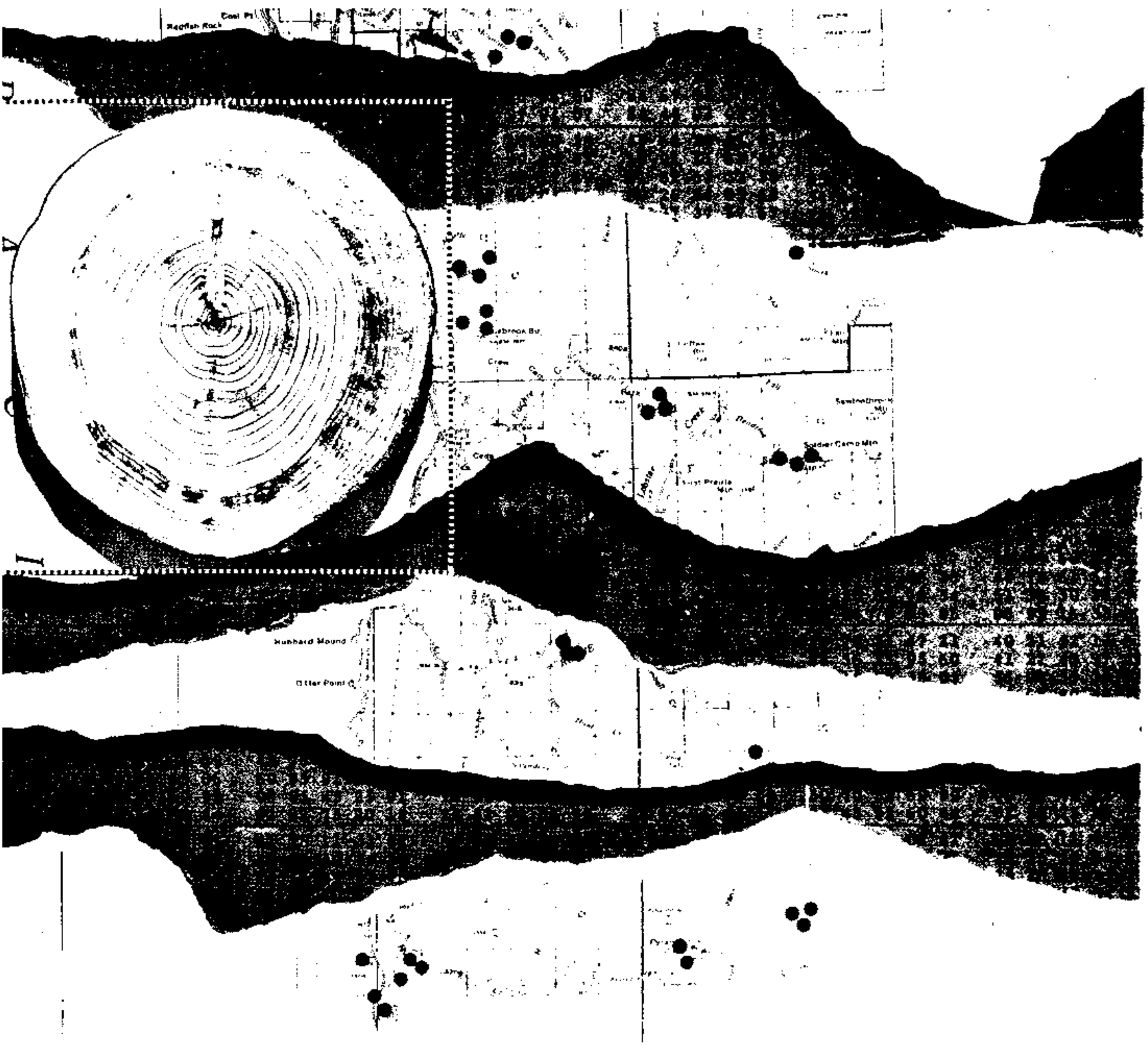
U. S. FOREST SERVICE
RESEARCH PAPER
FPL 53
FEBRUARY 1966

U.S. DEPARTMENT OF AGRICULTURE • FOREST SERVICE • FOREST PRODUCTS LABORATORY • MADISON, WIS

Strength and Related Properties of a Randomly Selected Sample of Second - Growth Redwood



ABSTRACT

Twenty–four trees were randomly selected from the second-growth redwood (Sequoia sempervirens) stands of four member companies of the California Redwood Association. Further random procedures were used to select 8-foot bolts from these trees and for the selection of specimen material from each bolt for the evaluation of the strength and related properties of second–growth redwood.

Most mechanical properties were found to be 20 to 25 percent lower than those of virgin material. Exceptions to this were maximum shearing strength parallel to grain and maximum tensile strength parallel to grain. The mechanical properties were generally substantially higher than previously reported for open–grown second–growth material but comparable to the properties of close–grown material. Important structural properties such as modulus of elasticity and modulus of rupture in bending, maximum crushing strength parallel to grain, and maximum shearing strength were substantially higher than an average of close– and open–grown material previously evaluated.

Although the average specific gravity was only approximately 10 percent lower than for virgin material, most strength properties are somewhat lower than those of virgin redwood of the same specific gravity.

Shrinkage characteristics are comparable to those previously reported for virgin and second–growth redwood.

Strength and Related Properties of a Randomly Selected Sample of Second - Growth Redwood

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INTRODUCTION

The redwood timber industries of the West Coast are faced with the loss of their primary resource, the virgin redwood (Sequoia sempervirens). It was estimated in 1948, however, that commercially stocked young-growth[2] redwood stands totaled 727,000 acres or 38 percent of the total redwood region (4).[3] The redwood industries have been reluctant to use this great potential source of material, principally because of the differences between the properties of virgin and second-growth redwood. Also, the second-growth redwood typically grows in a variety of stand types. This, together with its small diameter, have generally made it economically impractical to harvest.

A number of studies have been conducted which have generally shown that second-growth redwood is lower in specific gravity and inferior in most strength properties when compared to virgin timber. Fritz (2) found that fiber stress at the elastic limit and modulus of rupture in bending, maximum crushing strength, and hardness were lower than reported by the Forest Products Laboratory (7). However, he noted that modulus of elasticity in bending, stress at elastic limit in compression parallel to grain, compressive stress perpendicular to grain, and shear parallel to grain were higher in the second-growth redwood.

The work by Luxford and Markwardt (6) also indicates that second-growth redwood is weaker in most strength properties, and probably of greater importance, that the second-growth redwood is lower in some important strength properties than might be expected based upon the specific gravity. Paul (8) stated that, although the average specific gravity of second-growth redwood is slightly less than virgin-growth redwood, the range of specific gravity is considerably less in second-growth. Fritz (2), Luxford and Markwardt (6), and Schniewind (10) also reported lower specific gravity for the second-growth material.

Schniewind reported greater tangential shrinkage for second-growth but noted that the radial and longitudinal shrinkage of second- and virgin-growth was nearly comparable. Paul (8) found that the shrinkage of open-grown second-growth redwood was comparable to that of virgin growth in the tangential direction but somewhat less in the radial direction. In close-grown material he found that the radial shrinkage was approximately the same as in virgin material while shrinkage in the tangential direction was somewhat greater

[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.
[2] The term second-growth is used interchangeably with young-growth in this report to mean other than virgin timber.
[3] Underlined numbers in parentheses refer to Literature Cited at the end of this report.

than in the virgin-growth redwood.

Despite these reported differences in properties, certain economic factors in recent years have focused attention on the utilization of young-growth redwood. Improved logging equipment and techniques have made it practical to log smaller diameter material even under more adverse conditions. Added stimulus is provided by the fact that the young-growth timber stands are taxed as they reach merchantable size and, of course, the inevitable depletion of the virgin material is a primary consideration.

With the increased attention on the utilization of second-growth redwood, the question has arisen as to whether the difference between virgin- and second-growth material is as great as has been reported. It was felt that existing data regarding the strength and related properties of second-growth redwood were inadequate to meet the present-day needs of the redwood industries when considering the variety of conditions under which the young timber is developing. This evaluation of the mechanical and physical properties of second-growth redwood, was conducted in cooperation with the California Redwood Association as part of the Redwood Young Timber Evaluation Program undertaken by CRA's Research and Development Committee.

EXPERIMENTAL

Sampling Procedures

Since 1922, researchers in the United States, Canada,manyEuropeancountries,andmanyother countries of the world involved in the evaluation of the strength and related properties of tree species have followed the procedures specified by the American Society for Testing and Materials fixed designation D 143, the latest of these being D 143-52 (1). These methods descrive the entire procedure from the selection of trees to the manipulation of the tests. These methods have provided a basis for the accumulation of fundamental information regarding timber species of the world and for the world-wide unification and dissemination of results. However, modern sttistical theory suggests that an equally good estimation of the properties of a species might be obtained more efficiently and economically by random sampling procedures.

An important part of obtaining average properties for a timber species is that of estimating the average properties of a bolt since impications must be made from these averages regarding average properties of tree and finally of the entire population of the species. Hinz (3), selected specimens from the same bolts by both a random technique and by the standard ASTM cruciform method. Twenty-eight bolts were evaluated for compression parallel to grain properties while evaluation of static bending, compression perpendicular to grain, and shear parallel to grain properties were limited to half of these bolts. He concluded that random sampling can be used as an alternative to standard sampling.

There is ample evidence in the literature (9) to indicate that between-tree variance is greater than within-tree variation. This suggests that a better estimate of the properties of a species population can be obtained from a like number of samples if fewer samples are taken per tree but from a larger number of trees than has normally been sampled by the ASTM procedures. The between-tree variation probably assumes even greater significance in second growth redwood because of the various conditions under which it grows. Therefore, random procedures were used in the selection and sampling of a greater number of trees than normal and in the selection of individual test specimens from the trees.

Four member companies of the California Redwood Association cooperated in providing twenty-four 8-foot logs. Each company recorded areas from its stands which satisfied the following restrictions: (a) Second-growth timber stands having 50 percent or more redwood by volume; (b) stands 40 years old or older; and (c) stands transected or bordered by a usable truck road. Each company randomly selected two townships from its recorded areas and from each township randomly selected one section. Further random procedures were applied for the selection of a plot from each section and for the selection of three trees from each selected plot. Restrictions placed upon the selection of trees were (a) that they be at least 18 inches in diameter at breast height, (b) that they contain at least one 20-foot merchantable log, and (c) that there be no visible sign of rot int he tree or evidence of rot in an increment boring. Primary concern in the entire procedure for the selection of the trees was that each accessible, merchantable young-growth redwood tree in the holdings of the four companies involved had an equal chance of being selected.

The trees were bucked into 20– and 40–foot logs and shipped to mills of participating companies for further processing. One 8–foot bolt was selected from the logs from each tree by suitable random procedures. The 8-foot length at each end of each log and the central 8–foot length of each 40–foot log were considered as possible sections in the random selection of bolts.

Specimen Preparation

The twenty–four 8–foot bolts were then shipped to Madison, Wis., for further processing. Planks approximately 3 by 8 inches in cross section were cut from each log according to the sawing diagram shown in figure 1. Where there was sufficient material, four planks were selected from each bolt by placing a 2–1/2–inch numbered grid over the sawing diagram and reading numbers from an appropriate table of random numbers.

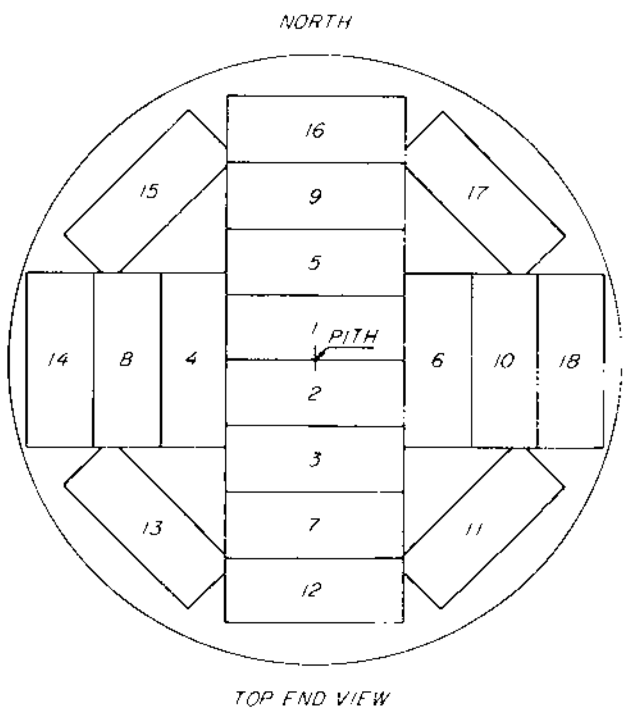

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Figure 1.--Diagram for sawing 3- by 8-inch flat-sawn planks from 8-foot bolts of redwood.

Each plank was then resawn into sticks approximately 2–1/2 inches in cross section and 8 feet long. One end of each stick was used for the preparation of green specimens and the other for the preparation of dry specimens. For evaluation of properties in the green condition, four toughness specimens, a radial–tangential pair of specimens for shear parallel to grain, cleavage and tension perpendicular to grain, and one specimen for each of the remaining strength tests were prepared from each plank. A similar set of specimens was prepared from each plank for the evaluation of air–dry properties, An effort was made to prepare specimens for the green and air–dry tests from opposite ends of the same stick; however, in many instances growth characteristics controlled the location of specimens, making it impossible to use a prescribed specimen layout system.

Specimens to be tested in the green condition were immediately machined to final dimension. Material to be evaluated in the air–dry condition was carefully dried to approximate equilibrium while in the 2–1/2–by 2–1/2–inch dimension and then machined to final size. All tests were conducted according to procedures outlined in ASTM D 143–52(1).

DESCRIPTION OF MATERIALS

Eighteen of the 24 trees evaluated came from Humboldt County, Calif., while the remaining 6 came from Mendocino County, Calif. Information regarding individual trees and of the 8–foot bolts evaluated is shown in table 1.

The bolts in general had many knots. In several the growth was quite eccentric about the pith and in some instances there was evidence of decay at or near the center of the bolt. Figures 2, 3, and 4, which show cross sections of several logs, were selected as being representative of the range of quality of the 24 bolts evaluated. The two upper cross sections in figure 2 were cut from the poorest logs of the shipment. They were less than 12 inches in diameter and extremely knotty. The sections in figure 3 represent the typical log evaluated. Those in figure 4 are from excellent second–growth logs, showing fairly uniform sate of growth and a circular cross section free of knots.

Table 1.--General information regarding the individual trees and bolts

FPL bolt No.	Tree location, California county	Position of bolt above stump	Total merchantable length	Diameter breast height outside bark	Bolt diameter	
					Top	Butt
		Ft.	Ft.	In.	In.	In.
1	Humbolt	0-8	40	18	13.0	16.0
2	Humbolt	32-40	60	25	13.5	16.0
3	Humbolt	0-8	60	26	18.5	23.0
4	Humbolt	0-8	40	18	14.0	17.0
5	Humbolt	32-40	60	41	18.0	20.0
6	Humbolt	20-28	60	26	14.5	16.0
7	Humbolt	52-60	60	24	10.5	12.0
8	Humbolt	12-20	60	25	20.5	21.5
9	Humbolt	12-20	80	30	17.5	18.5
10	Humbolt	32-40	100	26	17.0	18.0
11	Humbolt	52-60	80	35	16.5	17.0
12	Humbolt	52-60	100	26	13.0	13.5
13	Humbolt	12-20	80	22	14.5	15.5
14	Humbolt	12-20	80	30	21.5	23.0
15	Humbolt	20-28	100	31	21.5	22.5
16	Humbolt	32-40	80	36	23.5	25.0
17	Humbolt	52-60	100	33	9.0	10.0
18	Humbolt	12-20	80	30	21.0	22.0
19	Mendocino	12-20	100	30	21.0	21.5
20	Mendocino	60-68	80	52	19.5	19.0
21	Mendocino	92-100	130	62	29.0	33.0
22	Mendocino	32-40	100	26	16.0	16.5
23	Mendocino	52-60	120	31	17.5	19.0
24	Mendocino	20-28	100	26	16.5	18.0

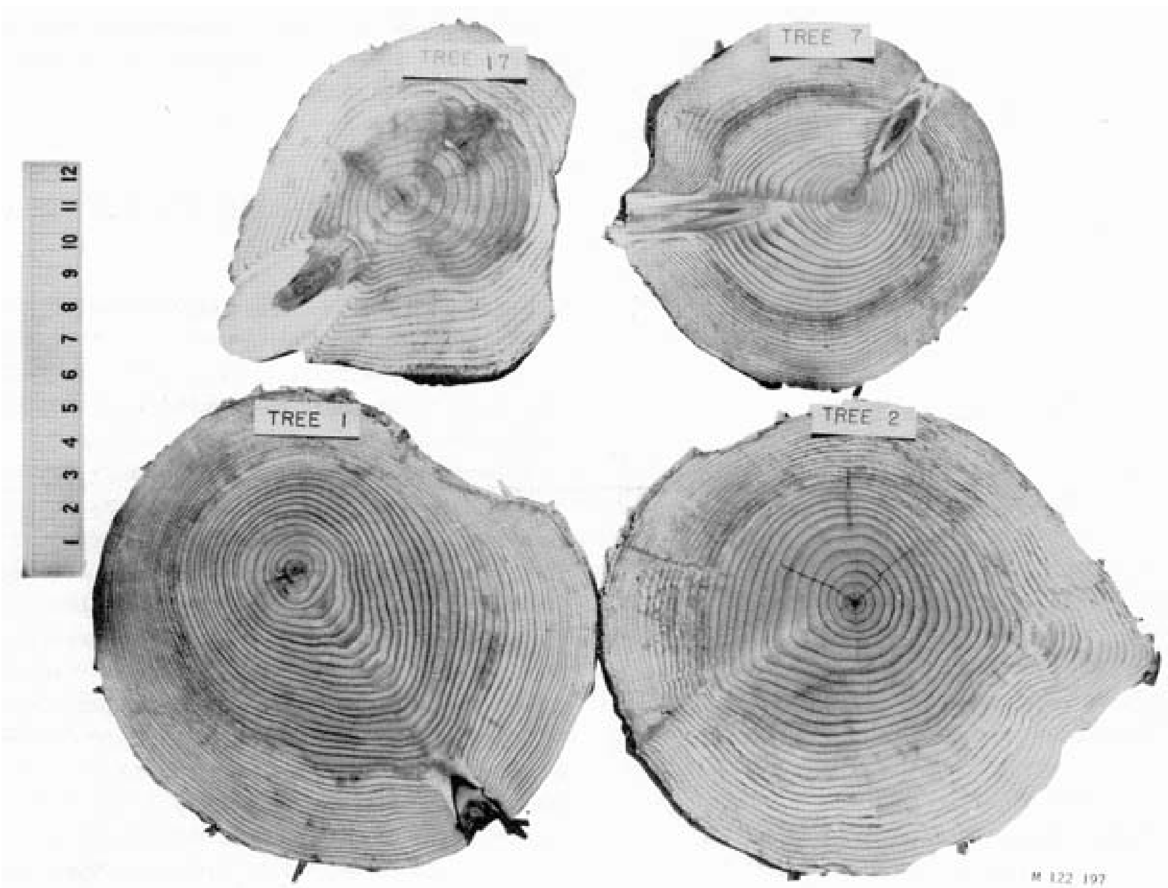


Figure 2.--Cross sections of extremely poor second-growth redwood logs.

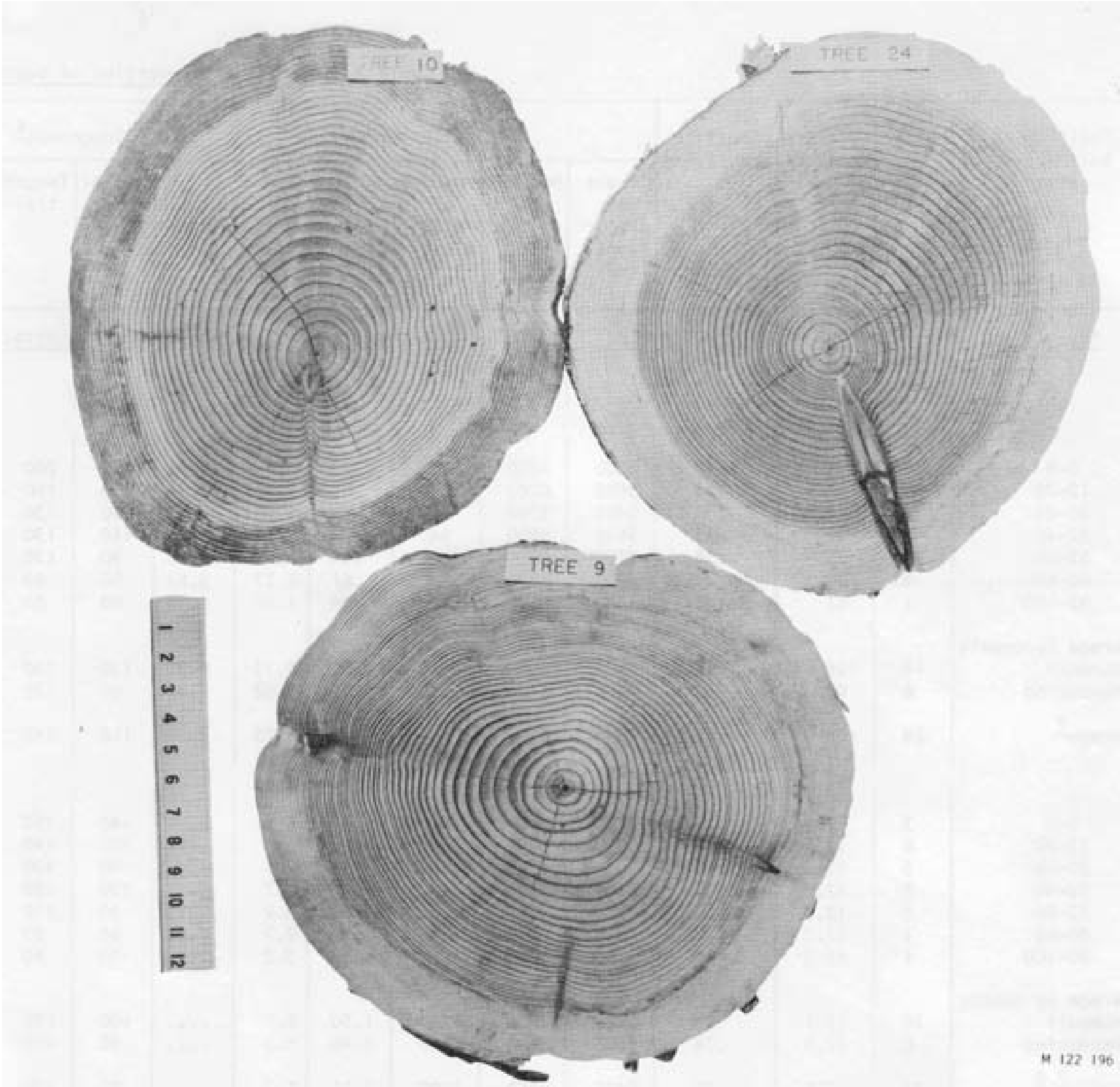


Figure 3.--Cross sections of typical second-growth redwood logs.

Figure 4.--Cross sections of excellent second-growth redwood logs.

Table 2.--Mechanical properties of second-growth

Position of bolt above stump	Number of bolts	Moisture content[1]	Specific gravity[2,3]	Static bending						Toughness[4]		Impact bending[5]
				Stress at propor-tional limit	Modulus of rupture	Modulus of elas-ticity	Work			Radial	Tangen-tial	
							Propor-tional limit	Maxi-mum load	Total			
Ft.		Pct.		P.s.i.	P.s.i.	1000 p.s.i.	In.-lb per cu.in.	In.-lb. per cu.in.	In.-lb. per cu.in.	In.-lb.	In.-lb.	In.
												GREEN
0-8	3	155	0.35	3200	5700	850	0.75	6.79	15.86	170	200	24
12-20	6	120	.36	3800	6200	1040	.81	5.85	10.74	130	160	18
20-28	3	86	.34	3400	5700	840	.79	5.94	6.32	90	130	16
32-40	5	99	.33	3600	5800	940	.79	5.22	9.15	110	130	16
52-60	5	75	.35	4000	6700	1100	.84	6.00	7.76	90	130	14
60-68	1	140	.24	2600	4000	630	.61	3.37	3.57	50	60	9
92-100	1	83	.29	3700	5200	800	.94	4.10	4.10	60	60	9
Average by county												
Humbolt	18	108	.34	3600	5900	940	.80	5.73	9.80	120	150	17
Mendocino	6	99	.33	3700	6100	1000	.78	5.62	7.65	80	120	16
Average[7]	24	105	.34	3600	5900	960	.80	5.70	9.30	110	140	16
												AIR-DRY
0-8	3	11.9	.36	5100	8800	950	1.62	8.9	....	140	150	20
12-20	6	12.0	.36	5900	8600	1240	1.60	5.8	....	100	140	17
20-28	3	12.4	.35	5000	7500	980	1.43	4.5	....	80	100	14
32-40	5	12.0	.34	5200	7500	1070	1.44	4.7	....	100	120	15
52-60	5	12.5	.36	5700	7900	1230	1.50	4.2	....	90	110	15
60-68	1	12.7	.25	3300	5000	720	.89	2.7	....	60	60	6
92-100	1	12.2	.30	5100	6600	1000	1.44	3.2	....	70	80	8
Average by county												
Humbolt	18	12.1	.35	5400	7800	1090	1.50	5.2	....	100	120	16
Mendocino	6	12.5	.34	5400	8100	1140	1.46	5.3	....	90	110	15
Average[7,8]	24	12.0	.35	5400	7900	1100	1.51	5.2	....	90	120	15

[1]Moisture content if static bending specimen.
[2]Based on ovendry weight and green volume.
[3]Average of static bending and compression parallel-to-grain specimens.
[4]Total toughness (inch-pounds per specimen) when loaded on face indicated.
[5]Height of drop causing complete failure (50-lb. hammer).
[6]Load required to embed a 0.444-inch ball to 1/2 its diameter.
[7]Average of tree averages for new second-growth redwood data.
[8]Average values adjusted to 12 percent moisture content.

PRESENTATION OF RESULTS

Data on the mechanical properties in the green and the air-dry condition are presented in table 2. The data are summarized by height in the tree. Table 3 shows the average green and air-dry properties and compares them to previous data on second-growth and on virgin timber. In table 4 the new data on second-growth redwood are expressed as percentages of the strengths obtained in previous evaluations of second-growth and virgin-growth redwood. Table 5 presents the results of linear regressions of certain important strength properties versus specific gravity. The regression curves for these analyses arc shown in figures 5 and 6. Variations of strength and related properties of green wood and how they compare to the variations in other species and in previous redwood data are presented in table 6. A number of flexural properties of sapwood and heartwood in air-dry condition from the same redwood in the green and air-dry condition

Compression parallel to grain: Stress at proportional limit	Compression parallel to grain: Maximum crushing strength	Compression parallel to grain: Modulus of elasticity	Compression perpendicular to grain stress at proportional limit	Hardness[6]: End	Hardness[6]: Side	Maximum shearing strength	Cleavage	Tension perpendicular to grain	Tension parallel to grain: Stress at proportional limit	Tension parallel to grain: Maximum tension strength	Tension parallel to grain: Modulus of elasticity	Nail withdrawal: End	Nail withdrawal: Side
P.s.i.	P.s.i.	1000 p.s.i.	P.s.i.	Lb.	Lb.	P.s.i.	Lb. per in. of width	P.s.i.	P.s.i.	P.s.i.	1000 p.s.i.	Lb.	Lb.
1660	2760	850	340	590	440	970	170	350	4000	8400	770	52	130
2330	3410	1220	260	530	370	880	170	280	6800	10300	1350	56	120
1710	3020	950	270	500	340	890	160	280	5500	8500	1060	53	120
1860	3010	1090	260	500	330	880	100	310	5700	9300	1170	60	120
2080	3420	1260	280	540	350	940	170	300	7000	9600	1305	80	150
1310	2010	730	160	360	180	670	120	220	2900	5600	700	...	...
2090	2830	980	200	410	230	820	150	270	5400	6500	1060	50	90
1930	5100	1060	270	530	360	910	160	300	5600	9100	1120	57	120
2060	3170	1180	270	490	310	850	150	290	6800	9100	1280	63	120
1970	3110	1090	270	520	350	890	160	300	5900	9100	1160	60	120
2090	4870	930	580	770	470	1260	170	250	5400	10700	960	60	120
3310	5600	1370	500	760	450	1090	150	240	7700	10600	1450	70	120
2740	4800	1110	540	720	420	1090	140	240	6700	7900	1180	70	110
3070	4900	1260	480	710	390	1060	150	260	8400	10100	1440	60	110
3190	5650	1390	540	780	430	1160	140	260	11000	11300	1550	80	120
1810	3430	830	340	500	230	870	110	200	5300	8400	770	50	70
2610	4310	1020	480	600	290	1150	110	220	7300	7600	1140	50	80
2830	5140	1200	520	740	430	1120	150	250	7720	9500	1310	70	110
3180	5080	1310	490	700	370	1110	140	240	8700	11300	1410	70	110
2960	5220	1230	520	740	420	1110	140	250	7900	10000	1340	70	110

trees are compared in table 7. Table 8 shows the shrinkage characteristics and compares them to those obtained in previous research on redwood.

DISCUSSION OF RESULTS

The strength properties of second-growth redwood evaluated in both the green and the air-dry condition were found to be considerably less than for virgin redwood (table 4). Exceptions to this are the maximum shearing strength parallel to grain, and the maximum tensile strength perpendicular to grain. Maximum shearing strength was approximately 10 percent higher in the green condition and 20 percent higher in the dry condition than virgin redwood while the maximum tensile strength was approximately 10 and 5 percent higher in the green and dry condition, respectively. All other mechanical properties of the second-growth redwood were lower than for virgin material. In important properties such as modulus of elasticity and modulus of rupture in bending and maximum crushing strength parallel to grain, the second-growth redwood was found to be approximately 75 to 80 percent as strong as the virgin material.

The second-growth redwood evaluated in this research, which includes both open- and close-grown material, was found to be substantially higher in mechanical properties than those previously reported for open-grown second-growth redwood. This difference was particularly pronounced in modulus of elasticity and total work in bending, maximum crushing strength parallel

Table 3.--Some strength and related properties of second-growth redwood compared to previous data on virgin and second-growth redwood

Data source	Shrinkage green to oven dry: Radial	Shrinkage green to oven dry: Tangential	Moisture content	Specific gravity [1]	Static bending: Stress at proportional limit	Static bending: Modulus of rupture	Static bending: Modulus of elasticity	Static bending: Work: Proportional limit	Static bending: Work: Maximum load	Static bending: Work: Total	Compression parallel to grain: Stress at proportional limit	Compression parallel to grain: Maximum crushing strength	Hardness [2]: End	Hardness [2]: Side	Impact bending [3]	Compression perpendicular to grain stress at proportional limit	Maximum shearing strength	Tension perpendicular to grain at maximum tension strength
	Pct.	Pct.	Pct.		P.s.i.	P.s.i.	1000 p.s.i.	In.-lb. per cu. in.	In.-lb. per cu. in.	In.-lb. per cu. in.	P.s.i.	P.s.i.	Lb.	Lb.	In.	P.s.i.	P.s.i.	P.s.i.
Virgin growth [4]	2.6	4.4	112	0.38	4800	7500	1180	1.18	7.4	15.2	3700	4200	570	410	21	520	800	260
Second-growth [4] (open growth)	2.0	4.4	146	.28	2800	4600	640	.68	5.1	6.3	1810	2320	390	280	14	310	640	260
Second-growth [4] (close grown)	2.4	5.0	112	.32	3600	6100	1000	.73	6.1	10.9	2840	3280	470	350	18	350	730	290
Average second-growth [4] (open & close grown)	2.2	4.7	129	.30	3200	5400	820	.70	5.6	8.6	2320	2800	430	320	16	330	680	280
Second-growth (new data)	2.2	4.9	105	.34	3600	5900	960	.80	5.7	9.3	1970	3110	520	350	16	270	890	300
Average all second growth [5]	2.2	4.8	113	.33	3500	5700	920	.77	5.7	9.2	2130	3020	490	340	16	290	820	290
AIR DRY																		
Virgin growth [4]	......	......	12	.40	6900	10000	1340	2.04	6.9	8.8	4560	6150	790	480	19	860	940	240
Second-growth [4] (open grown)	......	......	12	.30	4200	6400	760	1.35	4.7	4.9	2660	3810	590	340	11	550	860	240
Second-growth [4] (close grown)	......	......	12	.34	5500	8300	1120	1.50	5.7	7.9	3750	5240	710	400	16	640	930	280
Average second-growth [4] (open & close grown)	......	......	12	.32	4800	7400	940	1.40	5.2	6.6	3200	4520	650	370	14	600	900	260
Second-growth (new data)	......	......	12	.35	5400	7900	1100	1.51	5.2	......	2960	5220	740	420	15	520	1110	250
	......	......	12	.34	5240	7770	1050	1.48	5.2	6.6	3080	5000	710	400	14	550	1040	250

[1] Based on volume at test and ovendry weight

[2] Load required to embed a 0.444-inch ball to 1/2 its diameter.

[3] Height of drop causing complete failure (50-pound hammer).

[4] U.S.D.A. Tech. Bul. 479 (7).

[5] Average of all tree averages.

Table 4.--Some strength properties of the new second-growth redwood data expressed as a percent of the strength of previously evaluated redwood

Basis of comparison [1]	Specific gravity	Static bending: Stress at proportional limit	Static bending: Modulus of rupture	Static bending: Modulus of elasticity	Static bending: Work: Proportional limit	Static bending: Work: Maximum load	Static bending: Work: Total	Compression parallel to grain: Stress at proportional limit	Compression parallel to grain: Maximum crushing strength	Hardness: End	Hardness: Side	Impact bending	perpendicular grain stress proportional	Maximum shearing strength	grain maxi-mum tens ion strength
Virgin growth	89	75	79	81	68	77	61	53	74	91	85	76	52	111	I15
Second-growth (open grown)	121	129	128	150	118	112	148	109	134	133	125	114	87	139	I15
Second-growth (close grown)	106	100	97	96	110	93	85	69	95	111	100	89	77	122	103
Average second-growth (open and close)	113	112	I09	117	114	102	108	85	111	121	109	100	82	131	107
	88	78	79	82	74	75	.....	65	85	94	88	79	60	118	104
	117	129	123	145	112	111	.....	111	137	125	124	136	95	129	104
	103	98	95	98	101	91	.....	79	100	104	105	94	81	119	89
(close grown)															
Average second-growth (open and close grown)	109	113	107	117	108	100	.....	92	I15	114	114	107	87	123	96

to grain, and in maximum shearing strength parallel to grain. Values 25 to 50 percent greater than the previous data were noted in these properties in both the green and the air-dry condition. When compared to close-grown second-growth redwood previously evaluated, however, most of the mechanical properties are nearly comparable. When compared to all average of previously evaluated close- and open-grown material, the important structural properties of the material from the current evaluation, such as modulus of elasticity and modulus of rupture in bending, maximum crushing strength parallel to grain, and maximum shearing strength, are from 10 to 30 percent higher in both the green and the dry condition.

It is clear in table 3 that the average properties for the several data sources rank in about the same order as the average specific gravities. Thus, specific gravity differences provide at least partial explanation for the observed property differences. Linear regression analyses, summarized in table 5, and graphed in figures 5 and 6, show that this same order prevails for bending and compression parallel-to-grain properties throughout most of the range of specific gravities actually encountered in redwood. Thus, at any selected specific gravity, the average properties from the new sample of second-growth redwood rank between the virgin values and the young-growth values obtained from earlier studies.

Table 5.--Regression results for certain strength properties of second-growth and virgin redwood versus specific gravity

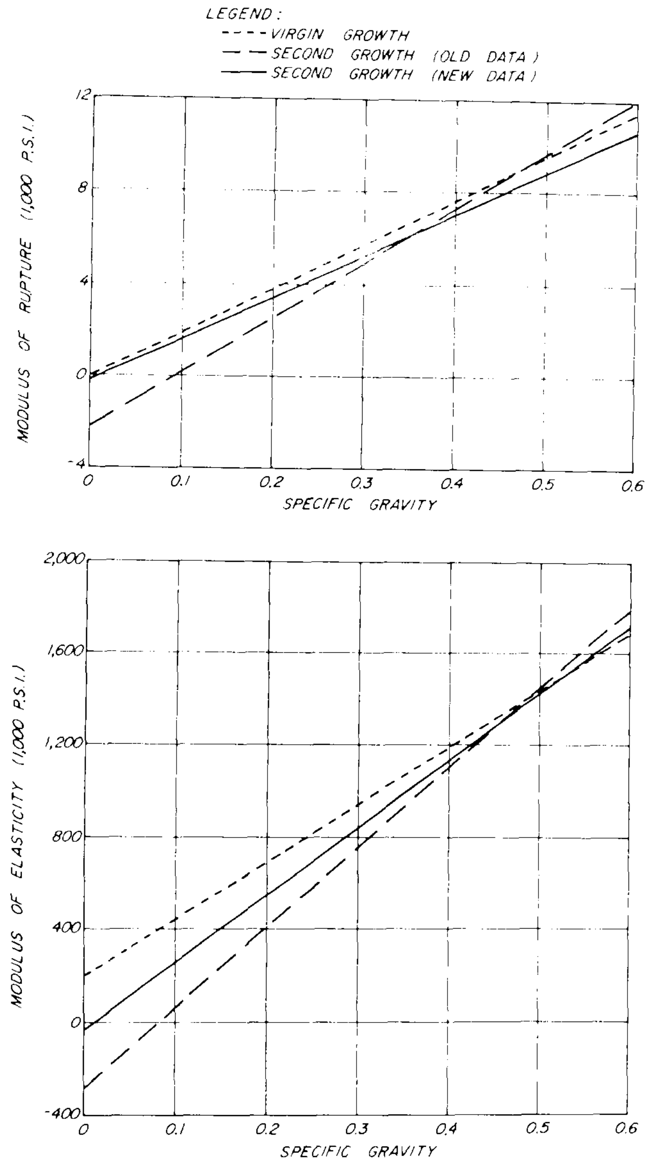
Source of data	A[1]	B[1]	Coefficient of correlation	Number of specimens
	P.s.i.	P.s.i.		
(STATIC BENDING)				
Second-growth redwood (new data)	-229	18,278	0.79	87
Second-growth redwood (old data)[2,3]	-2,227	24,027	.83	177
Virgin redwood[3]	-82	19,365	.75	233
MODULUS OF ELASTICITY (STATIC BENDING)				
Second-growth redwood (new data)	-41,000	2,934,000	.54	87
Second-growth redwood[2,3] (old data)	-287,000	3,483,000	.56	177
Virgin redwood[3]	194,000	2,491,000	.49	232
MAXIMUM CRUSHING STRENGTH (PARALLEL-TO-GRAIN)				
Second-growth redwood (new-data)	-142	9,531	.76	88
Second-growth redwood[2,3] (old data)	-1,898	15,601	.85	358
Virgin redwood[3]	-452	12,214	.80	484
MODULUS OF ELASTICITY (COMPRESSION PARALLEL-TO-GRAIN)				
Second-growth redwood (new data)	-289,000	4,055,000	.58	87
Second-growth redwood[2,3] (old data)	-838,000	6,085,000	.65	105
Virgin redwood[3]	194,000	3,449,000	.49	85

[1] Coefficients in the relationship y = A + BX where y is the value of the strength property being considered and X is the specific gravity.

[2] Includes close- and open-grown redwood previously evaluated.

[3] U.S.D.A. Tech. Bul. 479 (7).

In addition to being somewhat lower in most mechanical properties than virgin material, the second–growth redwood evaluated appeared to be extremely variable. This is evident from the appearance of the specimen failures. Failures in bending ranged from extremely tough splintering tension failures to extremely abrupt and brashy appearing failures. This is well illustrated in figures 7 and 8 which show typical static and impact bending failures. The splintering tension failures are best illustrated on specimens 9–5–6 and 9–5–3 in figure 7 and the abrupt brashy failures on the end view of specimen 5–5 in figure 8. It is interesting that the results of the variance analysis shown in table 6 do not indicate that there is substantially more variability than in 50 other common species or in the important structural properties of virgin redwood. Also, this analysis indicates that the material evaluated in this research appears to be considerably less variable than the second–growth redwood from the previous evaluation.



M 130 123

Figure 5.--Linear regression curves for modulus of rupture and modulus of elasticity (green) in static bending versus specific gravity.

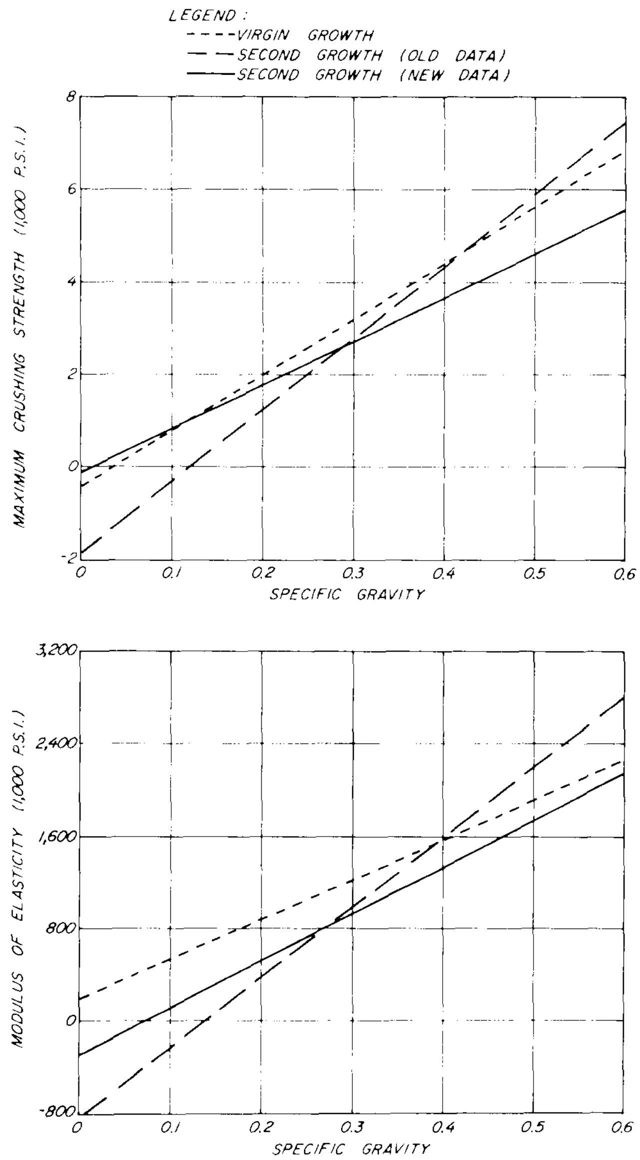


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Figure 6.--Linear regression curves for maximum crushing strength and modulus of elasticity (green) in compression parallel-to-grain versus specific gravity.

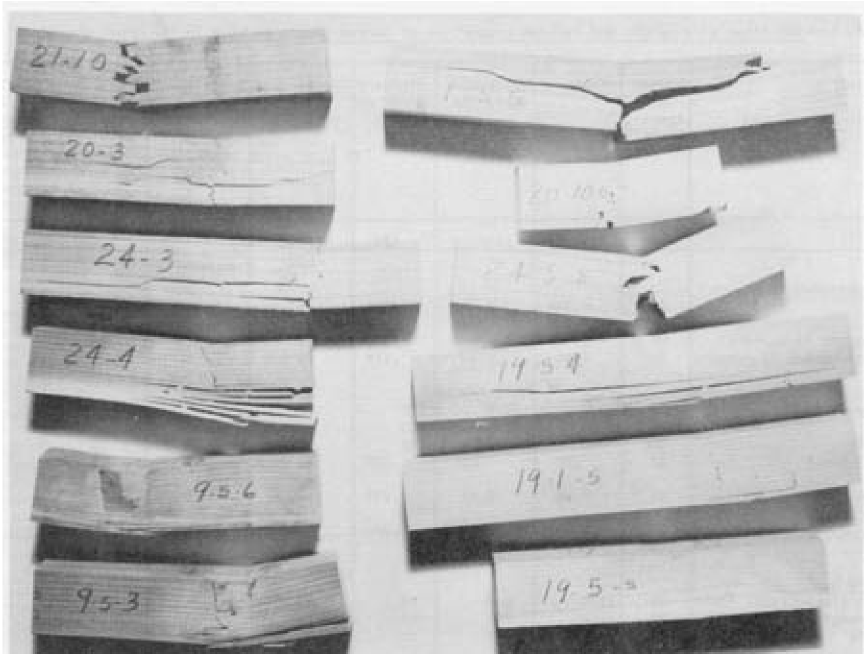

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Figure 7.--Typical static bending failures ranging from abrupt, brashy failures shown at the top of the figure to the tough, splintering tension failures shown at the bottom.

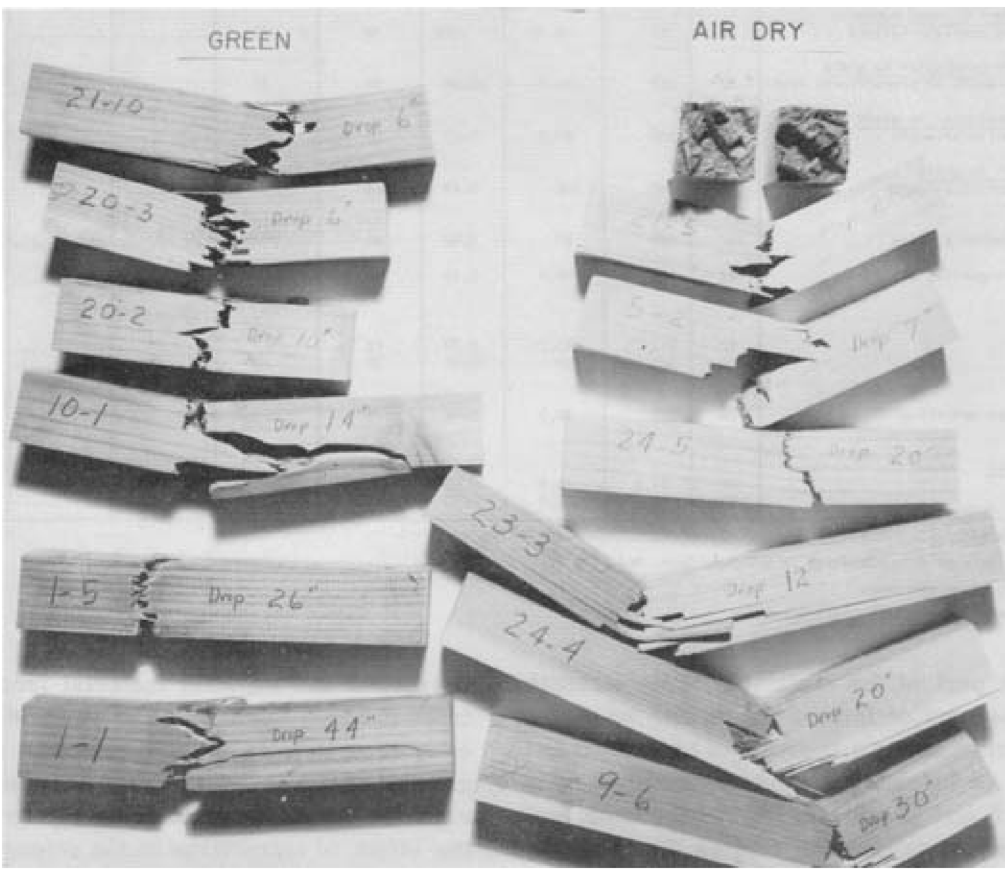

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Figure 8.--Typical impact bending failures. The air-dry speciments at the tight show a continuous rang of failures from the abrupt, brashy failures at top to the tough, splintering tension failures at the bottom.

Table 6.--Variation of strength and related properties of second-growth redwood in the green condition

Item	Number of speci- mens	Mean	Standard deviation	Standard error of mean	Coefficient of variation	Coefficient of variation at 50 species[1]	Coefficient of variation of virgin redwood[2]	Coefficient of variation of previous second growth redwood data[2]	Units for columns (3), (4) and (5)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
					Pct.	Pct.	Pct.	Pct.	
Specific gravity and shrinkage									
Specific gravity[3]	87	0.335	0.044	0.005	13	10	....	....	....
Specific gravity[4]	88	.341	.046	.005	14	....	....	....	....
Shrinkage, radial--green to ovendry	81	2.18	.559	.062	26	15	....	....	Percent
Shrinkage, tangential--green to ovendry	92	4.90	1.10	.115	22	14	....	....	Percent
Static bending									
Fiber stress at proportional limit	87	3650	719	77	20	22	....	....	P.s.i.
Modulus of rupture	87	5900	1020	110	17	16	18	25	P.s.i.
Modulus of elasticity	87	1940	240	26	25	22	23	35	1000 p.s.i.
Work to proportional limit	87	.82	.26	.028	32	38	....	....	In.-lb. per cu. in.
Work to maximum load	87	5.68	2.21	.237	39	34	....	....	In.-lb. per cu. in.
Total work	86	9.28	6.66	.718	72	....	....	....	In.-lb. per cu. in.
Compression parallel to grain									
Crushing strength at proportional limit	85	1970	628	68	32	24	....	....	P.s.i.
Maximum crushing strength	88	3110	587	63	19	18	19	28	P.s.i.
Modulus of elasticity	87	1090	327	35	30	29	22	40	1000 p.s.i
Tension parallel to grain									
Fiber stress at proportional limit	64	6020	2217	277	37	....	....	....	P.s.i.
Maximum tensile strength	70	9200	2725	326	30	....	....	....	P.s.i.
Modulus of elasticity	70	1200	388	46	32	....	....	....	1000 p.s.i.
	85	17	6.36	.689	38	25	....	....	In.
Compression perpendicular to grain									
Crushing strength at proportional limit	92	265	96.7	10.08	36	28	....	....	P.s.i
Tension perpendicular to grain									
Maximum tensile strength	172	293	67.8	5.15	23	25	....	....	P.s.i
Shear parallel to grain									
Maximum shearing strength	177	890	126	9.44	14	14	....	....	P.s.i
Toughness									
Loaded on radial surface	161	108	47	3.70	44	....	....	....	In.-lb. per specimen
Loaded on tangential surface	163	139	66.1	5.17	48	....	....	....	In.-lb. per specimen
Hardness									
End	92	512	93.2	9.72	18	17	....	....	Lb.
Side	92	346	104	10.81	30	20	....	....	Lb.
Cleavage									
Load to cause splitting	164	160	26.2	2.04	16	....	....	....	Lb. per in. of width
Nail withdrawal									
End	65	57.2	16.8	2.08	29	....	....	....	Lb.
Side	65	122	25.3	3.13	21	....	....	....	Lb.

[1] Wood handbook (11).

[2] Based on analysis of data presented in U.S.D.A. Tech. Bul. 479 (7).

[3] From static bending specimens.

[4] From compression parallel-to-grain specimens.

At least part of the variability in the strength and in the type of failure appears to be due to the difference in the properties of heartwood and sapwood. As indicated by the toughness failures in figure 9 and to a lesser degree the static and impact bending failures in figures 7 and 8, the flexural failures of sapwood generally were of the splintering tension type while the heartwood failures tended to be somewhat more abrupt and brittle. A comparison of the bending strength of heartwood and sapwood material from the same trees (table 7) shows that the sapwood is stronger even though it is somewhat lower in specific gravity. This is in contrast to what would be expected based on Luxford's (5) evaluation of the effect of extractives on the strength of wood. He stated that extractives increased the modulus of rupture of air-dried wood by an amount equivalent to or greater than that which would be caused by an equal amount of wood substance.

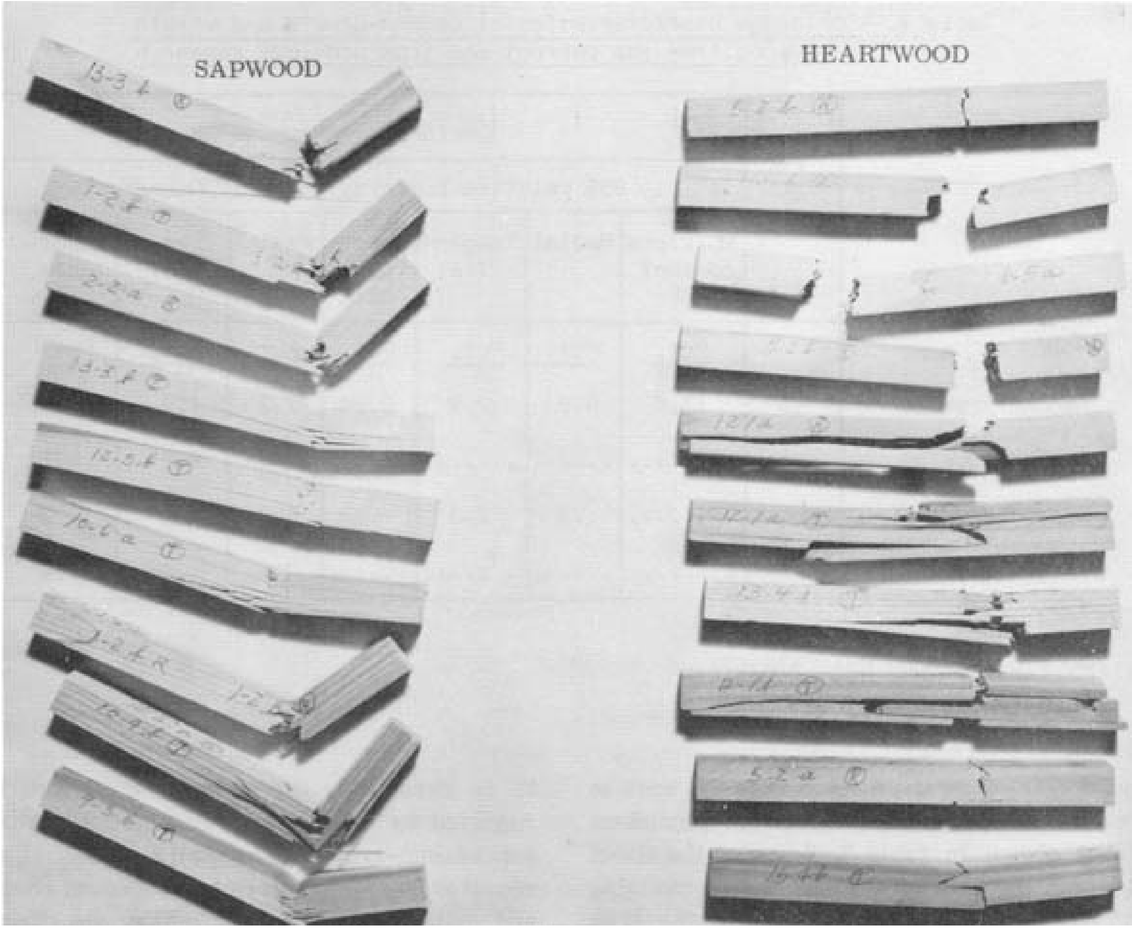

Figure 9.--Toughness failures of redwood in the air-dry condition were characterized by the abrupt brashness of the heartwood failures on the right and the tough, splintering tension failures of the sapwood on the left. M 125 893

Table 7.--Certain air-dry flexural properties of sapwood and heartwood from the same redwood trees

	Heartwood						Sapwood					
Tree No.	Number of tests	Rings per inch	Specific gravity[1]	Modulus of rupture	Modulus of elas-ticity	Work to maxi-mum load	lumber of tests	lings per inch	Specific gravity[1]	Modulus of rupture	Modulus of elas-ticity	Work to maxi-mum load
				P.s.i.	1000 p.s.i.	In.lb. per cu.in.				P.s.i.	1000 p.s.i.	In.lb. per cu.in.
3	3	7	0.382	8710	788	7.97	I	3	0.358	8450	900	10.61
11	3	4	.324	6480	I136	2.40	I	5	.316	7180	1101	2.87
13	3	6	.335	7580	1098	4.81	2	11	.348	8670	I298	7.51
16	3	4	.297	6100	716	5.97	I	4	.272	5890	771	2.77
18	2	5	.328	7490	906	4.62	2	6	.314	7500	958	4.50
22	2	7	.378	10440	1452	6.72	2	8	.392	11120	1572	8.68
Average		6	.341	7800	1016	5.42		6	.333	8140	1100	6.16

[1]Based on volume at test and ovendry weight.

Table 8.--Shrinkage characteristics of second-growth and virgin redwood from the current and from previous research

Redwood	Rings per inch	Shrinkage, green to						
		74° F., 65% relative humidity				Ovendry		
		Moisture content	Radial	Tangential	Longitudinal	Radial	Tangential	Longitudinal
		Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
Second growth [1]	5	13.8	0.8	2.2	0.04	2.2	4.9	0.19
Second growth [2]	5	....	......	....	......	2.2	4.7	.18
Second growth [3]	.....	....	.7	2.3	-.03	2.2	5.2	.12
Virgin [2]	16	....	......	....	......	2.6	4.4	.14

[2]U.S.D.A. Tech. Bul. 479 (7).

[3]Schniewind (10).

He found that extractives decreased the work to maximum load in bending which is consistent with that shown in table 7. Some of the effect noted probably could be associated with changing growth conditions during the life of the tree rather than the differences between heartwood and sapwood. However, the growth rate as indicated by the number of rings per inch in table 7 is not substantially different in the heartwood and sapwood.

The shrinkage properties (table 8) were found to be essentially the same as those previously reported by the Forest Products Laboratory (7) for second-growth redwood. Schniewind (10) reported somewhat greater tangential shrinkage and somewhat less longitudinal shrinkage for second-growth redwood. The radial and longitudinal shrinkages were slightly lower than reported by the Forest Products Laboratory for virgin-growth redwood while the tangential shrinkage was slightly greater.

CONCLUSIONS

The following conclusions have been developed from a consideration of the data collected.

1. Most mechanical properties were found to be 20 to 25 percent lower than those of virgin-growth redwood. The only exceptions were maximum shearing strength parallel to grain and maximum tensile strength perpendicular to grain which appear to be significantly higher than those for virgin material.

2. The mechanical properties generally ranged from 25 to 50 percent higher than previously reported for open-grown second-growth redwood, but nearly comparable to those of close-grown second-growth redwood. Important structural properties are 10 to 30 percent higher than an average of the previous open- and close-grown material. It was also noted that the specific gravities of the various sources of second-growth redwood data had a similar ranking.

3. The specific gravity of the new material is approximately 10 percent lower than that of virgin mateerial. This, together with the results of linear regression analyses of strength on specific gravity, indicate that in the range of specific gravity commonly encountered, second-growth redwood is not as strong as virgin material of the same density.

4. Shrinkage properties are similar to those for virgin redwood and to those previously reported for second-growth redwood.

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