AN EVALUATION OF SOUTHERN PONDEROSA PINE FOR MINING USES

by

Stanley John Patchet

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SIGNED: Stanley J [illegible]

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

W. C. Lacy
DR. W. C. LACY
Professor of
Mining and Geological Engineering

8/18/66
Date

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ABSTRACT

The gradual increase in timber cost and freight rates has made it desirable to use local timber if at all possible. A knowledge of the physical properties of local timber would make such a change less risky for the mine operator. The static bending modulus of elasticity, safe load ratio, density, and moisture were determined for 202 2 x 2 x 36 inch specimens. The modulus of elasticity and safe load ratio were then correlated to the density and moisture using five different functions. The modulus of elasticity can be expressed as a function of the density and moisture but the safe load ratio seems to be a function of other factors. Southern Ponderosa pine does not appear to be a suitable timber for the support of mine openings but it may have uses in areas where loads upon it do not become excessive.

CHAPTER I

Introduction

1.1 Definition of Problem

For many years timber has been used as the principal material for support in mines. Timber has the advantages of easy workability, fairly high strength, low weight, and safe manner of failure. The cost in most cases is fairly low. In many areas, however, local timber is not available in sufficient quantity and quality to allow its use in mining applications. Consequently other materials, such as concrete and steel, have been used or timber has been shipped in from areas which can supply a suitable type. The gradual increase in both timber cost and freight rates has often made it desirable to use local timber, if at all possible. Often a lack of knowledge about the properties of local timbers makes such a change risky. A knowledge, then, of the characteristics and physical properties of local timber would be of great assistance to the mine operator as it would allow him to make the greatest possible use of low-cost local timber. It is with these thoughts in mind that the southern Ponderosa pine was evaluated for mine use.

This evaluation for mine use will of necessity be different from an evaluation for home construction or some other use. A timber, to be suitable for use in supporting mine workings, should have the following characteristics:

1. it should be fairly strong both in bending and in compression,
2. it should be elastic and adapt itself to forces acting on it,
3. it should give warning of impending failure, either by cracking or, as the miners say, it should "talk",
4. it should give support for a period after its failure long enough to permit installation of new timber.

All four of these points are important and would seem fairly obvious. The critical points, however, are numbers three and four. Number three is important for the safety of men working under the timber, and both three and four are important from the viewpoint of operation and maintenance.

It is difficult, however, to say exactly what is and is not warning of impending failure, and what constitutes sufficient support after failure to permit replacement. Of these two items, the former is difficult to measure, and it cannot be assigned a numerical value except in an arbitrary manner. The latter, however, does seem to be amenable to evaluation in some manner, inasmuch as it is composed of measurable quantities in the form of loads before and after failure.

This, then, is the problem: to evaluate southern Ponderosa pine for mine use, to determine its physical properties, and to attempt to relate these properties to its usefulness in mining applications.

1.2 Method of Evaluation

In practically all timber applications in mining support methods the timber is caused to bend. When the load increases beyond certain values the ultimate result of this bending is the failure of the timber. In fact, it can be shown that any column, no matter how it is loaded, will fail in bending. For example, a column in compression will fail in bending if $P > \frac{\pi^2 EA}{(L/r)^2}$ where

P = compressive load in pounds,

π = constant = 3.14159,

E = modulus of elasticity in pounds per square inch,

A = cross-sectional area in square inches,

L = length of column in inches,

r = radius of gyration = $\sqrt{I/A}$ where

I = moment of inertia of column cross-section,

A = as above (Harris, 1959).

In the above formula L/r is the slenderness ratio and since for any particular material $\pi^2E \approx$ constant, $P/A = f(L/r)^2$. Thus for any slenderness ratio there exists a unit strain that will cause a bending failure (see Wangaard, 1950 and Harris, 1959). Should $(L/r)^2$ be small (as in a bearing block) this column failure will probably not occur because other factors do not permit a sufficiently high load to be applied to the specimen.

Since the large majority of actual failures are in bending and since it can be shown theoretically that bending failures will usually occur in most mine-size timbers, it seemed best to test the timber specimens in static bending to determine both the modulus of elasticity and the suitability of the timber for application in areas where bending will occur.

It is generally accepted that the density is the best criterion of strength in timber. According to Wangaard (1950), "density or specific gravity ... [is the best] ... criterion of its clear wood strength" and "factors of growth ... [are] ... of practical importance only as far as they affect the density". Moisture, however, greatly affects both density and strength, but the relationship between the three has not been investigated nearly as much as between density and strength alone.

As mentioned previously, a mine timber should fail in a manner such that replacement or repair can be facilitated. Ideally the failure should occur with no loss of strength. This would be perfect for mine use. At the other extreme a failure that was complete and gave no support after failure would be of no value for mining because of the dangers involved both to men and to physical plant. Since failure of the timber lowers the strength and, therefore, the supporting ability of the timber, the ratio of the load supported after failure to the maximum load supported would be a measure of the ability of the timber to continue giving support after its failure. The ratio of the load supported after the maximum load is reached and failure occurs to the maximum load is referred to hereafter as the "safe load ratio".

1.3 Definition of Terms

1. Density (ρ) is the weight per unit volume and has the units pounds per cubic foot.

2. Moisture (M) is the weight per cent of water and has no units.
3. Safe Load Ratio (S) is the ratio of the load held after failure at maximum load to the maximum load and has no units. Its range is $0 \leq R < 1$.
4. Modulus of Elasticity (E) is the ratio of stress to strain as determined in the static bending tests and has the units pounds per square inch.

The following definitions are from the ASTM "Standard Definitions of Terms Relating to Timber (D9-30)" (ASTM, 1965).

5. A Defect is "In the case of wood, any irregularity occurring in or on the wood that may lower its strength".
6. A Check is "In the case of wood, a separation along the grain, the greater part of which occurs across the rings of annual growth".
7. Cross-Grained Wood is "In the case of wood, wood in which the fibers are not parallel with the axis of a piece".

8. A Knot is "In the case of wood, that portion of a branch which has become incorporated in the body of a tree".

9. A Shake is "In the case of wood, a separation along the grain, the greater part of which occurs between the rings of annual growth".

10. A Pitch Pocket is "An opening between the grain of the wood, containing more or less pitch".

CHAPTER II

Parameter Determinations

2.1 Specimen Preparation

The specimens used for parameter determinations consisted of nominal 2-inch by 2-inch by 36-inch sticks. These were cut from four 10-inch by 10-inch by 6-foot timbers and four 10-inch by 10-inch by 10-foot timbers supplied by Western Pine Sales. The 10-inch by 10-inch timbers were sawed into one 6-inch by 8-inch timber and the remaining material was cut into 2-inch by 2-inch sticks. These sticks were then cut into 36-inch lengths. The 2-inch by 2-inch specimens were numbered using the large timber number in the hundreds position (i.e., those cut from timber 3 became 301, 302, ..., 340). The small specimens were numbered in a random fashion in order to avoid observer bias.

2.2 Density Determination

Several methods were considered for density determination and were discarded for various reasons. Water displacement was not used for several reasons. First, the specimens were naturally dried and had somewhat reached a point of equilibrium. To submerge them in water would certainly wet the sides and ends and destroy the naturally dried condition. Water losses into the wood would make the equipment difficult to use accurately and the method did not adapt itself to the specimens' shape. Using paraffin or a light plastic film covering over the specimens could, in the former case, possibly have an adverse effect on the physical properties of the specimens and, in the latter, negate the reason for using the submersion method (the cracks and pits would not be filled with water because of the film covering).

The method finally used was to weigh and measure the specimens as accurately as possible. This method has several disadvantages but they seemed to be outweighed by the advantages. In favor of the method is the fact that the specimen is in no way affected by the method. Also, it is the method that would probably be used on larger or full-size timbers because of the difficulties in using other methods such as immersion. This method does not take into account checks, shakes or other openings in the specimens. This has the effect of lowering the estimate of the density, but at the same time, these flaws adversely affect the strength of the piece.

The specimens' ends were squared-off as closely as possible, and the length was measured. The specimens were then weighed to ± 0.25 gram on a beam balance. The cross-section of the specimen was then measured at both ends and the middle. All length measurements were to 0.01 of an inch. The density was calculated as part of the computer program which did all the numerical calculations. The prismoidal formula in the form

$$\rho = \frac{W/454.0}{\frac{L}{1728.0}\left[\frac{A_1+4.0A_2+A_3}{6.0}\right]}$$

where

W = weight in grams,

L = length in inches,

A_1 = one end cross-sectional area in square inches,

A_2 = middle cross-sectional area in square inches,

A_3 = other end cross-sectional area in square inches,

454.0 and 1728.0 = unit conversion constants,

was used to calculate the density of each of the specimens.

2.3 Moisture Determination

The moisture determination for each sample was straight-forward. From each specimen two small blocks were cut at right angles to the long dimension of the specimen. The blocks were cut to such a size that they each weighed before drying from 20 to 30 grams. The blocks were cut from about midway between the end of the specimen and the end of the failure cracks of the specimen. The blocks were all cut and initially weighed on the same day as the static bending tests were made, in order to eliminate as far as possible any moisture loss due to cracks induced by the bending test. The samples from each specimen were marked with the sample number followed by a 1 or 2 (i.e., the two samples from specimen 325 were marked 3251 and 3252).

The blocks were marked before they were cut from the specimen to avoid any possible errors in numbering. After cutting, all slivers and loose chips were brushed from each sample, and the blocks were weighed to 0.05 gram using a small beam balance. The samples were then dried in a gravity-convection electric oven at a temperature of 105 $\pm$ 3° C. until they each came to a constant weight (see Figure 1). For the most part, the samples required 48 to 72 hours to reach a constant

Figure 1. Drying Oven. Note the aluminum foil used to prevent pitch from dripping on heating elements.

weight, but some of the larger blocks required as long as 5 days. The initial and final weighings were then used to calculate the weight-per cent moisture in each block. The moisture content for the specimen was then taken to be the mean of these two values. The computation of the moisture for all the specimens was done by computer using the simple weight per cent formula.

In a few cases the blocks contained large amounts of pitch or sap which came to the surface of the blocks as they were heated. This viscous fluid presented two problems: one, it upset the moisture determination by either sealing in the water or running off and causing excessive weight-loss, and two, it presented a serious fire hazard. The second problem was overcome by placing aluminum foil trays underneath the rows of blocks in the oven to keep the sap or pitch from dripping onto the heating elements. The first problem occurred in only a few places and if the loss of pitch seemed excessive, the block was discarded.

2.4 Determination of Modulus of Elasticity

The modulus of elasticity of each specimen was found by subjecting it to static bending. The specimens were tested in a "Versa-Tester" hydraulic compression machine using attachments specifically designed for the machine. The specimens were tested with two-point loading for two reasons. First, in most mining uses the load on a beam will be applied in several different locations. Second, when using two-point loading, the resultant stresses are uniform throughout the center one-third of the beam. Since the stresses are uniform in this section of the piece, the effects of defects on the failure of the specimen can be easily compared between specimens without considering the location of the failure. In two-point loading, the beam is loaded at two points, each one-third of the distance from the end supports (see Figure 2). The load is applied in such a manner that there is no momentum effect on the piece.

Figure 2. Two-point Loading. The span L is the distance between supports. The load blocks are the distance L/3 in from the supports. The large plus sign indicates the center of the neutral axis. Note the black foam-rubber cushion mounts on the supports, load blocks and entire load head.

The rate of application of load is governed by the cross-head velocity. Several different methods for determining the cross-head velocity rate have been suggested. For example, the ASTM in "Standard Methods of Static Tests of Timbers in Structural Sizes" (D 198-27) (1965) suggests a rate of

$$N = \frac{Za}{3d}(3L-4a)$$

where

N = rate of motion of moving-head in inches per minute,

Z = 0.0015,

a = distance from load to adjacent support in inches,

d = depth of beam in inches,

L = span in inches.

Wangaard (1950) uses the formula

$$N = \frac{ZL^2}{5.4d}$$

where

Z, N, L, d, are as above.

The difference between the two is very slight. For a beam 2 x 2 x 36 inches with a span of 30 inches, the

ASTM formula gives N = 0.125 inches per minute. Wangaard's formula yields N = 0.125 inches per minute also.

The testing machine has a rate control valve which may be set to any reading from 0.01 to 20.00. This rate control valve was calibrated and a chart was drawn which gave cross-head velocity in terms of rate control valve reading. Because of the generally small difference in depth of the specimens, a constant load rate of 0.125 inches per minute was used on all specimens.

Deflections were measured at the middle of the neutral axis as shown in Figure 2. The deflections were measured with a dial indicator reading to one one-thousandth of an inch. A reversing arm was used to reverse the direction of movement of the indicator arm in order to keep the indicator out from under the test apparatus and to avoid damage to the indicator in case of sudden, complete failure. The end of the reversing arm rested on a small piece of razor blade stuck in the specimen at the center of the neutral axis (Figure 3).

After the specimen was properly placed in the machine, the end of the arm was placed on the blade,

Figure 3. Reversing Arm. The reversing arm is used primarily to prevent damage to the indicator in case of sudden and complete failure of the specimen.

and the indicator was zeroed using the movable dial on the indicator. Often the piece moved slightly as the load was picked up, and if this happened the indicator was re-zeroed. At 0.025-inch increments the load on the piece was read.

The static bending accessories conform to ASTM standards. The supports are mounted on heavy foam rubber in such a manner that they can rotate and twist and still completely support the specimen. The load blocks are similarly mounted and the entire loading head is also foam-mounted to give complete freedom of movement during the test. These can be seen in Figure 2.

The specimens' sides were referred to as A, B, C and D; the top was side A, the bottom was side C, the side on which the deflection readings were taken was side B, and the opposite side was side D. The top was the tangent-sawed side nearest the pith or center of the tree. A complete written test log was kept for each specimen (Appendix A). Load readings were taken at each 0.025 inches of deflection. Noises made by the specimen as it failed were marked on the log with checks. Minor failures which caused jumps on the deflection gage were noted on the log with small crosses. Major failures of the specimen were noted on the log with large crosses.

2.5 Determination of Safe Load Ratio

The Safe Load Ratio was found during the static bending tests. When the piece had failed, both the load still held and the maximum load held were recorded. Many times the specimens suffered major failures but the load on them continued to increase. In many instances the specimens failed and the load dropped considerably, only to start to increase and eventually exceed the previous maximum load. The loads used for the Safe Load Ratio were not taken until a failure occurred which marked the highest load on the specimen.

The Safe Load Ratio is given by

$$S = \frac{\text{load after failure}}{\text{maximum load}}$$

and is dimensionless. It is given in this form for two reasons. First, timber is not generally replaced until complete failure is imminent, and second, S increases with increasing load after failure. Thus the range of S is confined to $0 \leq S < 1$, and there is no need to "think in reverse" (i.e., if S were defined as maximum load divided by load after failure, the range would be $1 < S \leq \infty$).

CHAPTER III

Manner of Failure in Specimens

3.1 General Observations

The static bending tests showed a considerable variation between the Ponderosa pine and Douglas fir in type of failure and ability to continue support after failure. Failures almost always occurred at a defect in the center third of the beam. In many instances it was possible to predict just where the specimen would fail. In most instances, however, it was impossible to predict when the failure would occur.

Practically all the Ponderosa pine specimens contained knots. In some specimens these knots filled a large amount of the cross-sectional area. The Ponderosa pine also had a definite cross-grain and this generally occurred at or near knots. In a few pieces pitch pockets were noted. The Douglas fir, on the other hand, was almost entirely free of knots and only a few specimens had any cross-grain. Both species were checked and split, the Douglas fir slightly more so than the Ponderosa pine.

3.2 Ponderosa Pine Failures

The Ponderosa pine specimens contained many defects such as knots, cross-grain, checks and splits. Each of these defects caused failure at one time or another, but by far the largest number of failures was caused by cross-grain. The cross-grain generally occurred at or near a knot and failures could, in most instances, be attributed to the cross-grain rather than the knot. Cross-grain which came out on the bottom or lower half of the sides (Figure 4) of any of the specimens seemed to cause most of the cross-grain failures.

Failures in knots most often occurred where the knot constituted a large part of the cross-sectional area of the specimen. Smaller knots, knots that were tight, and vertical knots rarely caused a failure. Checks which were deep and long caused failures because they, in effect, cut the specimen into several sections. Vertical or nearly vertical checks had the effect of concentrating any stresses present in a smaller area and acted much like a keyway in a motor shaft. Checks that were more horizontal caused shear failures along the check but usually there was little loss of strength.

Figure 4. Cross-grain Failures. A, Side View. In this piece of Ponderosa pine the rings have separated where the cross-grain corners out at the bottom of side B. B, Bottom View. This piece of Ponderosa pine has failed through the cross-grain near a large knot rather than through the knot.

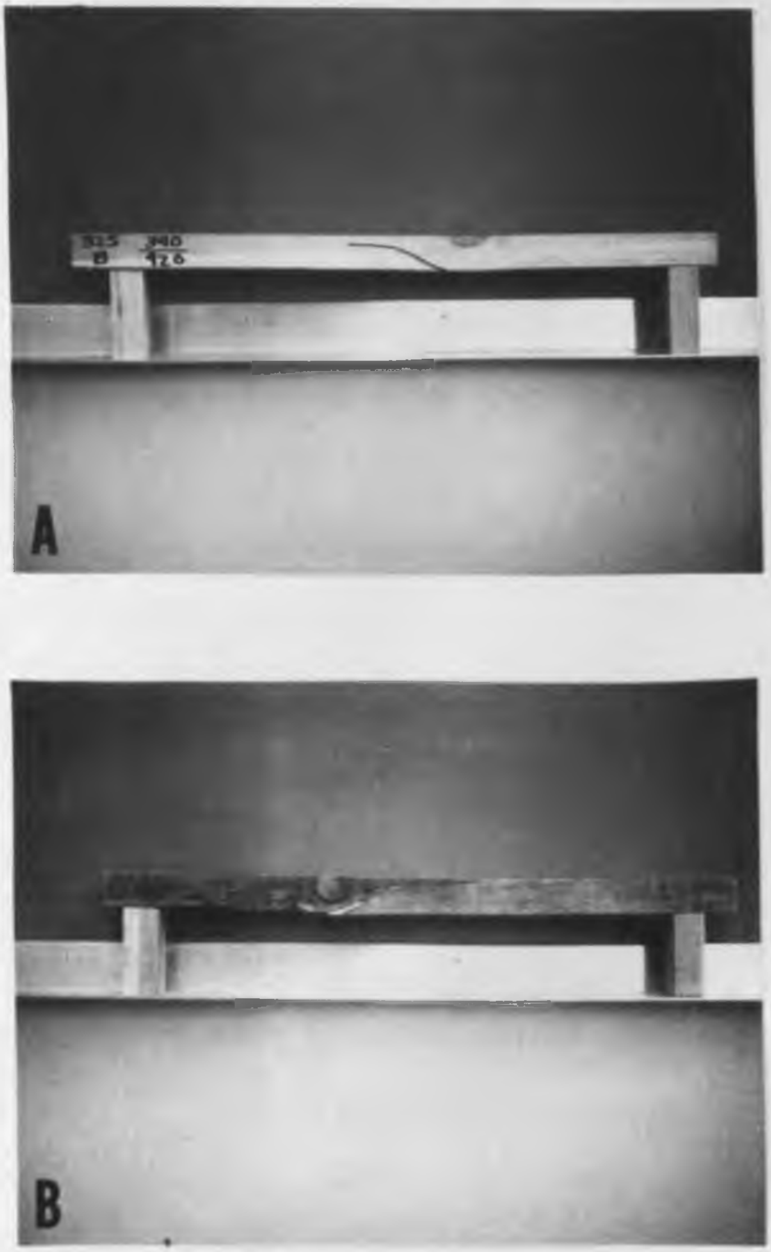


Figure 4. Cross-grain Failures.

3.3 Douglas Fir Failures

The Douglas fir specimens were almost completely free of defects with the exception of the checks previously mentioned. These pieces for the most part were straight-grained. Several from one group, however, had large sections which were badly termite-eaten. Inasmuch as this is not a natural defect, these specimens were discarded and were not tested. Deep checks were found in about one-third of the specimens and they had the same effect on the Douglas fir as they had on the Ponderosa pine.

3.4 Comparison of Failures

The two species seemed to fail in very different manners. The Ponderosa pine generally failed suddenly and completely with little warning. The Douglas fir, on the other hand, failed more slowly, and with much popping and cracking. The reasons for the substantial difference in the manner of failure seems to be due to differences in the strength of the rings and the strength of the bond between rings. In the Ponderosa pine the strength of the rings seems to be greater than the strength of the bond between the rings. In the Douglas fir the opposite appears to be true. In Ponderosa pine, when a ring fails or cross-grain comes to the surface, the relatively weak inter-ring adhesive forces are quickly overcome. The cross-sectional area and the ability to support a load are thus lessened. Another ring breaks and the cycle is repeated--many times instantaneously. Since in the Douglas fir the inter-ring adhesion is stronger than the rings themselves, the failure of a ring does not cause an appreciable loss of strength. Not until the inter-ring forces are overcome does the ring cease to carry its portion of the load. The piece does not fail completely until a number of ring and inter-ring failures meet and reduce the cross-sectional area to that which contains only unbroken rings (see Figures 5 and 6).

Figure 5. Typical Ponderosa Pine Failures

A. Splintery failure in straight-grained defect-free specimen.

B. Failure through large knot. Compare with Figure 6B.

C. Cross-grain failure.

D. Failures between and through large checks.

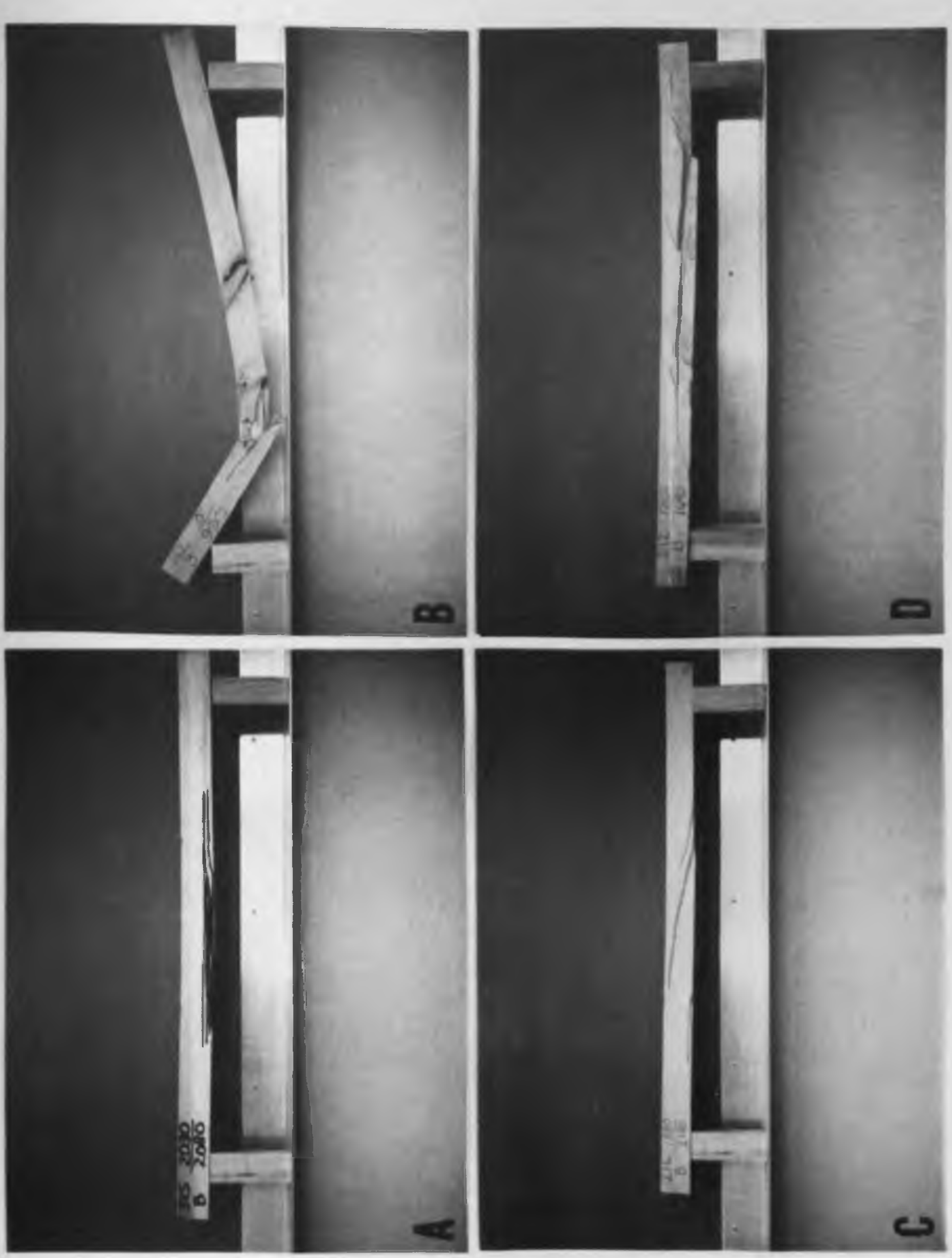


Figure 5. Typical Ponderosa Pine Failures.

Figure 6. Typical Douglas Fir Failures.

A. Splintery failure in straight-grained defect-free specimen.

B. Failure through knot. Compare with Figure 5B.

C. Cross-grain failure.

D. Failure through large check.

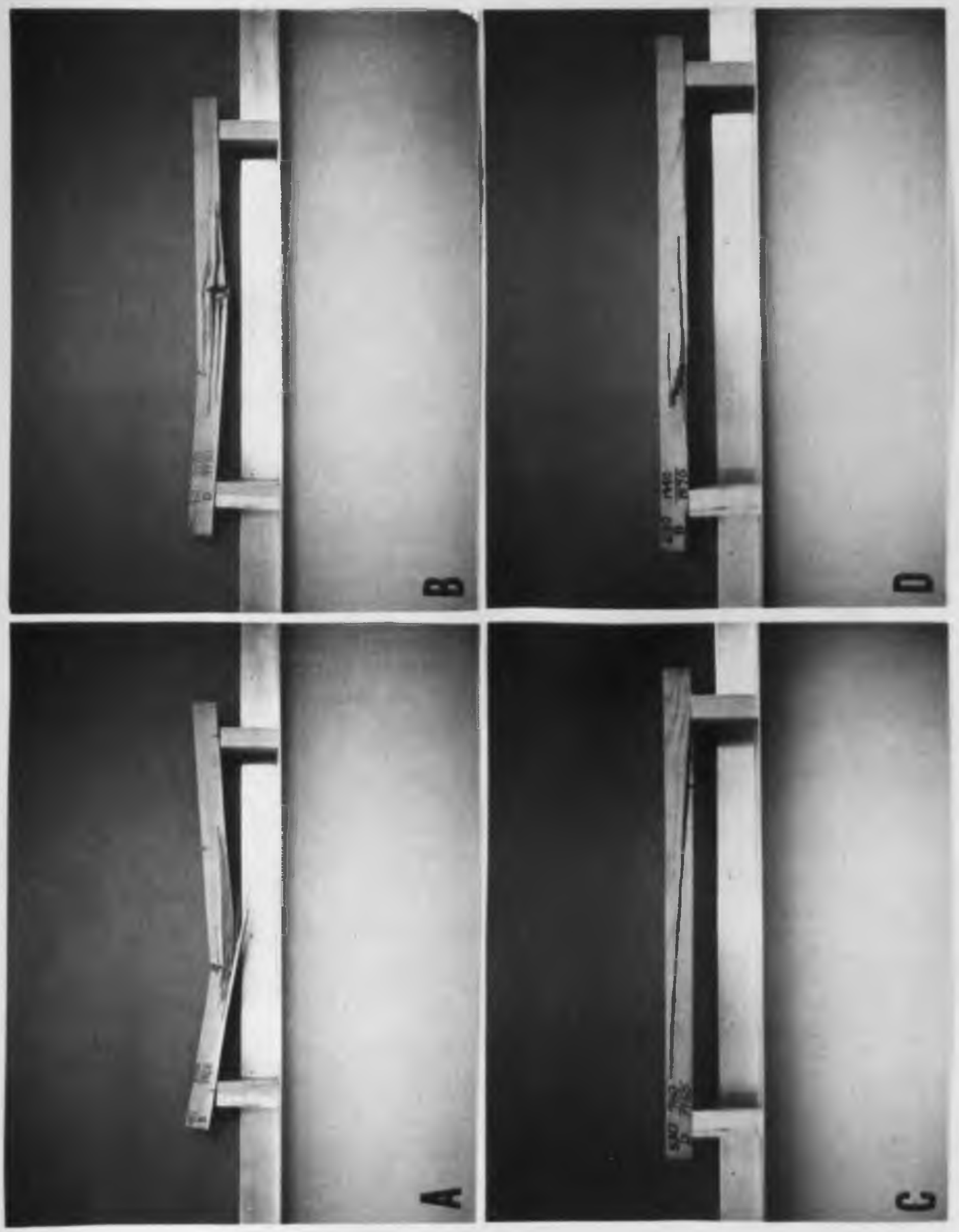


Figure 6. Typical Douglas Fir Failures.

CHAPTER IV

Computation of Timber Parameters and Their Relationships

4.1 Data Collection and Reduction

As the data for each specimen were collected, they were recorded on dittoed data sheets (Appendix A). The data from these sheets were then punched onto cards. This was a convenient, compact method of storage and the data for any specimen were readily available. These cards were then used in two computer programs written in the FORTRAN language. Each of these programs computed the density, moisture, modulus of elasticity and safe load ratio. One program then coded the data and punched new cards which were used in the CORR2 correlation and MR1 multiple regression library programs available in the University of Arizona Numerical Analysis Laboratory. The other program performed a two-variable linear regression between the four parameters.

A total of ten functions were used in an attempt to find the best inter-relationship between the parameters. The ten are

1. $E = V_1(\rho) + V_0$,

2. $E = V_1(M) + V_0$,

3. $E = V_1(\rho) + V_2(M) + V_0$,

4. $E = V_1(\rho) + V_2(\rho)^2 + V_3(M) + V_4(M)^2 + V_5(\rho)(M) + V_0$,

5. $\log E = V_1 \log(\rho) + V_2 \log(M) + V_0$,

6. $S = V_1(\rho) + V_0$,

7. $S = V_1(M) + V_0$,

8. $S = V_1(\rho) + V_2(M) + V_0$,

9. $S = V_1(\rho) + V_2(\rho)^2 + V_3(M) + V_4(M)^2 + V_5(\rho)(M) + V_0$,

10. $\log S = V_1 \log(\rho) + V_2 \log(M) + V_0$,

where

E = Modulus of Elasticity,

S = Safe load ratio,

M = Moisture,

ρ = Density, and

V_1, V_2, V_3, V_4, V_5, V_0 are constants which are not necessarily the same in different equations.

The equations were kept fairly simple for several reasons. The graphs of several of these functions indicated a linear, and at highest, a cubic relationship. The logarithmic functions were added to find any possible exponential relationships. In order to be of practical use to the mine operator any relationship found, and the computations involved when using it, should be straightforward. Each of these functions was tried on each group of specimens cut from a single large timber, on all the groups of a single species, and on all the specimens together.

4.2 Description of Ponderosa Pine Samples

The Ponderosa pine series consisted of 113 samples in four groups. Group 150 consisted of 31 specimens. Of these 31 specimens, thirteen contained large knots, five had small knots, and thirteen no knots. Eight contained large checks. Group 200 consisted of 24 specimens. Of these, seven contained large knots, eight had small knots, and nine no knots. Eleven contained no appreciable cross-grain and twelve had large checks. Group 300 had 38 specimens. Nineteen contained large knots, six contained small knots, and thirteen had no knots. Thirty-three were cross-grained and fifteen had large checks. The last group, 800, had twenty specimens. Thirteen contained large knots, twelve had small knots, and five had no knots. Fifteen had substantial cross-grain and nine contained checks. The parameters for this series are shown in Tables 1 and 2.

4.3 Description of Douglas Fir Samples

The Douglas fir series consisted of 89 samples in four groups. Group 400 contained sixteen specimens. Eight contained knots which were all fairly small. Only one contained appreciable cross-grain and ten contained large checks. Group 500 consisted of 32 specimens. None of the specimens in this group had any knots or appreciable cross-grain, but fourteen contained checks. Of the 22 specimens in group 600, none had any knots, one had slight cross-grain and nine contained large checks. Group 700 consisted of 19 specimens, thirteen of which contained knots, ten were cross-grained and eight contained large checks. The parameters for the Douglas fir series are shown in Tables 1 and 2. Table 3 ranks the parameters of the two species.

TABLE 1

Density and Moisture Values for Individual and Combined Groups

	Density (lb/ft^3)			Moisture %		
Group	Mean	S. Deviation	Range	Mean	S. Deviation	Range
150	35.53	± 3.995	28.96-46.50	7.02	± 0.659	6.03-8.45
200	31.99	± 1.856	29.62-35.78	6.69	± 0.461	6.14-7.64
300	33.63	± 3.115	28.90-43.49	6.55	± 0.827	3.36-7.65
800	29.40	± 1.264	27.51-32.32	6.27	± 0.298	5.96-7.12
Ponderosa Pine	33.05	± 3.61	27.51-46.50	6.66	± 0.690	3.36-8.45
400	38.86	± 1.319	36.24-41.07	8.25	± 0.345	7.64-8.86
500	29.69	± 1.170	27.17-31.55	6.38	± 0.625	5.82-7.26
600	33.40	± 1.390	30.89-35.82	6.26	± 0.378	5.32-6.83
700	36.49	± 2.707	32.83-44.89	7.70	± 1.290	6.36-12.33
Douglas Fir	33.71	± 3.885	27.17-44.89	6.97	± 1.100	5.32-12.33
All Specimens	33.34	± 3.748	27.17-46.50	6.80	± 0.907	3.36-12.33

TABLE 2

Modulus of Elasticity and Safe Load Ratio Values for Individual and Combined Groups

	Modulus of Elasticity (psi x 10^6)			Safe Load Ratio (-)		
Group	Mean	S. Deviation	Range	Mean	S. Deviation	Range
150	0.812	± 0.2003	0.443-1.278	0.650	± 0.297	0-0.993
200	1.005	± 0.1856	0.533-1.444	0.655	± 0.204	0.265-0.965
300	0.919	± 0.1896	0.469-1.222	0.630	± 0.286	0-0.976
800	0.769	± 0.1213	0.559-1.034	0.469	± 0.347	0-0.967
Ponderosa Pine	0.882	± 0.2007	0.443-1.444	0.612	± 0.294	0-0.993
400	1.622	± 0.2823	1.228-2.283	0.852	± 0.133	0.540-0.974
500	1.442	± 0.1814	1.034-1.756	0.667	± 0.256	0-0.980
600	1.460	± 0.2661	1.043-2.135	0.616	± 0.275	0-0.973
700	1.638	± 0.3916	0.997-2.355	0.832	± 0.141	0.507-0.984
Douglas Fir	1.520	± 0.2904	0.997-2.355	0.723	± 0.243	0-0.984
All Specimens	1.163	± 0.4003	0.443-2.355	0.661	± 0.278	0-0.993

TABLE 3

Ranked Parameters. One is lowest value and eleven is highest value

Group	Density			Moisture			Modulus of Elasticity			Safe Load Ratio		
	μ	S.D.	Range	μ	S.D.	Range	μ	S.D.	Range	μ	S.D.	Range
150	9	11	8	9	6	6	2	5	4	5	10	9
200	3	5	5	6	4	4	5	3	5	6	3	3
300	7	7	7	4	8	7	4	4	3	4	8	6
800	1	2	2	2	1	1	1	1	1	1	11	4
Ponderosa Pine	4	8	10	5	7	9	3	6	6	2	9	10
400	11	3	3	11	2	2	10	8	7	11	1	1
500	2	1	1	3	5	3	7	2	2	8	5	7
600	6	4	4	1	3	5	8	7	8	3	6	5
700	10	6	6	10	11	8	11	10	9	10	2	2
Douglas Fir	8	10	9	8	10	10	9	9	10	9	4	8
All SpeciMens	5	9	11	7	9	11	6	11	11	7	7	11

CHAPTER V

Correlation Results

5.1 Modulus of Elasticity Correlations

5.1.1 $E = f(\rho)$ of the Forst Degree

As shown in Table 4 this is an equation of the form

$$E = V_1(\rho) + V_0.$$

Of the eleven groups, significant correlations were found in six. These six include the two species series but do not include the "All Specimens" group. In four of the six significant correlations, E is adversely dependent on the density. (Adverse as used here means a negative direct relation, i.e., $A - -cB$.) In all the significant Ponderosa pine correlations this adverse density - modulus of elasticity relationship holds, but in the case of the two Douglas fir correlations, the relationship is direct.

The reason for the adverse relationship found in the Ponderosa pine groups is probably due to the

TABLE 4

Coefficients for the Equation $E = V_1 \times 10^4 (\rho) + V_0 \times 10^6$ (r_{crit} from Owen (1962))

Group	V_1	V_0	DF	r	r_{crit}
150	-3.435	+2.033	29	0.685	0.355
200	-3.605	+2.158	22	0.360	0.404
300	-3.635	+2.142	36	0.597	0.321
800	-5.800	+2.474	18	0.604	0.444
Ponderosa Pine	-2.349	+1.658	111	0.423	0.184
400	+17.312	-5.105	14	0.809	0.497
500	+3.911	+0.281	30	0.252	0.349
600	-1.041	+1.808	20	0.054	0.423
700	+0.313	+1.524	17	0.021	0.456
Douglas Fir	+2.353	+0.727	87	0.315	0.210
All Specimens	+0.625	+0.955	200	0.058	0.138

increase in density and the decrease in strength caused by knots. The relatively defect-free condition of the Douglas fir leads to the direct relationship. While the "All Specimens" correlation is not significant here, the relationship found is direct and this can probably be taken to be the relationship between species.

5.1.2 $E = f(M)$ of the First Degree

Here the equation is

$$E = V_1(M) + V_0.$$

See Table 5. In this instance only five groups have significant correlations, four of Ponderosa pine and one of Douglas fir. The Ponderosa pine series correlation is significant, but those of the Douglas fir series and the "All Specimens" group are not. As in the previous equation with the Ponderosa pine there is an adverse modulus of elasticity - moisture relation while with the single Douglas fir correlation, the relation is direct. Due to the small number of correlations found here, it is difficult to determine any relationship between the species.

TABLE 5

Coefficients for the Equation $E = V_1 \times 10^7 (M) + V_0 \times 10^6$ (r_{crit} from Owen (1962))

Group	V_1	V_0	DF	r	r_{crit}
150	-1.835	+2.100	29	0.603	0.355
200	-1.972	+2.323	22	0.490	0.404
300	-0.991	+1.569	36	0.432	0.321
800	-0.816	+0.257	18	0.201	0.444
Ponderosa Pine	-1.093	+1.610	111	0.376	0.184
400	-0.921	+2.382	14	0.113	0.497
500	+1.245	+0.647	30	0.428	0.349
600	-2.908	+3.280	20	0.413	0.423
700	-0.835	+2.281	17	0.274	0.456
Douglas Fir	+0.370	+1.263	87	0.140	0.210
All Specimens	+0.479	+0.837	200	0.108	0.138

5.1.3 $E = f(\rho, M)$ of the First Degree

The equation correlated in this instance is

$$E = V_1(\rho) + V_2(M) + V_0.$$

Table 6 shows that significant correlations are found in eight of the eleven groups. All the Ponderosa pine groups as well as the Ponderosa pine series show significant correlations. Two Douglas fir groups and the Douglas fir series also show significant correlations. The moisture in every instance but one adversely affects the modulus of elasticity. The density acts just as it did in the density - modulus of elasticity correlation. It should be noted that in the "All Specimens" group the modulus of elasticity has an adverse relationship to the density and a direct relationship to the moisture.

5.1.4 $E = f(\rho, M)$ of the Second Degree

Here

$$E = V_1(\rho) + V_2(\rho)^2 + V_3(M) + V_4(M)^2 + V_5(\rho)(M) + V_0.$$

TABLE 6

Coefficients for the Equation $E = V_1 \times 10^4 (\rho) + V_2 \times 10^7 (M) + V_0 \times 10^6$
(R_{crit} from Owen (1962))

Group	V_1	V_2	V_0	DF	R	R_{crit}
150	-3.215	-0.153	+2.062	28	0.685	0.439
200	-3.114	-1.838	+3.228	21	0.580	0.498
300	-3.075	-0.458	+2.253	35	0.623	0.399
800	-5.842	-0.049	+2.517	17	0.605	0.545
Ponderosa Pine	-1.713	-0.559	+1.819	110	0.450	0.234
400	+19.093	-2.735	-3.540	13	0.871	0.608
500	+3.961	+1.248	-0.531	29	0.498	0.432
600	+0.014	-2.911	+3.275	19	0.414	0.520
700	+8.341	-2.193	+0.281	16	0.459	0.559
Douglas Fir	+3.433	-0.521	+0.725	86	0.342	0.269
All Specimens	-0.256	+5.486	+0.876	199	0.110	0.200

Table 7 gives the values of the constants and the multiple regression coefficient for this equation. Here only seven significant correlations are found versus eight in the previous section. Group 500 had $R = 0.575$ while $R_{crit.} = 0.576$. The groups with significant correlations here are identical with those of the previous section, except for previously mentioned group 500. Only two relationships seem evident here. First, the modulus of elasticity is related directly to the moisture. And second, the modulus of elasticity is adversely related to the density - moisture interaction term. Also the multiple regression coefficient of the "All Specimens" group most nearly approaches the critical value for any of the modulus of elasticity functions with this equation.

5.1.5 $\mathrm{LOG}_e(E) = f(\mathrm{LOG}_e(\rho), \mathrm{LOG}_e(M))$

The equation

$$\mathrm{LOG}_e(E) = V_1\mathrm{LOG}_e(\rho) + V_2\mathrm{LOG}_e(M) + V_0$$

was used to check on any possible exponential functions. Significant correlations are again found in eight of the eleven groups. See Table 8. As was the case in the previous two sections, all the Ponderosa pine groups, the Ponderosa pine series, two Douglas fir groups and

TABLE 7

Coefficients for the Equation $E = V_1 \times 10^5 (\rho) + V_2 \times 10^4 (\rho)^2 + V_3 \times 10^8 (M) + V_4 \times 10^8 (M)^2 + V_5 \times 10^6 (\rho)(M) + V_0 \times 10^6$
(R_{crit} from Owen (1962))

Group	V_1	V_2	V_3	V_4	V_5	V_0	DF	R	R_{crit}
150	-0.578	+0.471	+0.509	+8.152	-4.568	+0.721	25	0.713	0.585
200	+11.336	-1.486	+1.489	-4.811	-2.960	-346.6	18	0.665	0.660
300	+2.912	-0.739	-1.051	+0.960	+2.653	+0.156	32	0.683	0.533
800	-7.954	+1.935	+2.471	-4.213	-6.780	+5.998	14	0.734	0.717
Ponderosa Pine	+1.531	-0.217	+0.054	+0.082	-0.289	-1.534	107	0.506	0.319
400	-18.786	+3.879	+3.217	+6.735	-11.723	+672.9	10	0.931	0.790
500	-13.744	+2.243	-0.780	+4.159	+1.508	+389.6	26	0.575	0.576
600	+10.980	-1.939	-1.054	-2.504	+3.174	-343.6	16	0.439	0.687
700	+12.525	-1.171	+0.089	+8.904	-4.317	-439.6	13	0.539	0.733
Douglas Fir	-3.523	+1.011	+1.013	+2.265	-4.100	+3.323	83	0.507	0.364
All Specimens	+2.763	-0.401	-0.075	+1.467	-0.119	-3.445	196	0.199	0.260

TABLE 8

Coefficients for the Equation $LOG_e(\frac{E}{1000}) = V_1 LOG_e(100\rho) + V_2 LOG_e(10000M) + V_0$
(R_{crit} from Owen (1962))

Group	V_1	V_2	V_0	DF	R	R_{crit}
150	-1.524	-0.166	+8.761	28	0.684	0.439
200	-1.416	-1.467	+12.078	21	0.649	0.498
300	-1.445	-0.286	+8.837	35	0.654	0.399
800	-2.190	0.024	+10.525	17	0.591	0.545
Ponderosa Pine	-0.812	-0.396	+6.896	110	0.467	0.234
400	+3.858	-1.300	-6.844	13	0.863	0.608
500	+0.645	+0.435	-30.165	29	0.450	0.432
600	-0.103	-0.916	+6.070	19	0.329	0.520
700	+1.602	-1.056	+0.539	16	0.412	0.559
Douglas Fir	+0.507	-0.047	+1.517	86	0.288	0.269
All Specimens	-0.281	+0.268	+3.263	199	0.084	0.200

the Douglas fir series have significant correlations. The log of the modulus of elasticity appears to be adversely related to the log of the moisture (seven of eight correlations) but again, in Ponderosa pine the modulus of elasticity-density relation is adverse, and in Douglas fir is direct.

5.1.6 Comments on Modulus of Elasticity Correlations

Significant correlations are found for all of the five equations, but the latter three, which give the modulus of elasticity in terms of both density and moisture, have more group correlations than do the first two equations. The moisture almost always adversely affects the modulus of elasticity. The effect of the density depends on species. For Ponderosa pine the density has an adverse effect on the modulus of elasticity while for Douglas fir the effect is direct.

None of the equations gave significant correlation for groups 600, 700, and "All Specimens". There are several possible explanations for the fact that no correlations can be found for the "All Specimens" group. Only two species are included in the group. Add to this the opposite density effects on the modulus of elasticity, and it is easy to see why no significant correlation can be found. It is also entirely possible that these variables cannot be correlated using these equations. It is difficult to see any reasons for the lack of significant correlations for groups 600 and 700.

The standard deviation and ranges of group 600 are not nearly as large as are those of some other groups. The density mean of group 600 is the lowest of the eleven groups while the moisture and modulus of elasticity means are higher than average. There would then seem to be little correlation between the density and modulus of elasticity. Of the five equations, the modulus of elasticity - moisture equation gives the fewest significant correlations. Group 700 has large mean values, standard deviations, and, except for density, large ranges. It is possible that the large standard deviations mask any correlations that might be present, or that there is no correlation between the variables.

5.2 Safe Load Ratio Correlations

5.2.1 $S = f(\rho)$ of the First Degree

The equation

$$S = V_1 (\rho) + V_0$$

gave three significant correlations as shown in Table 9. Two of these are Douglas fir groups, one of which is the species series. The effect of the density term is opposite between the species. Density has an adverse effect on the Ponderosa pine safe load ratio while the effect is direct in the case of Douglas fir. With only three of eleven groups giving significant correlations it is difficult to determine if there is any relationship between the species.

5.2.2 $S = f(M)$ of the First Degree

Table 10 shows that only one significant correlation was found for the equation

$$S = V_1(M) + V_0.$$

The Douglas fir series has a significant correlation with the safe load ratio being directly affected by the moisture. Only two other groups have multiple regression coefficients which approach critical values.

5.2.3 $S = f(\rho, M)$ of the First Degree

Three significant correlations (Table 11) are found for the equation

TABLE 9

Coefficients for the Equation $S = V_1 \times 10^{-2} (\rho) + V_0$ (r_{crit} from Owen (1962))

Group	V_1	V_0	DF	r	r_{crit}
150	-4.0	+1.35	29	0.484	0.355
200	+4.0	-1.14	22	0.345	0.404
300	-2.0	+0.79	36	0.235	0.321
800	-1.0	+0.22	18	0.020	0.444
Ponderosa Pine	-1.0	+0.30	111	0.085	0.184
400	+1.0	-0.41	14	0.125	0.497
500	+10.0	-2.81	30	0.443	0.349
600	+6.0	-2.02	20	0.315	0.423
700	-0.05	+0.23	17	0.083	0.456
Douglas Fir	+2.0	-0.71	87	0.368	0.210
All Specimens	+1.0	-0.22	200	0.115	0.138

TABLE 10

Coefficients for the Equation $S = V_1 (M) + V_0$ (r_{crit} from Owen (1962))

Group	V_1	V_0	DF	r	r_{crit}
150	-15.24	+1.14	29	0.337	0.355
200	+0.31	+0.05	22	0.007	0.404
300	-10.72	+0.77	36	0.310	0.321
800	+15.29	-0.90	18	0.131	0.444
Ponderosa Pine	-5.71	+0.45	111	0.134	0.184
400	-10.41	+0.94	14	0.270	0.497
500	+1.81	-0.05	30	0.044	0.349
600	+21.64	-1.29	20	0.297	0.432
700	-1.41	+0.19	17	0.129	0.456
Douglas Fir	+6.65	-0.39	87	0.300	0.210
All Specimens	+3.48	-0.17	200	0.114	0.138

TABLE 11

Coefficients for the Equation $S = V_1 \times 10^{-1} (\rho) + V_2 (M) + V_0$
(R_{crit} from Owen (1962))

Group	V_1	V_2	V_0	DF	R	R_{crit}
150	-0.555	+13.784	+1.655	28	0.508	0.439
200	+0.382	-1.377	-0.474	21	0.346	0.498
300	-0.107	-8.866	+1.570	35	0.327	0.399
800	-0.084	+16.349	-0.802	17	0.133	0.545
Ponderosa Pine	-0.007	-5.512	+1.001	110	0.134	0.234
400	+0.208	-12.339	+1.077	13	0.339	0.608
500	+0.968	+1.921	-2.328	29	0.445	0.432
600	+0.555	+18.916	-2.423	19	0.407	0.520
700	+0.021	-1.758	+0.889	16	0.131	0.559
Douglas Fir	+0.200	+1.472	-0.054	86	0.370	0.269
All Specimens	+0.053	+2.015	+0.346	199	0.125	0.200

$$S = V_1(\rho) + V_2(M) + V_0.$$

Again the same two Douglas fir groups, one of which is the species series, and one Ponderosa pine group give significant correlations. The effects of the independent variables are the same as were found in the individual independent variable correlations.

5.2.4 $S = f(\rho, M)$ of the Second Degree

As Table 12 shows, four significant correlations are found for the equation

$$S = V_1 (\rho) + V_2 (\rho)^2 + V_3 (M) + V_4 (M)^2 + V_5 (\rho)(M) + V_0.$$

It is important to note which groups give the significant correlations. Of the four, only one is an individual group. The other three are the Ponderosa pine series, Douglas fir series and the "All Specimen" series. Notice the similarity between the coefficients of the significant equations both in regard to sign and numerical value. Because of this it would seem that the equation for the "All Specimens" group would give one of the best fits of all of 110 equations listed. The

TABLE 12

Coefficients for the Equation $S = V_1 (\rho) + V_2 \times 10^{-3} (\rho)^2 + V_3 \times 10^2 (M) + V_4 \times 10^2 (M)^2 + V_5 (\rho)(M) + V_0$

R_{crit} from Owen (1962))

Group	V_1	V_2	V_3	V_4	V_5	V_0	DF	R	R_{crit}
150	+0.458	-4.221	-2.832	+27.578	-2.808	+3.111	25	0.638	0.585
200	+0.091	+3.583	-1.204	+18.959	-4.327	+2.938	18	0.495	0.660
300	-0.196	+0.442	-0.762	-1.100	+2.244	+7.210	32	0.403	0.533
800	-0.017	+38.363	+8.885	-46.504	-9.601	-4.179	14	0.378	0.717
Ponderosa Pine	+0.342	-6.360	-0.881	+3.544	+1.252	-2.125	107	0.331	0.319
400	+0.368	-6.894	-2.423	+8.320	+2.300	+3.939	10	0.394	0.790
500	+1.450	-38.760	-3.382	-6.374	+14.271	-453.2	26	0.557	0.576
600	+3.411	-62.301	-3.649	-4.126	+12.940	-1092.9	16	0.622	0.687
700	+0.233	-6.012	-0.388	-3.957	+2.745	-2.027	13	0.338	0.733
Douglas Fir	+0.133	-5.253	-0.254	-6.238	+3.429	-1.002	83	0.466	0.364
All Specimens	+0.349	-5.715	-0.224	+0.441	+0.634	-4.682	196	0.320	0.260

density directly influences the safe load ratio while density-squared adversely affects it. Just the opposite is true for the moisture and moisture-squared terms. The interaction term in three out of four instances directly affects the safe load ratio.

5.2.5 $\mathrm{LOG}_e(S) = f(\mathrm{LOG}_e(\rho), \mathrm{LOG}_e(M))$

The equation of the form

$$\mathrm{LOG}_e(S) = V_1\mathrm{LOG}_e(\rho) + V_2\mathrm{LOG}_e(M) + V_0$$

has only one significant correlation and that is for Ponderosa pine group 150 (Table 13). Only two other groups have multiple regression coefficients whose values approach critical values.

5.2.6 Comments on the Safe Load Ratio Correlations

Of the 55 regression lines obtained, only twelve have multiple regression coefficients of significant value as compared to 34 of 55 for the modulus of elasticity regression lines. Two groups, Ponderosa pine group 150 and the Douglas fir series, contributed eight of the twelve significant lines. Groups 200, 300, 400, 600, 700, and 800 do not give a single significant

TABLE 13

Coefficients for the Equation $LOG_e\ (1000S) = V_1 LOG_e\ (100\rho) + V_2 LOG_e\ (10000M) + V_0$
(R_{crit} from Owen (1962))

Group	V_1	V_2	V_0	DF	R	R_{crit}
150	-12.982	+7.179	+28.156	28	0.468	0.439
200	+2.212	-0.435	-3.727	21	0.359	0.498
300	-5.331	-0.212	+21.900	35	0.253	0.399
800	+13.795	+19.484	-497.200	17	0.309	0.545
Ponderosa Pine	-1.491	+0.366	+6.702	110	0.069	0.234
400	+0.364	-0.013	+5.390	13	0.288	0.608
500	+10.224	-0.938	-30.099	29	0.400	0.432
600	+13.996	+0.226	-53.002	19	0.347	0.520
700	-0.162	+0.001	+3.449	16	0.054	0.559
Douglas Fir	+2.299	+0.146	-5.747	86	0.240	0.269
All Specimens	+0.044	+0.959	-0.247	199	0.076	0.200

correlation. The second-degree equation seems to give the most consistent results for the coefficients, and it also gives the only significant correlation for the "All Specimens" group.

It seems that the safe load ratio depends upon other factors such as defects or rings per inch. Items such as these cannot be readily evaluated and assigned a numerical value except in a somewhat arbitrary manner. It might be possible to eliminate all specimens where $S = 0$ but to do this would seriously affect both the mean and the standard deviation of the group to which it is applied. To eliminate these specimens from the correlation and regression analysis and not from the mean and standard deviation calculations would render any significant equation obtained useless as it would apply to an entirely different population than that which included specimens with $S = 0$.

CHAPTER VI

Conclusions

6.1 Test Procedures

The test procedures used appear to give consistent and accurate results. The static bending modulus of elasticity test, while not conforming entirely to ASTM standards for small clear specimens, comes as close to the actual manner of mine timber failure as can be expected in the laboratory.

6.2 Comparison of Ponderosa Pine and Douglas Fir

A study of the failures of both the Ponderosa pine and Douglas fir 2 x 2 x 36 inch specimens indicates that the two species fail in entirely different ways. The Ponderosa pine failed in a sudden and usually complete fashion, mean safe load ratio for 113 specimens being $S = 0.612 \pm 0.294$. The abrupt failures seem to be due to weak inter-ring adhesion forces which are easily broken whenever rings fail. The Ponderosa pine has a fairly low modulus of elasticity. The mean value of the Ponderosa pine modulus of elasticity is 881,200 ± 200,700 pounds per square inch.

By way of comparison the 89 Douglas fir specimens failed in a slower and less-complete manner. The Douglas fir specimens were much more defect-free than the Ponderosa pine specimens and rarely failed completely. Cross-grain was a defect which consistently caused complete and sudden failures in the Ponderosa pine. While cross-grain was present in a few Douglas fir specimens it did not cause the sudden and complete failures that it did in the Ponderosa pine. This is probably due to the large difference in the inter-ring adhesive forces of the two species. The Douglas fir safe load ratio for 89 specimens is 0.722 ± 0.243. This is 1.2 times greater than the Ponderosa pine value and the standard deviation is only 0.8 times as great as that of Ponderosa pine.

In addition to having a higher safe load ratio, the Douglas fir has a higher modulus of elasticity. The Douglas fir modulus of elasticity is 1,520,000 ± 290,382 pounds per square inch. This is approximately twice the value of the modulus of elasticity of Ponderosa pine. The Douglas fir standard deviation, however, is about 1.5 times that of the Ponderosa pine.

6.3 Modulus of Elasticity Formulas

The modulus of elasticity was found to be a function of the density and moisture for both Ponderosa pine and Douglas fir. The effect of the moisture on the modulus of elasticity is adverse for both species. The density effect, however, is opposite between the species. In the instance of the Ponderosa pine, an increase in density yields a decrease in the modulus of elasticity, while for Douglas fir, an increase in density yields an increase in the modulus of elasticity. Because only two species were tested it was impossible to determine accurately any relationship between species. It appears, however, that between species the modulus of elasticity is directly dependent on density and adversely dependent on moisture.

The value of the modulus of elasticity can be calculated from the following equations. For Ponderosa pine

$$E = -2.35 \times 10^4 (\rho) + 1.658 \times 10^6, \quad (1)$$

$$E = -1.71 \times 10^4 (\rho) - 5.59 \times 10^6 (M) + 1.819 \times 10^6, \quad (2)$$

and

$$E = +1.53 \times 10^5 (\rho) - 0.22 \times 10^4 (\rho)^2 + 5.39 \times 10^6 (M) + 8.24 \times 10^6 (M)^2 - 0.29 \times 10^6 (\rho)(M) - 1.534 \times 10^6. \quad (3)$$

For Douglas fir, the corresponding equations are

$$E = +2.35 \times 10^4 (\rho) + 0.727 \times 10^6, \quad (4)$$

$$E = +3.43 \times 10^4 (\rho) - 5.21 \times 10^6 (M) + 0.725 \times 10^6, \quad (5)$$

and

$$E = -3.52 \times 10^5 (\rho) + 1.01 \times 10^4 (\rho)^2 + 1.01 \times 10^8 (M) + 2.26 \times 10^8 (M)^2 - 4.10 \times 10^6 (\rho)(M) + 3.323 \times 10^6. \quad (6)$$

In these equations

E = modulus of elasticity in pounds per square inch,

ρ = density in pounds per cubic foot,

and M = moisture (dimensionless).

For most applications the first or second equation should give sufficiently accurate results. Should it be desired to have a more accurate value of the modulus of elasticity, in order to determine loads due to over-burden, for instance, the third formula should be used.

These formulas (or more exactly, these coefficients) may be used for species other than Ponderosa pine and Douglas fir. This should not be done without checking the validity of the coefficients for the new species. These formulas should not be extrapolated much beyond the ranges given even for the same species.

6.4 Safe Load Ratio Formulas

The safe load ratio was found to be a function of the density and moisture in fewer instances than was the modulus of elasticity. The safe load ratio is directly dependent on the density and adversely dependent on the moisture. A significant correlation is found between the two species. The mean safe load ratio for 113 Ponderosa pine specimens is 0.612 $\pm$ 0.294 and for 89 Douglas fir specimens is 0.722 $\pm$ 0.243. The safe load ratio may be calculated for Ponderosa pine from the following equation:

$$\begin{aligned} S = {} & +3.42 \times 10^{-1} (\rho) - 6.36 \times 10^{-3} (\rho)^2 - \\ & 0.88 \times 10^{2} (M) + 3.54 (M)^2 + \\ & 1.25 (\rho)(M) - 2.125. \quad (7) \end{aligned}$$

For Douglas fir either

$$\begin{aligned} S = {} & +2.00 \times 10^{-2} (\rho) + 1.47 (M) - \\ & 5.38 \times 10^{-2} \quad (8) \end{aligned}$$

or

$$S = 1.32 \times 10^{-1} (\rho) - 5.25 \times 10^{-3} (\rho)^2 - 0.25 \times 10^2 (M) - 6.24 \times 10^2 (M)^2 + 3.43 (\rho)(M) - 1.002 \quad (9)$$

may be used. If desired, the formula

$$S = +3.49 \times 10^{-1} (\rho) - 5.72 \times 10^{-3} (\rho)^2 - 0.22 \times 10^2 (M) + 0.44 \times 10^2 (M)^2 + 0.63 (\rho)(M) - 4.682 \quad (10)$$

may be used for either species. In these equations,

S = Safe Load Ratio (dimensionless),

ρ = Density in pounds per cubic foot,

M = Moisture (dimensionless).

The formulas given for the individual species should not be used for any other species and should not be extrapolated beyond the ranges given in Tables 1 and 2. The formula given last should not be used for different species until it is proven to be valid for these species. In view of the large standard deviation in both species, the safe load ratio should be calculated using as many significant formulas as possible, and the lowest value should be used.

6.5 Suitability of Ponderosa Pine for Mine Use

Ponderosa pine, as tested, does not appear to be a wood suitable for the support of mine openings. Its low strength, safe load ratio and abrupt and frequently complete manner of failure render it unsuitable for this use. This is not to say that Ponderosa pine has no use in mining. While not suitable for support in mines having bad ground conditions it could be used in areas where only light support, to prevent slabbing for instance, is needed. Even here though, careful attention should be paid to the selection of the size of timber used. It is here that the safe load ratio can be employed to best advantage. Ponderosa pine may be used as lagging, in chutes and raises, and as a general construction wood.

The formulas presented should make it much easier for the mine owner and operator to select an adequate, safe timber for use in mine opening support. By cutting down on size of timber wherever possible, by changing type of timber used when conditions permit, and by suitably matching the timber to the job, it should be possible for the mine operator to save substantial amounts of money both on the timber and on freight.

CHAPTER VII

Areas for Further Study

The investigation of the inter-relationships of moisture, density, and modulus of elasticity should be extended by studying different species with densities higher, such as oak, and lower, such as southern pine, than Douglas fir and Ponderosa pine in order to determine a definite relation between species. The safe load ratio deserves more study especially in view of the fact that it seems to depend on factors other than density and moisture. Should a more significant relationship be found, timber supports used could be tailored much more closely to sizes required. The use of a computer permits rapid re-evaluation of old data and any future work in these areas should be carried out with this in mind.

APPENDIX A

Sample Data Sheets

DATE 6 / 7 / 66 SPECIMEN NUMBER 221

SPECIES Pond. Pine TEST Static Bend. LOADING 2 point

SPAN 30 in. MACHINE SPEED 0.125 in./min.

HEIGHT 2.00 in. WIDTH 1.98 in. LENGTH 35.93 in.

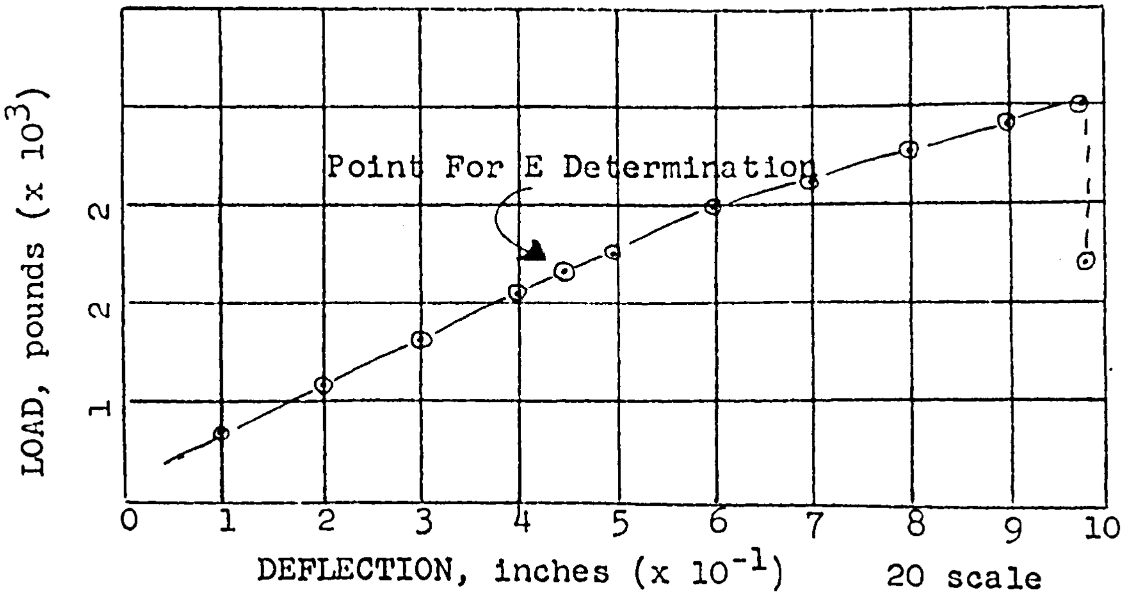
WEIGHT 1172.5 gm. MOISTURE 6.9 % DENSITY 33.49 lb./ft^3

KIND OF FAILURE: SPEED sudden, DEFECT EFFECT through check,

MAXIMUM LOAD 2080 lb. LOAD AFTER FAILURE 1240' lb.

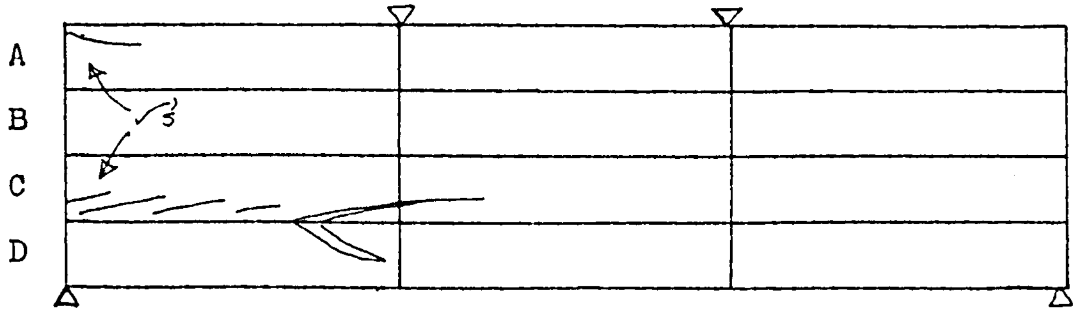
REMARKS piece made cracking noises in spurts with periods of quiet between

PHOTOGRAPHS 6-7-12



SPECIMEN NUMBER 221 DATE 6 / 7 / 66

SIDE VIEWS



DEFECTS GREEN FAILURES RED

MOISTURE:

SAMPLE	WT. W.	WT. D. 1	Wt. D. 2	Wt. D. 3	Wt. D. AVE.
1	22.35	20.85	20.75	20.75	___/3=___
2	23.60	22.10	22.05	22.05	___/3=___

$$\frac{\text{Wt. W. - Wt. D. Ave.}}{\text{Wt. W.}} = \underline{\ 6.9\ }\ \%$$

DENSITY:

END A	2.04 in. x 2.02 in.	=	___ ft.^{2}		
END B	2.00 in. x 1.98 in.	=	___ ft.^{2}		
MIDDLE	2.00 in. x 1.98 in.	=	___ ft.^{2}		
AREA			___/3	=	___ ft.^{2}
LENGTH					___ ft.
VOLUME					___ ft.^{3}

$$= \underline{\quad}\ \frac{\text{lb}}{\text{ft.}^3} = \underline{\ 33.49\ }\ \text{lb./ft.}^3$$

SAFE LOAD RATIO

$$\frac{\text{LOAD AFTER FAILURE}}{\text{MAXIMUM LOAD}} = \underline{\qquad}\ \frac{\text{lb.}}{\text{lb.}} = \underline{\ 0.596\ }$$

MODULUS OF ELASTICITY

SPAN L ____ L^3 ____, DEFLECTION D 0.450, LOAD P 1210,
BREADTH b ____, DEPTH d ____ d^3 ____,

$$E = \frac{PL^3}{4.7Dbd^3} = \frac{X}{4.7\ X\quad X\quad X\quad X} = 1.091 \times 10^6$$

lbs./in.^{2}

APPENDIX B

Static Bending Tests on Large Timbers

Eight 6 x 8 inch timbers were cut from each of the samples provided by the Western Pine Sales. These eight timbers were to be tested in static bending but it proved impossible to adapt the test apparatus to the four shorter timbers. The four longer timbers were then tested in a 100,000 pound mechanical compression machine in the University of Arizona Civil Engineering Department. The procedure for testing these large timbers was very similar to that used on the small specimens. Deflections were read using a streched wire rather than a dial indicator. Two-point leading was used (Figure 7). Moisture samples were taken with an electric drill. Holes were drilled on each side of the specimen to one-half the thickness of the specimen. The chips were then collected and treated the same as the small specimen moisture samples. The results of these tests are compared with values calculated from the equations presented in Chapter 6 in Table 14. The timbers after testing are shown in Figure 8.

Figure 7. Large Timber Test Apparatus. This figure shows a short 6 x 8 inch timber in the compression machine. The support blocks were not stable enough and thus the short timbers could not be tested. The four longer timbers were supported on the flat plates welded to the support rail.

The moisture values for all the large timbers are somewhat higher than for the small specimens. This is possibly due to the difference in the manner in which they were taken. With the exception of the values

TABLE 14

Actual and Calculated Values of Parameters for Four Large Timbers

	Specimen	200	300	500	600
	Density	33.80	34.65	30.55	35.80
	Moisture	9.74%	13.90%	10.70%	10.80%
Modulus of Elasticity	Actual	911,000	854,000	1,415,000	1,545,000
	Eq. 1	863,700	844,000	---------	---------
	Eq. 2	797,000	450,000	---------	---------
	Eq. 3	775,000	638,000	---------	---------
	Eq. 4	-------	-------	1,445,000	1,568,000
	Eq. 5	-------	-------	1,215,000	1,390,000
	Eq. 6	-------	-------	2,333,000	1,715,000
Safe Load Ratio	Actual	0.523	0.211	0.975	0.580
	Eq. 7	1.071	2.716	-----	-----
	Eq. 8	-----	-----	0.713	0.821
	Eq. 9	-----	-----	0.481	0.277
	Eq. 10	0.927	1.365	0.855	1.052

Figure 8. Failures of Large Timber Specimens.

A. Specimen 200 (Ponderosa pine). This timber failed through a check and cross-grain.

B. Specimen 300 (Ponderosa pine). Note the local nature of the failure zone.

C. Specimen 500 (Douglas fir). Piece failed at knot but continued to support a substantial load.

D. Specimen 600 (Douglas fir). An excellent example of a Douglas fir failure. The rings failed (short vertical failures) and these failures were then connected by the inter-ring failures (long horizontal failures). As these latter failures occur the piece slowly lost its ability to support a load.

Figure 8. Failures of Large Timber Specimens.

obtained with equation 6, the modulus of elasticity values are quite close to the actual value. Equation 7 gives Safe Load Ratio values greater than 1.000 for the Ponderosa pine timbers. The Douglas fir Safe Load Ratios, from equations 8, 9 and 10 were reasonably close to actual values (approximately ± one standard deviation).

APPENDIX C

Grading Rules for Mine Timbers

The following grading rules are from 1965 Standard Grading Rules: Western Wood Products Association, pp. 157, Douglas Fir and Larch - Beams & Stringers.

"124-c. "STANDARD" (No. 1 MINING) - BEAMS AND STRINGERS"

"Timbers of this grade are recommended and widely used for general construction and mine timbering. Where they occur, the natural characteristics of lumber are so limited, that each piece of this grade may be used in the form in which it is shipped.

Some pieces of this grade may have:

Stained Wood.
Seasoning Checks.
Medium Splits.
Torn Grain.
Pitch Streaks.
Skips 1/8" deep and 2' in length, or 1/16" scant full length.
Pitch Pockets.
Wane approximately 1/3 of any face.
Firm white specks, narrow streaks.
Shake 1/2 length, 1/2 thickness.
Small spots of unsound wood, well scattered.
Knots, large, unsound, or not firmly fixed, not larger than approximately 1/2 the width of the face.
Holes, large, scattered.

All or nearly all of the permissible characteristics of the grade are never present in maximum size or number in any one piece. Any piece with an unusual combination of characteristics which seriously affects normal serviceability is excluded from the grade."

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