the possible cause or causes.

Withdrawal Resistance of Wood Screws

Appendix III summarizes the results of the wood screw withdrawal demonstration. Each prism has two values for each face, a withdrawal load in lbs. and the specific gravity. Mean value for straight withdrawal was 493.4 lbs. tangentially, 476.2 lbs. radially and 379 lbs. for the transverse face. The "sidegrain" (the average of the mean tangential and radial values) was 484.8 lbs. The Wood Handbook[6] gives the following formula to estimate the sidegrain withdrawal resistance (p) of a wood screw as follows:

$$p_{screw} = 15{,}700\, G^2 DL \qquad [2]$$

where:

p_{screw} = maximum withdrawal resistance (lbs.)
G = specific gravity of the wood member
D = shank diameter of the screw (in.)
L = penetration of threaded portion into member (in.)

Given the average specific gravity for all samples of 0.42, a screw shank diameter of 0.188" and a depth of penetration of 0.85", the mean sidegrain withdrawal load of 484.8 lbs. is 1.10 times greater than the 442.6-lb. load predicted by Equation [2]. The reason for this difference has not been determined, but a relatively small sample size may be a factor.

The ratio of the mean end-grain screw withdrawal resistance, $\mathbf{p}_{transverse}$ to the combination of radial and tangential or sidegrain resistance, $\mathbf{p}_{sidegrain}$ is equal to 0.77, which is approximately equal to the value obtained by using the Wood Handbook estimator of endgrain withdrawal resistance of approximately 0.75 $\mathbf{p}_{sidegrain}$

The ratio of the $\mathbf{p}_{radial}$ to $\mathbf{p}_{tangential}$ is listed in Table 3, with the mean value for $\mathbf{p}_{radial}$ approximately 3% lower than the mean value for $\mathbf{p}_{tangential}$. Due to the relatively small sample and inherently large variance, this difference is most likely not statistically significant. For all practical purposes, the two values are the same.

Appendix III also lists the value of the ratio of the experimentally-derived sidegrain value for **p** and the

[6] U.S. Dept. Agric. 1989. Wood Handbook. Agric. Hndbk. #72. p. 7-9.

estimated value obtained from use of Equation [1]. The 1.10:1 ratio of test vs. calculated values indicates that western juniper has a slightly higher-than-expected screw withdrawal resistance. A Graphic comparison between the withdrawal resistance of wood screws in western juniper and other western species is shown in Figure 2.

Conclusions

Plate-Joint Strength

1. The principal cause of failure in joints with end-grain included is longitudinal shear manifested by a displaced portion of the outer leg in the approximate shape of the compressed wood plate.

2. No relationship between specific gravity and joint strength was seen in this demonstration.

3. Radial shearing and cleavage in the joint area were the principal causes of failure in side-grain joints.

4. Cleavage failures parallel to the grain in the center of the legs was seen in one-third of the test specimens. These failures, which occurred at bending moments well below the mean, were probably caused by stress concentrations at small, radially-oriented checks.

Dowel-Joint Strength

1. One-quarter inch (0.250) diameter birch dowels are not strong enough to withstand the bending moment of western juniper corner joints as configured in this demonstration.

2. End-grain corner joints that showed leg breakage during testing exhibited radial shear failures in the leg with the dowel hole in the face of the leg.

3. No correlation was found linking joint strength and specific gravity of the component legs..

4. The mean bending moment resistance for the sidegrain joints was approximately 33% higher than that of the end-grain joints.

Nail Withdrawal Resistance

1. For practical applications the means of radial and tangential nail withdrawal loads were essentially equal. The combination of the types of withdrawal would be best-described as the "sidegrain" withdrawal resistance for nails, p_{nail}.

2. Mean transverse-face nail withdrawal loads were about 70% of the mean sidegrain values.

3. Mean sidegrain nail withdrawal strength was approximately 1.5 times that of the value predicted by the equation commonly used to determine the general nail withdrawal load of wood.

4. Contrary to fears prior to this project, western juniper does not appear inclined to split when nailed without lead holes.

Screw Withdrawal Resistance

1. For practical applications the mean screw-withdrawal resistances in the radial and tangential faces were equal. The combination of these would be best-described as the "sidegrain" screw withdrawal resistance, **p**.

2. Western juniper's transverse to sidegrain screw withdrawal ratio of 77% is essentially equal to the Wood Handbook-suggested value of 75%.

3. Sidegrain screw withdrawal strength was approximately 1.1 times that of the value predicted by the Wood Handbook equation commonly used to predict this value. The slightly elevated level of screw holding capacity might possibly be explained by the small sample size.

Implications for Industry

Plate-Joint Strength

1. While small seasoning checks are an appearance issue for panel products, their presence should generate a concern for the structural integrity of western juniper products, as they appear to weaken the wood in the radial direction.

2. Plate joints are a feasible method of making strong corner joints in western juniper, as they do in other materials such as particleboard medium density fiberboard and solid pine. Comparisons with other species and materials cannot be made at this time as the research into these relationships is still underway at this time.

Dowel-Joint Strength

1. Dowelled joints are used when the two members of a joint are either inherently weak when glued (particleboard and fiberboard) or need the added accuracy in alignment that dowelling provides.

2. Since bending strength of 0.250" dowels is less than the bending moment resistance of the western juniper corner joint, dowelled joints will need to use either larger dowels or at least two 0.250" dowels in order to achieve the strength potential of the wood.

3. Further study could include using larger diameters, and, possible, two dowel pins per joint. Due to the small number of samples in this study, further work designed to accurately describe the relationship between joint configuration and strength needs to be completed.

Nail Withdrawal Resistance

1. The Wood Handbook suggests using a value of 75% of the sidegrain value to approximate the transverse-face nail withdrawal-resistance load. Given the small sample size and the probable variation in the species, the deviation from the predicted value is most likely insignificant.

2. It is unknown why western juniper appears to be more effective in nail holding than is commonly calculated,but the small sample size may have had some effect on the results. Prior to industry use of these values in engineering solutions, it would be appropriate to undertake more-extensive tests to determine the range and mean values for this important property.

3. Reports of panel breakage caused by longitudinal splitting initially generated questions concerning this potential problem. But experience gained during these tests provides evidence of a stable nailing platform so long as normally-recommended nailing procedures, such as the use of blunted, box nails for thin members, are followed.

4. Use as furniture corner blocks, where high nail, and staple, withdrawal resistance are required, is a potential product made from western juniper.

5. If two species are used in a nailed-joint system, such as a deck using Douglas-fir joists and western juniper decking, the relatively small amount of in-service shrinking and swelling (movement) normally displayed by juniper would decrease the amount of "nail pull". Resetting of nail heads and other fastener-related maintenance would be decreased.

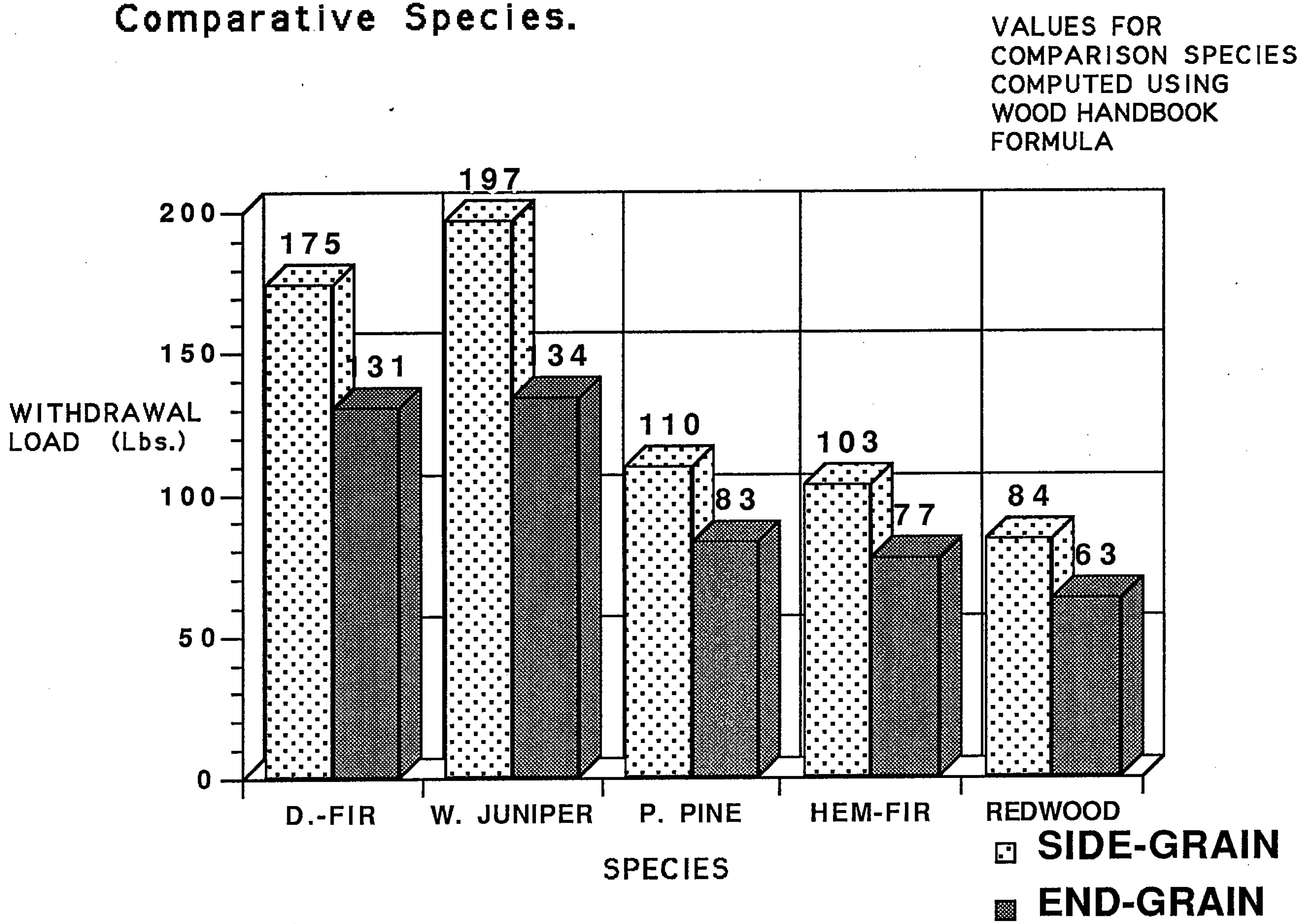
Screw Withdrawal Resistance

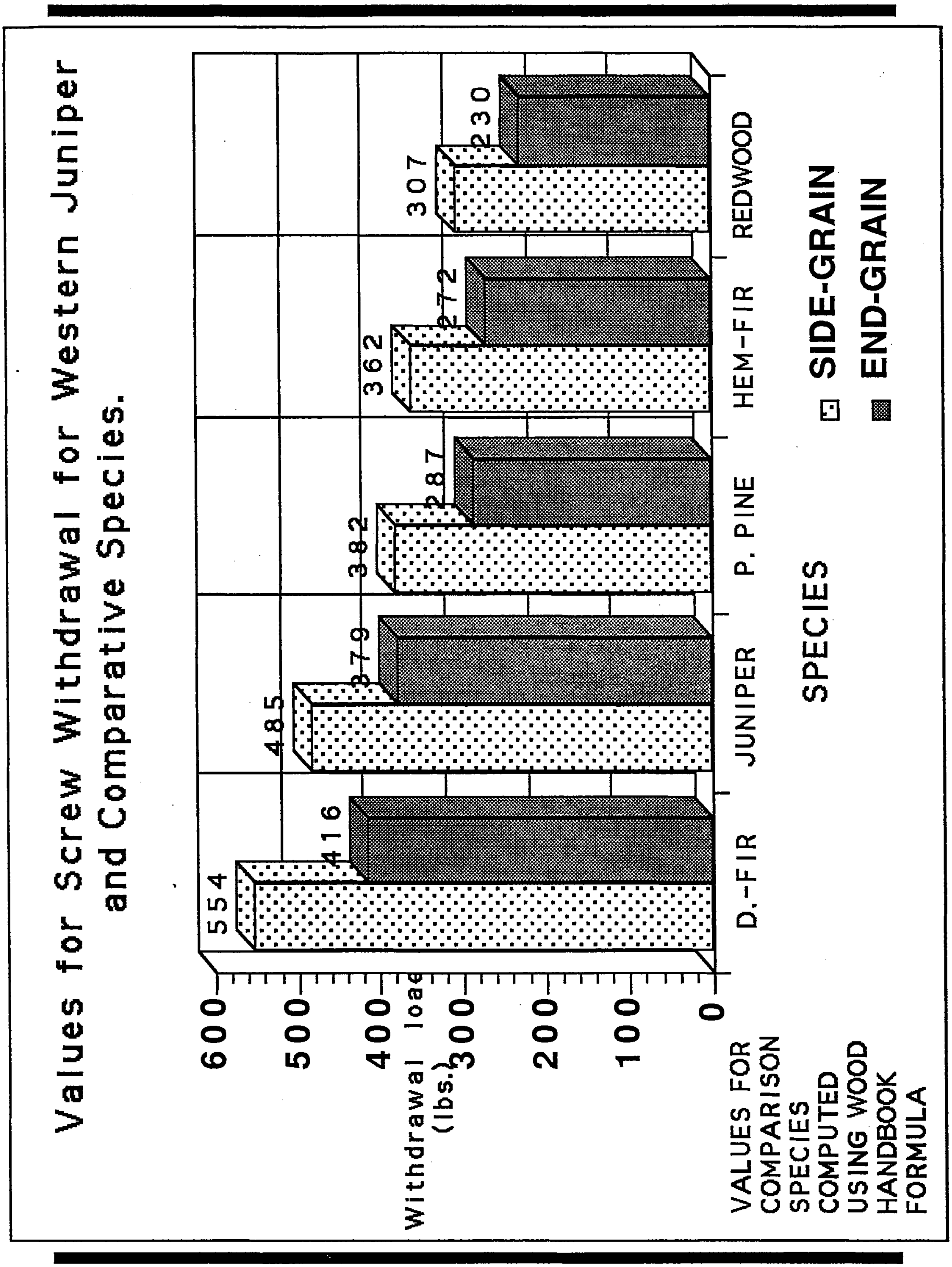
1. It is unknown why western juniper appears to be more effective in screw holding than is commonly calculated,but the small sample size may have had some effect on the results. Prior to industry use these values in engineering solutions, it would be appropriate to perform tests to determine the range and mean values for this important property.

2. Use as furniture corner blocks, where high nail, and staple, withdrawal resistance are required, is a potential avenue for industry to utilize western juniper.

3. As with nailed components, use of juniper in structural systems utilizing screwed joints is a likely commercial use of this species. Chemical reaction with the fasteners, especially uncoated steel screws and nails, is an area in need of immediate study since some extractives in wood are known for their corrosion-enhancing qualities.

Values for Nail Withdrawal for Western Juniper and Comparative Species.




Values for Screw Withdrawal for Western Juniper and Comparative Species.
600
500
400
300
200
100
0
Withdrawal load (lbs.)
554
416
485
379
382
287
362
272
307
230
D.-FIR
JUNIPER
P. PINE
HEM-FIR
REDWOOD
SPECIES
SIDE-GRAIN
END-GRAIN
VALUES FOR COMPARISON SPECIES COMPUTED USING WOOD HANDBOOK FORMULA

APPENDIX I. RESULTS OF TENSION TESTS OF CORNER-JOINTS FASTENED WITH #20 WOOD PLATES

ID #	MAX. LOAD (lbs.)	MAX. MOMENT (lb.-ins.)	Sp. Grav. (OD wt. vol@12%)	FAILURE MODE
END-GRAIN JOINTS				
PE-1	89.5	176.3	0.4	radial shear@ joint
PE-2	62.0	122.1	0.4	radial shear@ joint
PE-3	83.0	163.5	0.39	radial shear @ joint; plate failure
PE-4	81.0	159.6	0.4	radial shear@ joint
PE-5	78.5	154.6	0.42	radial shear@ joint
PE-6	79.0	155.6	0.46	radial shear @ joint; plate failure
PE-7	82.0	161.5	0.44	radial shear@ joint
PE-8	76.0	149.7	0.38	radial shear@ joint
PE-9	90.5	178.3	0.38	radial shear@ joint
PE-10	76.5	150.7	0.39	radial shear @ joint; plate failure
PE-11	79.0	155.6	0.4	radial shear@ joint
PE-12	83.0	163.5	0.45	radial shear@ joint
PE-13	88.0	173.4	0.4	radial shear@ joint
PE-14	73.0	143.8	0.4	radial shear@ joint
PE-15	78.5	154.6	0.42	radial shear@ joint
HIGH	90.5	178.3	0.46	
LOW	62.0	122.1	0.38	
MEAN	80.0	157.5	0.41	
SIDE-GRAIN JOINTS				
PS-1	70.0	128.1	0.44	radial cleavage in center of leg
PS-2	52.0	95.2	0.4	radial cleavage in center of leg
PS-3	96.0	175.7	0.37	radial shear@ joint
PS-4	38.0	69.5	0.41	radial cleavage in center of leg
PS-5	35.5	65.0	0.39	radial cleavage in center of leg
PS-6	69.5	127.2	0.38	radial shear@ joint
PS-7	70.0	128.1	0.4	radial shear@ joint
PS-8	83.0	151.9	0.42	radial shear@ joint
PS-9	66.0	120.8	0.42	radial cleavage in center of leg
PS-10	91.0	166.5	0.36	radial shear@ joint
PS-11	64.0	117.1	0.47	radial shear@ joint
PS-12	61.0	111.6	0.46	radial shear@ joint
PS-13	57.0	104.3	0.42	radial shear@ joint
PS-14	74.0	135.4	0.37	radial shear@ joint
PS-15	70.5	129.0	0.37	radial shear@ joint
HIGH	96.0	175.7	0.47	
LOW	35.5	65.0	0.36	
MEAN	66.5	121.7	0.41	

APPENDIX II. RESULTS OF TENSION TESTS OF CORNER-JOINTS FASTENED WITH 0.25" DIAMETER-DOWELS

ID #	MAX. LOAD (lbs.)	MAX. MOMENT (lb.-ins.)	Sp. Grav. (OD wt. vol.@12% MC)	FAILURE MODE
END GRAIN JOINTS				
DE-1	17.0	33.5	0.38	radial shear; dowel failure
DE-2	21.0	41.4	0.39	radial shear; dowel failure
DE-3	21.0	41.4	0.36	radial shear; dowel failure
DE-4	34.0	67.0	0.41	radial shear; dowel failure
DE-5	19.5	38.4	0.44	radial shear; dowel failure
DE-6	26.5	52.2	0.45	radial shear; dowel failure
DE-7	19.0	37.4	0.42	radial shear; dowel failure
DE-8	22.0	43.3	0.37	radial shear@ joint
DE-9	21.5	42.4	0.46	radial shear; dowel failure
DE-10	18.0	35.5	0.38	radial shear; dowel failure
DE-11	29.0	57.1	0.48	radial shear; dowel failure
DE-12	30.0	59.1	0.44	radial shear; dowel failure
DE-13	20.0	39.4	0.41	radial shear@ joint
DE-14	26.5	52.2	0.4	radial shear; dowel failure
DE-15	21.0	41.4	0.44	radial shear; dowel failure
HIGH	34.0	67.0	0.48	
LOW	17.0	33.5	0.36	
MEAN	23.1	45.4	0.42	
SIDE-GRAIN JOINTS				
DS-1	38.5	70.5	0.44	radial shear@joint leg end; dowel failure
DS-2	39.0	71.4	0.4	radial shear@joint leg end; dowel failure
DS-3	31.0	56.7	0.4	radial shear@joint leg end; dowel failure
DS-4	33.0	60.4	0.4	radial shear@joint leg end; dowel failure
DS-5	36.0	65.9	0.39	radial shear @ leg end in joint
DS-6	36.5	66.8	0.43	radial shear @ leg end in joint
DS-7	33.0	60.4	0.46	radial shear@joint leg end; dowel failure
DS-8	29.0	53.1	0.44	radial cleavage in center of leg
DS-9	33.0	60.4	0.46	radial shear@joint leg end; dowel failure
DS-10	37.0	67.7	0.43	radial shear@joint leg end; dowel failure
DS-11	29.5	54.0	0.39	radial shear@joint leg end; dowel failure
DS-12	28.0	51.2	0.39	radial cleavage in center of leg
DS-13	27.0	49.4	0.41	radial shear@joint leg end; dowel failure
DS-14	30.0	54.9	0.44	radial shear@joint leg end; dowel failure
DS-15	26.5	48.5	0.46	radial shear@joint leg end; dowel failure
HIGH	39.0	71.4	0.46	
LOW	26.5	48.5	0.39	
MEAN	32.5	59.4	0.42	

APPENDIX III. RESULTS OF WITHDRAWAL TESTS OF 6D COMMON NAILS

ID #	Max. Load (lbs.)	Mean Load (lbs.)	Sp.Gr. (OD wt. 12% vol)	ID #	Max. Load (lbs.)	Mean Load (lbs.)	Sp.Gr. (OD wt.& 12% vol)	ID #	Max. Load (lbs.)	Mean Load (lbs.)	Sp.Gr. (OD wt. & 12% vol)
TANGENTIAL				RADIAL				TRANSVERSE			
NT-1A	201			NR-1A	207.0			NX-1A	132		
NT-1B	207	204.0	0.45	NR-1B	211.0	209.0	0.44	NX-1B	123.5	127.8	0.45
NT-2A	201.5			NR-2A	252.0			NX-2A	144		
NT-2B	206	203.8	0.43	NR-2B	234.0	243.0	0.45	NX-2B	149	146.5	0.43
NT-3A	202			NR-3A	194.0			NX-3A	124		
NT-3B	143	172.5	0.4	NR-3B	197.0	195.5	0.42	NX-3B	140	132.0	0.42
NT-4A	260			NR-4A	244.0			NX-4A	150		
NT-4B	245	252.5	0.47	NR-4B	230.0	237.0	0.46	NX-4B	136	143.0	0.45
NT-5A	187			NR-5A	202.0			NX-5A	128.5		
NT-5B	185	186.0	0.41	NR-5B	188.0	195.0	0.42	NX-5B	139	133.8	0.42
NT-6A	194			NR-6A	210.0			NX-6A	132		
NT-6B	185	189.5	0.41	NR-6B	189.0	199.5	0.4	NX-6B	139	135.5	0.41
NT-7A	166			NR-7A	159.0			NX-7A	122		
NT-7B	174.5	170.3	0.4	NR-7B	164.0	161.5	0.41	NX-7B	119	120.5	0.39
NT-8A	185			NR-8A	202.0			NX-8A	120		
NT-8B	169	177.0	0.4	NR-8B	168.0	185.0	0.41	NX-8B	128.5	124.3	0.4
NT-9A	211			NR-9A	188.0			NX-9A	125		
NT-9B	203.5	207.3	0.45	NR-9B	184.5	186.3	0.42	NX-9B	129	127.0	0.43
NT-10A	221			NR-10A	193.0			NX-10A	149.5		
NT-10B	209	215.0	0.44	NR-10B	226.5	209.8	0.43	NX-10B	133	141.3	0.45
NT-11A	178			NR-11A	199.0			NX-11A	132		
NT-11B	186	182.0	0.4	NR-11B	183.0	191.0	0.41	NX-11B	140	136.0	0.43
NT-12A	159			NR-12A	174.0			NX-12A	122		
NT-12B	164	161.5	0.36	NR-12B	162.0	168.0	0.38	NX-12B	118	120.0	0.36
NT-13A	188			NR-13A	187.0			NX-13A	127		
NT-13B	169	178.5	0.4	NR-13B	175.0	181.0	0.41	NX-13B	130.5	128.8	0.39
NT-14A	225			NR-14A	210.0			NX-14A	148		
NT-14B	198	211.5	0.44	NR-14B	202.0	206.0	0.44	NX-14B	151	149.5	0.44
NT-15A	210.5			NR-15A	218.0			NX-15A	148		
NT-15B	214	212.3	0.45	NR-15B	224.0	221.0	0.46	NX-15B	144	146.0	0.45
HIGH	260	252.5	0.47	HIGH	252.0	243.0	0.46	HIGH	151	149.5	0.45
LOW	143	161.5	0.36	LOW	159.0	161.5	0.38	LOW	118	120.0	0.36
MEAN	194.9	194.9	0.42	MEAN	199.2	199.2	0.42	MEAN	134.1	134.1	0.42

"Side-Grain" Withdrawal Loa		Ratio of Transverse to "Side-Grain" Withdrawal		
HIGH	260.0	HIGH	0.59	0.47
LOW	143.0	LOW	0.74	0.36
MEAN	197.1	MEAN	0.69	0.42

Ratio of side-grain withdrawal load to			R:T ratio	
HIGH	1.49	Wood Handbook formula (p=7,850G 2.5DL)	HIGH	1.02
LOW	1.59		LOW	1.06
MEAN	1.49		MEAN	1.01

APPENDIX IV. RESULTS OF WITHDRAWAL TESTS OF #10 FLATHEAD WOODSCREW

ID #	Max. Load (lbs.)	Mean Load (lbs.)	Sp.Gr. (OD wt. 12% vol)	ID #	Max. Load (lbs.)	Mean Load (lbs.)	Sp.Gr. (OD wt. 12% vol)	ID #	Max. Load (lbs.)	Mean Load (lbs.)	Sp.Gr. (OD wt. 12% vol)
TANGENTIAL				RADIAL				TRANSVERSE			
ST-1A	479			SR-1A	450			SX-1A	414.5		
ST-1B	480	479.5	0.41	SR-1B	491	470.5	0.43	SX-1B	419.5	417.0	0.42
ST-2A	475			SR-2A	462			SX-2A	336		
ST-2B	479	477.0	0.42	SR-2B	466	464.0	0.41	SX-2B	290	313.0	0.38
ST-3A	506			SR-3A	461.5			SX-3A	404		
ST-3B	554	530.0	0.42	SR-3B	488	474.8	0.42	SX-3B	313	358.5	0.42
ST-4A	497.5			SR-4A	520.5			SX-4A	366.5		
ST-4B	503.5	500.5	0.44	SR-4B	489.5	505.0	0.44	SX-4B	371	368.8	0.44
ST-5A	484			SR-5A	445			SX-5A	395		
ST-5B	469	476.5	0.41	SR-5B	470	457.5	0.41	SX-5B	400	397.5	0.42
ST-6A	494			SR-6A	484			SX-6A	375		
ST-6B	506	500.0	0.43	SR-6B	490	487.0	0.42	SX-6B	380	377.5	0.42
ST-7A	522			SR-7A	493			SX-7A	410		
ST-7B	486	504.0	0.41	SR-7B	499	496.0	0.41	SX-7B	376	393.0	0.42
ST-8A	510			SR-8A	480			SX-8A	365		
ST-8B	500	505.0	0.43	SR-8B	472	476.0	0.43	SX-8B	412	388.5	0.42
ST-9A	473			SR-9A	446			SX-9A	405		
ST-9B	515	494.0	0.4	SR-9B	457.5	451.8	0.4	SX-9B	388.5	396.8	0.4
ST-10A	485			SR-10A	475			SX-10A	335		
ST-10B	492.5	488.8	0.41	SR-10B	491	483.0	0.4	SX-10B	349	342.0	0.39
ST-11A	514			SR-11A	505			SX-11A	426		
ST-11B	535	524.5	0.42	SR-11B	496	500.5	0.44	SX-11B	448	437.0	0.43
ST-12A	512			SR-12A	463			SX-12A	401		
ST-12B	476	494.0	0.44	SR-12B	468.5	465.8	0.44	SX-12B	387.5	394.3	0.42
ST-13A	488.5			SR-13A	512			SX-13A	387.0		
ST-13B	503	495.8	0.41	SR-13B	502	507.0	0.46	SX-13B	392.0	389.5	0.41
ST-14A	484			SR-14A	492			SX-14A	363		
ST-14B	479	481.5	0.4	SR-14B	501	496.5	0.4	SX-14B	378	370.5	0.4
ST-15A	438			SR-15A	420			SX-15A	322		
ST-15B	462	450.0	0.39	SR-15B	396	408.0	0.37	SX-15B	361	341.5	0.38
HIGH	554	530.0	0.44	HIGH	520.5	507.0	0.46	HIGH	448	437.0	0.44
LOW	438	450.0	0.39	LOW	396	408.0	0.37	LOW	290	313.0	0.38
MEAN	493.4	493.4	0.42	MEAN	476.22	476.2	0.42	MEAN	379	379.0	0.41

"Side-Grain" Withdrawal Loa		Ratio of Transverse to "Side-Grain" Withdrawal		
HIGH	554.0	HIGH	0.82	0.46
LOW	396.0	LOW	0.70	0.37
MEAN	484.8	MEAN	0.77	0.42

Ratio of side-grain withdrawal load to Wood Handbook			R:T ratio	
HIGH	1.04	formula (p=15,700(G*G)DL)	HIGH	0.96
LOW	1.15		LOW	0.91
MEAN	1.10	436.9609	MEAN	0.97