# R 573

Technical Report

# DYNAMIC PROPERTIES OF SMALL, CLEAR SPECIMENS OF STRUCTURAL-GRADE TIMBER

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NAVAL FACILITIES ENGINEERING COMMAND

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Port Hueneme, California

## EVALUATION SHEET

Technical Report TR-573

Title DYNAMIC PROPERTIES OF SMALL, CLEAR SPECIMENS OF STRUCTURAL-GRADE TIMBER

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The following questions are designed to elicit comments that will help NCEL improve the quality of its reports. Specific and detailed answers will be most appreciated.

1. Was the technical material worth publishing?

2. Was the technical material organized in a coherent manner?

3. Were the title, abstract, and introduction indicative of the reports' contents?

4. Did the report contain any unnecessary or irrelevant material, or did it lack essential material?

5. Do you have any comments about the typography used, the layout of the report, or its general readability?

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## INTRODUCTION

Considerable attention has been given in recent years to the resistance of structural materials to loads simulating those imposed by atomic blasts. Original experiments involved field tests of full-scale structures and structural elements subjected to loads imposed by actual atomic blasts. Subsequently, most research testing was moved to the laboratories, where testing and recording equipment has become more and more sophisticated and where specimen sizes have varied from full-scale structural elements to test coupons a few inches long.

Of all structural materials included in blast-resistance research, timber seems to have been most neglected except in the early field tests where wooden buildings were exposed to atomic blasts. In addition, great strides have been made in manufactured timber components such as glued-laminated beams and plywood. This study was undertaken to provide up-to-date information on the response of wood to dynamic (rapidly applied) loads approximating those experienced in atomic blasts.

Allowable unit stresses for wood originated with what are known as basic stresses, which, in turn, were obtained from tests of small, clear wood specimens. Accordingly, research in this study was limited to tests on small, clear specimens (2 x 2 inches) of Douglas fir (coast type), selected as typical of widely used structural timbers. The specimens were selected and prepared to conform with an equivalent grading of dense select structural. (See the Appendix.)

## PHYSICAL CHARACTERISTICS OF WOOD

The following discussion of the structure of wood is taken from References 1, 2, and 3. Wood is an organic material consisting principally of hollow tube like cells of cellulose cemented together by lignin and containing minor amounts of extractives. Most of the cells (or fibers) are oriented vertically in the growing tree. In most timbers the length of a cell is as much as 100 times its width, varying from about 0.04 to 0.33 inch in length and from 0.0004 to 0.0033 inch in diameter.

The strength of wood depends upon the thickness of its cell walls rather than upon the length of its cells. The thickness of the cell walls varies with the species and varies throughout a growing season. The cell walls are not as thick in the early part of the growing season (springwood) as they are in the later season (summerwood). In turn, the wood showing wider summerwood rings is a stronger wood, other things being equal.

The hollow portion of the cell, called the cell cavity, is usually full of water when the wood is green. The cell walls (the woody material) are porous and highly hygroscopic. The capillaries existing in the cell walls have significantly large surface areas and can accommodate relatively large amounts of water. The presence of this capillary water contributes to the flexibility of wood; however, green wood generally has lower strength than the more brittle dry wood.

As wood dries, the water in the cell cavities evaporates first; the depletion of this water has been found to have no effect upon the strength properties. The fiber saturation point is the moisture content at which the cavity water is removed but the cell capillaries remain saturated. For Douglas fir, the fiber saturation point is 25% to 30% moisture. As the water in the capillaries begins to evaporate, the woody material composing the cell starts to stiffen and gains in strength, principally in the direction of the length of the fibers (cells). The moisture content of the wood is defined as the weight of the water present divided by the oven-dry weight of the wood.

The average specific gravity of woody material is about 1.49, which means that if it were voidless, it would not float in water. Due to the porosity and general makeup of wood, however, the bulk specific gravity of structural timber ranges between 0.3 and 0.6. The specific gravity (or density), then, is a measure of the inherent strength of wood, because in general, the more woody material present per unit volume, the higher the strength.

As the moisture content falls below the fiber saturation point, surface tensile stresses set up in the pores of the cell walls cause the wood to shrink. Most shrinkage occurs along the length of the cells, that is, along the grain. It is the action of the shrinkage stresses which imparts the higher inherent strength to dry wood by tending to bind the cells tighter together in compression. As the wood cells become drier and stiffer, they also become more brittle, with the result that properly dried wood has higher strength than green wood but is not as flexible.

## RESEARCH PROGRAM

### Selection and Preparation of Specimens

Under a contractual agreement, personnel at the Oregon Forest Research Laboratory at Corvallis, Oregon, selected and prepared the timbers for this study, using a randomized mill sampling procedure. Timbers (flitches) of clear Douglas fir wood about 25 feet long were selected from six different mills in Oregon. Names of individual mills and other data pertinent to the timbers are presented in the Appendix. Forty-one individual timbers were selected, from which 2 x 2-inch sticks about 5 feet long were cut. Half of the sticks from each timber were green with an average moisture content of about 46%, and half were kiln-dried to an average moisture content of about 11% prior to being shipped. Thus, green sticks and dry sticks from the same timber were available for comparisons of seasoning effects. Considerable care was exercised by representatives of Oregon Forest Research Laboratory in cutting the timbers and sticks to assure proper orientation of grain with respect to edges of specimens.

The sticks from each timber were designated at random with regard to the speed at which they were to be tested. One specimen for each type of test was cut from each stick.

### Testing Procedures

Tests were made in shear parallel to the grain, in bending, in compression parallel to the grain, and in compression perpendicular to the grain. Procedures for static tests conformed to ASTM D-143.[4] Dynamic test procedures departed from ASTM D-143 only in speed of testing. Tests were conducted at four different dynamic speeds, nominally 6 inches per minute, 60 inches per minute, 600 inches per minute, and 1,800 inches per minute. These are designated in this report as dynamic speeds 1, 2, 3, and 4, respectively. The actual achieved testing speed varied with the individual test specimen. Computation of the results of tests at dynamic speed 1 was discontinued after the first series of dynamic tests was concluded, because the results did not warrant the extra expenditure of money and time. (See Table 1 for the results of tests of shear parallel to grain for green specimens.)

### Testing Facilities

All tests were made in the NCEL dynamic testing machine previously used in tests of other engineering materials. An overall view of the machine can be seen in Figure 1. Details of the operation of the machine were presented in Reference 5. The machine is basically hydraulic, with extremely fast speed (head velocity) obtained by utilizing a pneumatic surcharge to drive the piston. The head velocities are fairly constant throughout its full stroke of 4 inches. Static tests were conducted in the machine by using a hand valve to maintain the slow rate of head travel.

For all the tests, the testing speed (rate of head travel) was determined by a potentiometer attached to the upper end of the piston. Except for the bending tests, the strain rate was calculated by dividing the testing speed by the length of the test specimen (in the direction of head travel). The strain rate in the bending specimens was calculated from a deflection rate based on the testing speed.

**Shear Parallel to Grain.** Test specimens for determining shear parallel to the grain conformed to the specifications in ASTM D-143,[4] where the sheared face is 2 x 2 inches. A typical test installation is shown in Figure 2, which also shows the special shear device obtained for this purpose; the load cell is below the lower loading plate. Results of all shear tests were recorded on a direct-writing oscillograph.

**Bending.** Test specimens for bending tests were 2 x 2 x 30 inches long, with a span of 28 inches between supports. The test installation for a typical bending test is shown in Figure 3. The beam deflection at the center relative to the beam ends was measured with a potentiometer. The load was measured with the specially designed strain gage load cell which can be seen just above the loading block in Figure 3. The load cell and potentiometer were calibrated over the range of load and deflection expected in the bending tests, and the outputs were recorded either on magnetic tape or by a direct-writing oscillograph. Data on magnetic tapes were reduced on an IBM 1620 computer.

**Compression Parallel to Grain.** Test specimens for determining compression parallel to grain were 2 x 2 x 8 inches long. A typical test installation is pictured in Figure 4; load was measured with the strain gage load cell shown beneath the lower loading plate. Strain (or compression) in the central portion of the specimen was measured with two 5-inch resistance strain gages placed on the vertical centerline on opposite faces of the specimen. The Wheatstone bridge was arranged so that the output consisted of the sum of the signals of the two gages, thus doubling the sensitivity. The total output of the bridge was then halved to obtain true strain in the test specimen. The block hanging adjacent to the test specimen in Figure 4 contains two strain gages, which complete the four-arm bridge. Outputs of both the load cell and the strain gages were recorded on either magnetic tape or direct-writing oscillograph.

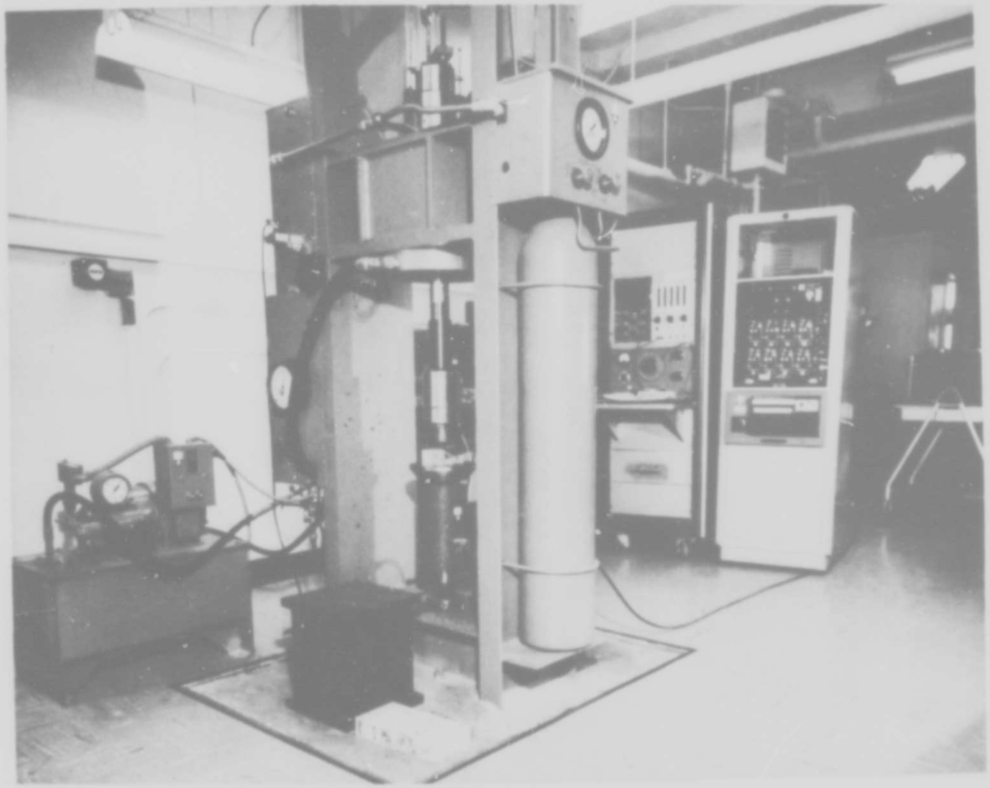

Figure 1. NCEL dynamic testing machine used in wood tests.

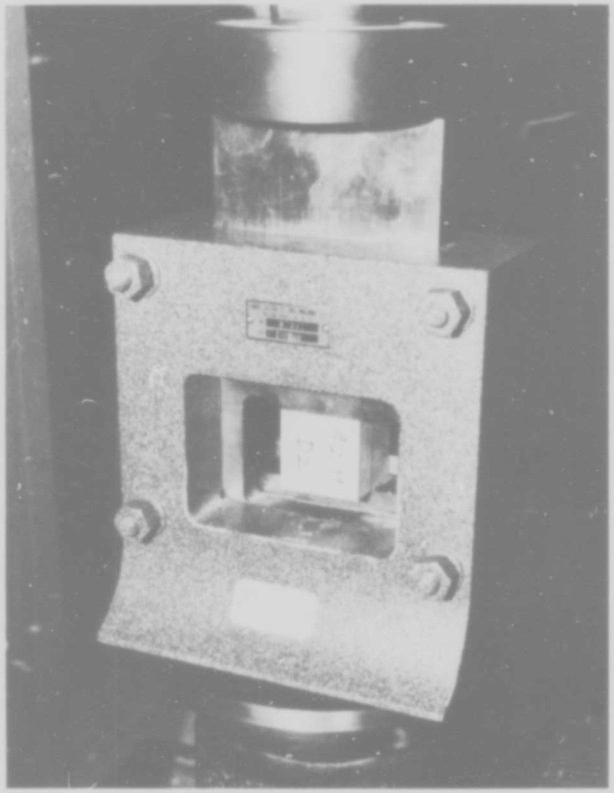

Figure 2. Installation for shear tests.

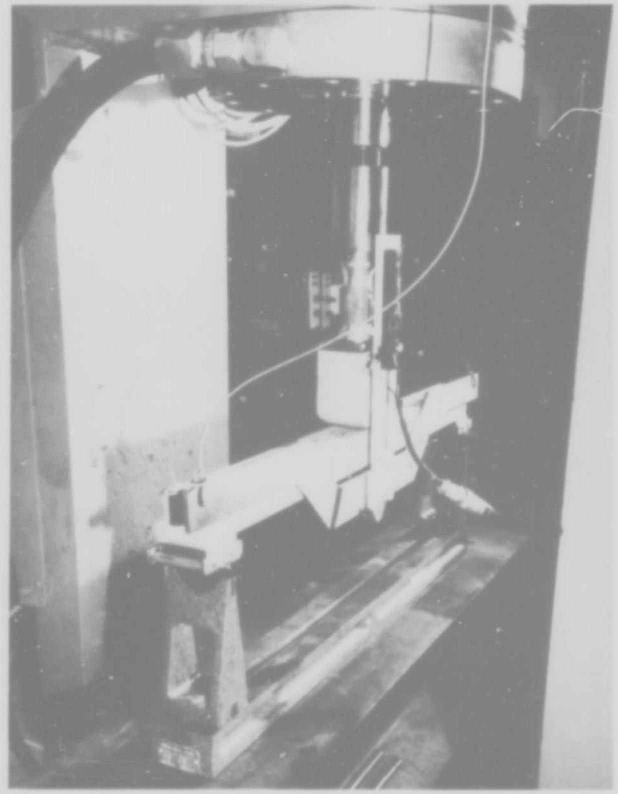

Figure 3. Installation for bending tests.

**Compression Perpendicular to Grain.** Test specimens for determining compression perpendicular to grain were 2 x 2 x 6 inches long. A typical test installation can be seen in Figure 5. The load cell is beneath the lower loading plate. Compression (deformation) between horizontal faces of the specimen was measured as total head travel by means of a potentiometer attached to the upper end of the piston (not shown in Figure 5). Test results were recorded either on magnetic tape or by a direct-writing oscillograph.

## TEST RESULTS

### Shear Parallel to Grain, Green Specimens

The relationship between testing speed and maximum shear stress of green specimens is shown in Table 1 and in Figure 6. There is a pronounced increase in maximum shear stress as testing speed increases. At testing speeds higher than about 100 inches per minute, the effect of speed is even more dramatic. The inherent variability of wood is clearly shown in Figure 6 by the points representing the individual tests at each testing speed. The curves shown in Figure 6 represent certain relationships obtained by statistical methods. Testing speed is the independent variable, and variations in speed at one speed level were due principally to inherent differences in the wood specimens and to difficulty in setting the controls of the testing machine at precisely the same spot for each test series.

Structural design allowances for timber are usually conservative, perhaps even ultraconservative. Decisions of structural designers are often based on the lower 95% confidence limit, which, in effect, defines a property below which not more than 2-1/2% of all the population will fall. In other words, 95% of the population will fall between the upper and lower 95% confidence limits.

At the lower 95% confidence limit (Figure 6) the increase in maximum shear stress between the static speed and dynamic speed 4 is about 54%. Since the first series of tests at dynamic speed 1 did not add materially to the data establishing the relationships between testing speed and maximum shear stress, it was decided to eliminate this speed from the subsequent tests.

### Shear Parallel to Grain, Dry Specimens

Table 2 and Figure 7 contain the results of the shear tests made on dry specimens. As noted for the green specimens, the maximum shear stress increases as the testing speed increases. At the lower 95% confidence limit, the increase in strength between static speed and dynamic speed 4 is about 43%.

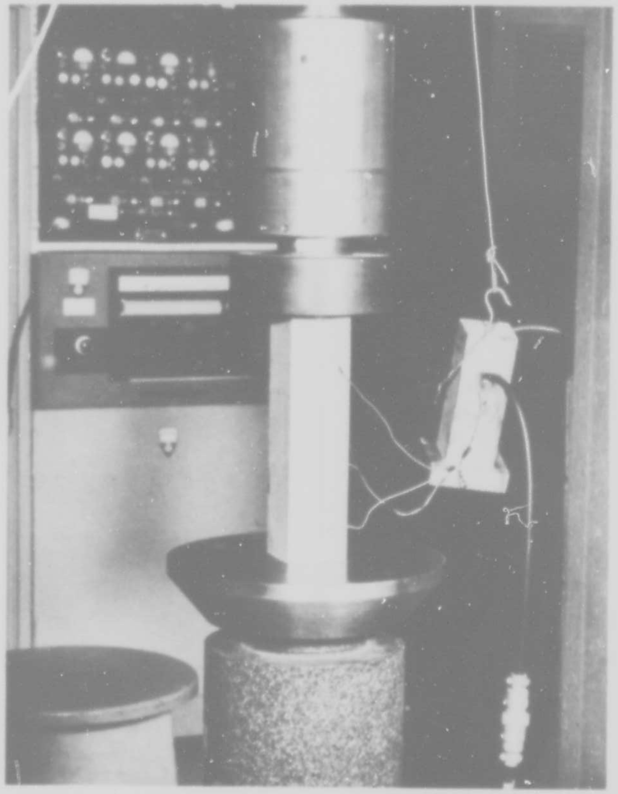

Figure 4. Installation for tests of compression parallel to grain.

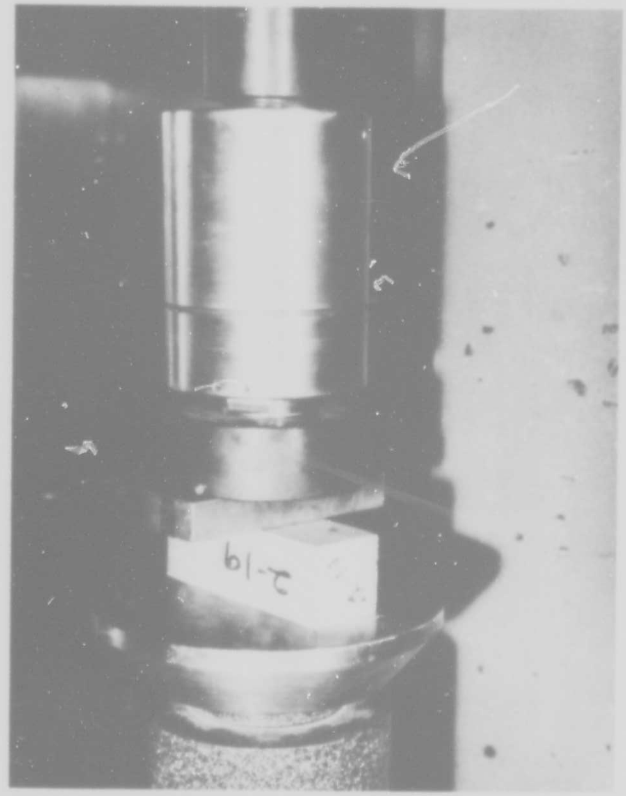


Figure 5. Installation for tests of compression perpendicular to grain.

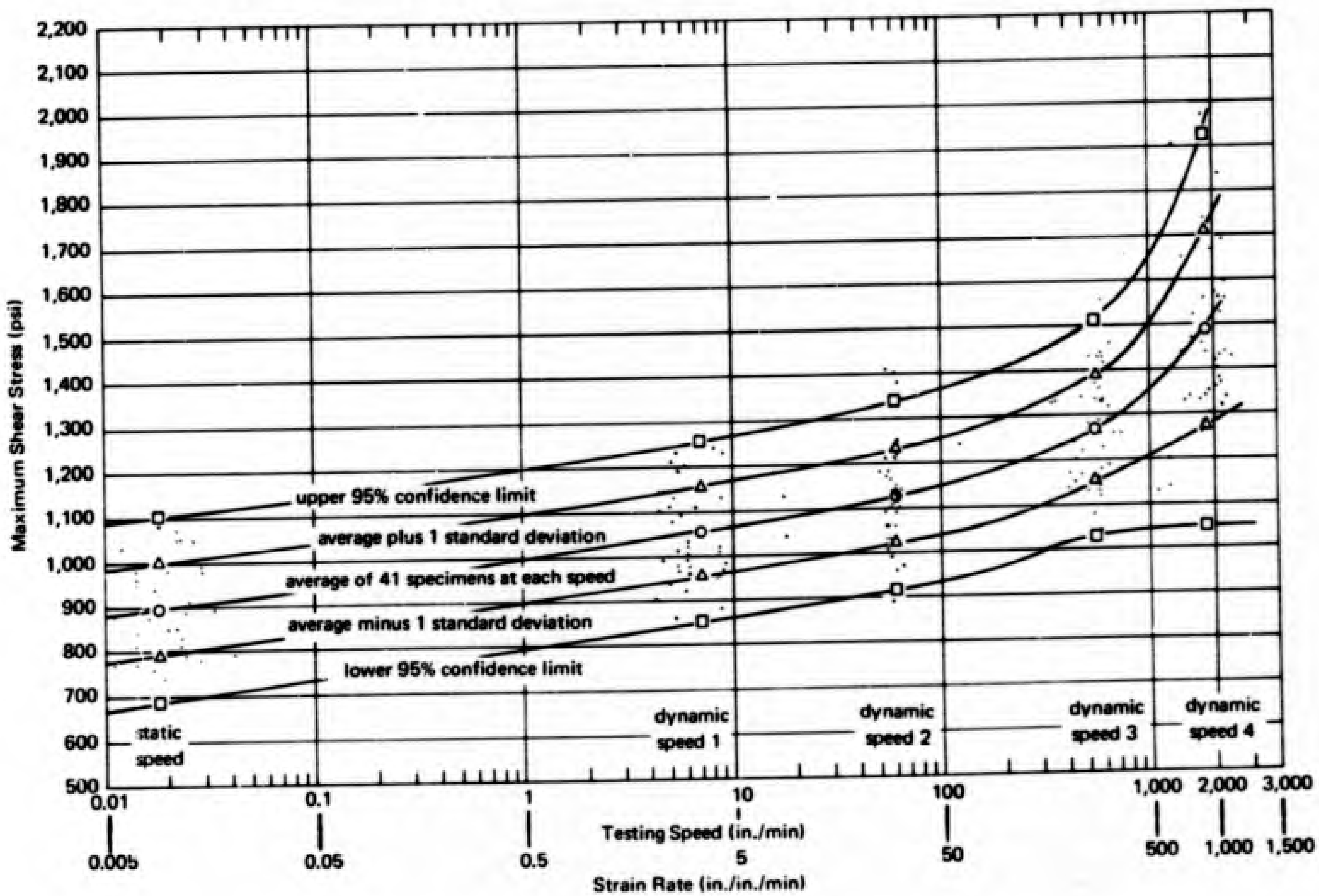


Figure 6. Relation between shear stress and testing speed (green specimens, parallel to grain).

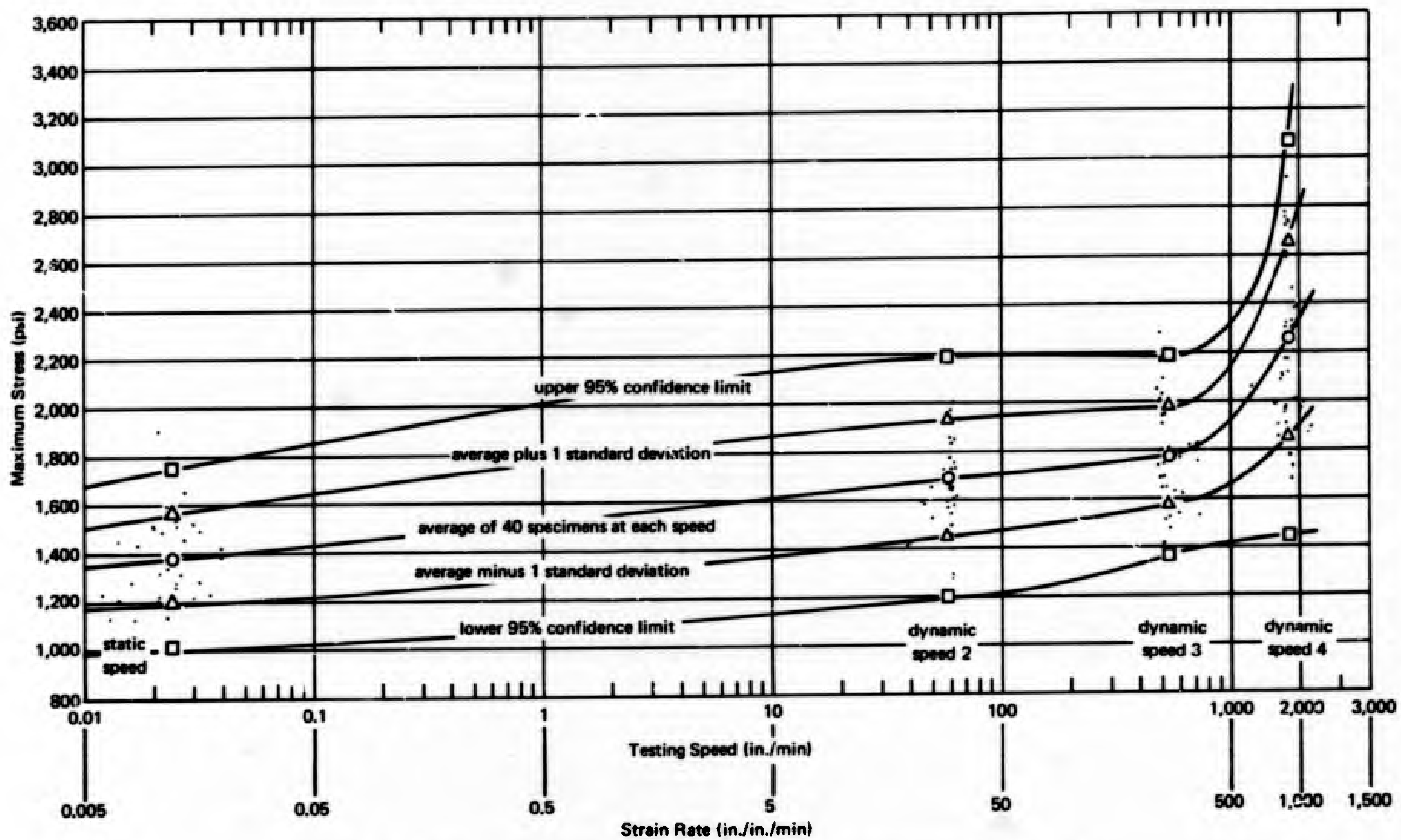


Figure 7. Relation between shear stress and testing speed (dry specimens, parallel to grain).

**Bending, Green Specimens**

**Fiber Stress at Proportional Limit.** The relationship between testing speed and proportional limit in bending is shown in Table 3 and in Figure 8 for green specimens. At the lower 95% confidence limit, the increase in proportional limit from static speed to dynamic speed 4 is about 124%.

**Modulus of Elasticity.** The relationship between testing speed and modulus of elasticity (**E**) in bending of green specimens (Table 3 and Figure 9) indicates a trend toward a reduction in **E** value at increasing speeds, rather than a pronounced increase as in the case of the proportional limit.

**Modulus of Rupture.** The relationship between modulus of rupture (**MOR**) and testing speed in bending of green specimens is shown in Table 3 and in Figure 10. At the lower 95% confidence limit (Figure 10) the increase in **MOR** from static test speed to dynamic speed 4 is about 54%.

**Bending, Dry Specimens**

**Modulus of Elasticity.** Test results for bending modulus of elasticity in dry specimens are reported in Table 4 and in Figure 11. Testing speed seems to have little effect on **E** up to about 60 inches per minute, but at testing speeds beyond 60 inches per minute there is a decided drop in **E**. At about 1,000 inches per minute the modulus increases slightly. At the lower 95% confidence limit, the decrease in **E** from the static speed to dynamic speed 4 is about 35%. Possible explanations for the decreases in values with increasing testing speeds are presented in the "Discussion" section of this report.

**Modulus of Rupture.** Table 4 and Figure 12 show the relationship between testing speed and modulus of rupture in bending of dry specimens. The **MOR** at 60 inches per minute is about 6% higher than that at the static speed but, as with the **E** values, there is a marked decrease in **MOR** as the speed increases to about 2,000 inches per minute. At the lower 95% confidence limit, the decrease in **MOR** from static speed to dynamic speed 4 is about 34%.

**Compression Parallel to Grain, Green Specimens**

**Modulus of Elasticity.** The relationship between testing speed and modulus of elasticity of green specimens tested in compression parallel to the grain is presented in Table 5 and in Figure 13. Testing speed has only a slight effect upon **E** for speeds up to about 500 inches per minute, above which the **E** increases rapidly to the top speed of about 1,200 inches per minute. At the lower 95% confidence limit, the increase in **E** from static speed to dynamic speed 4 was about 27%.

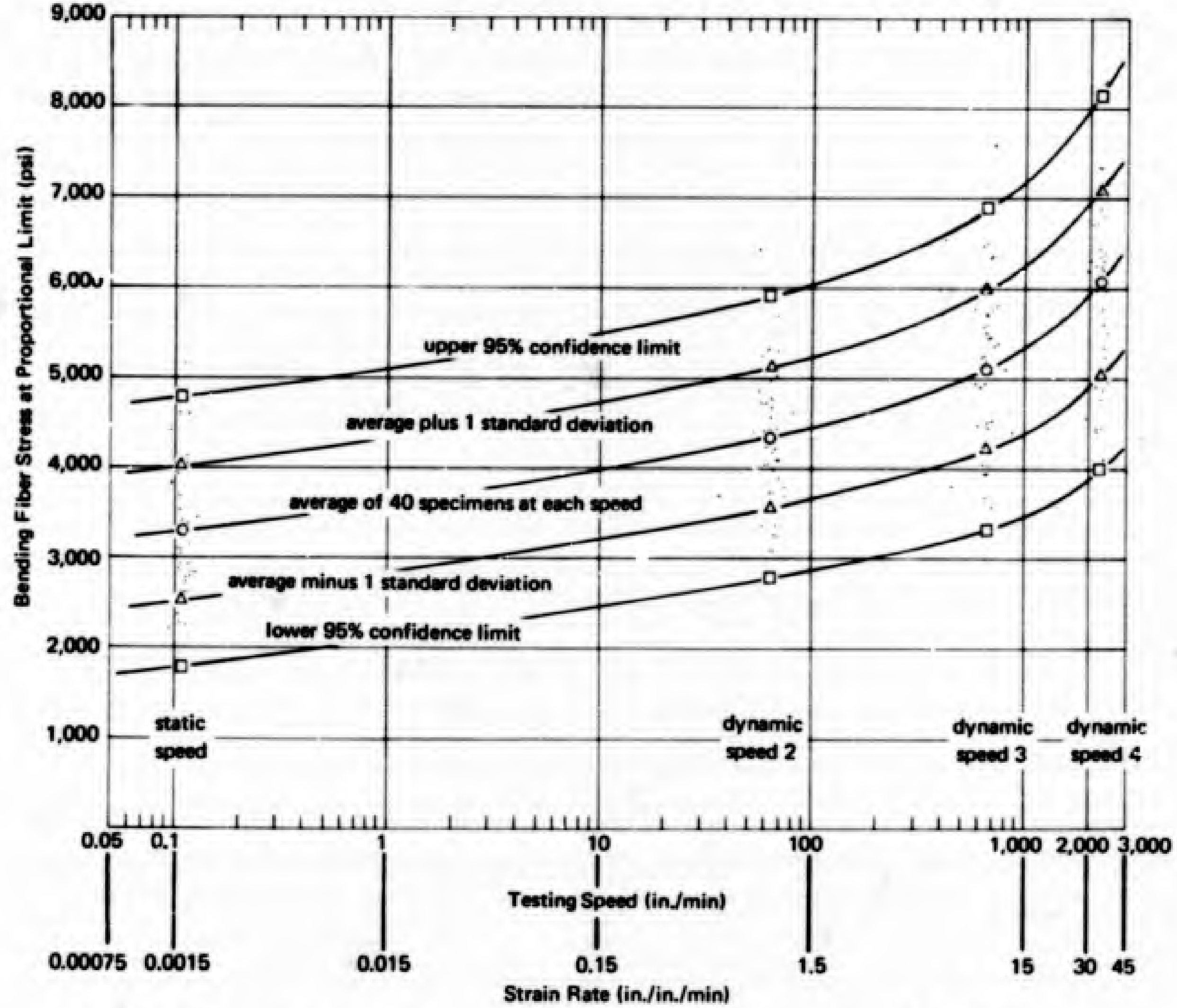


Figure 8. Relation between fiber stress at proportional limit and testing speed (bending tests on green specimens).

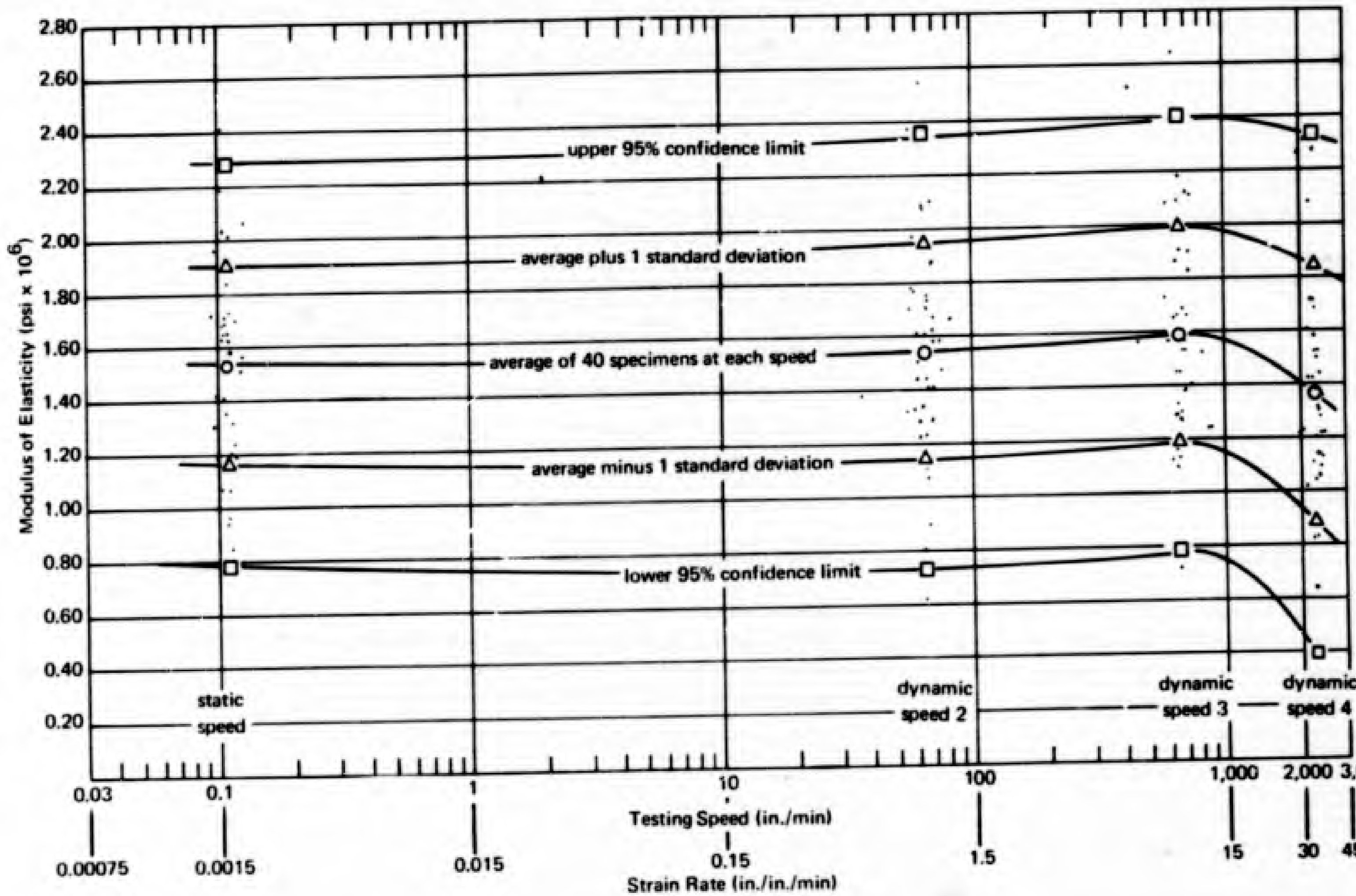


Figure 9. Relation between modulus of elasticity and testing speed (bending tests on green specimens).

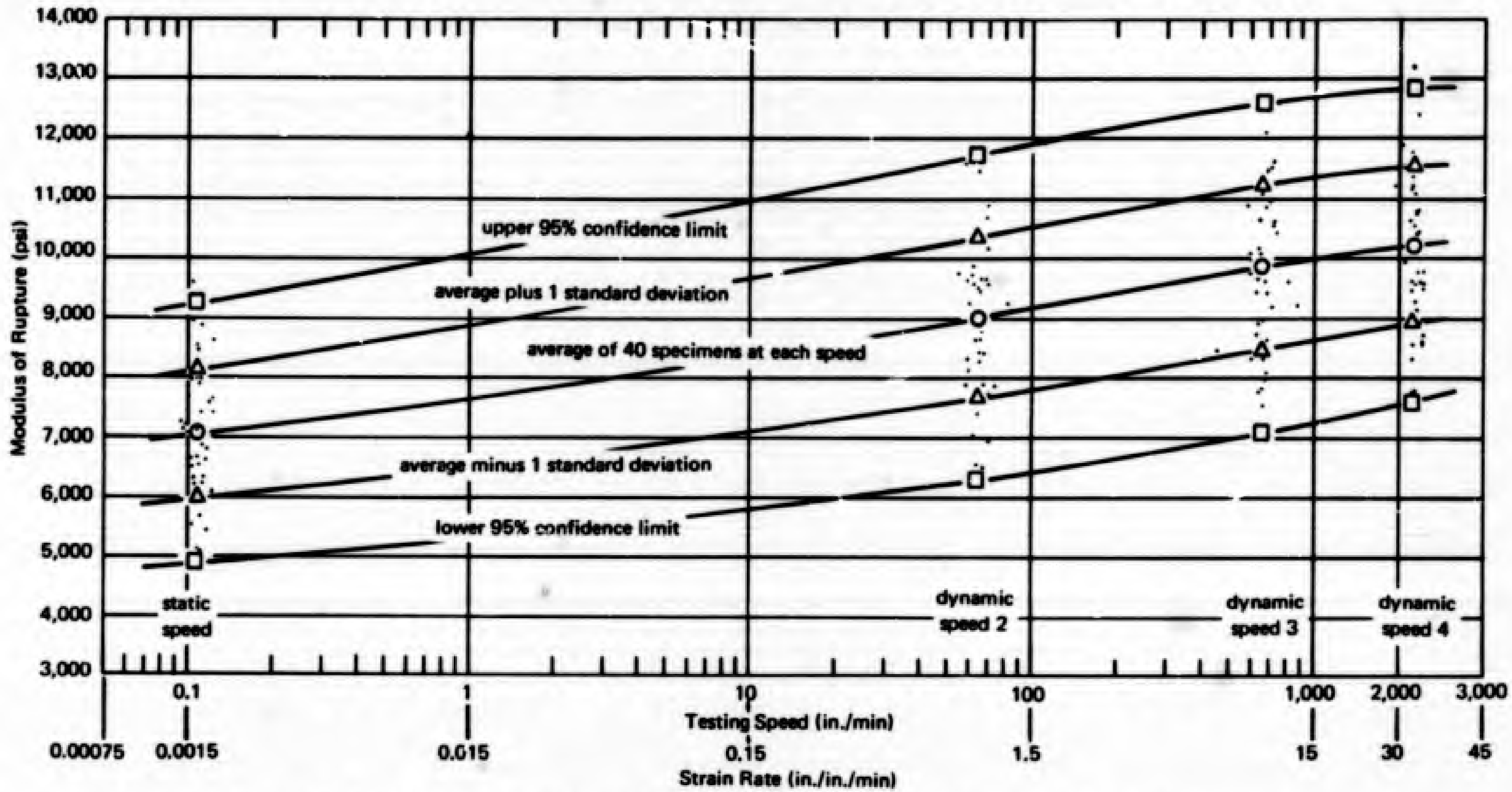


Figure 10. Relation between modulus of rupture and testing speed (bending tests on green specimens).

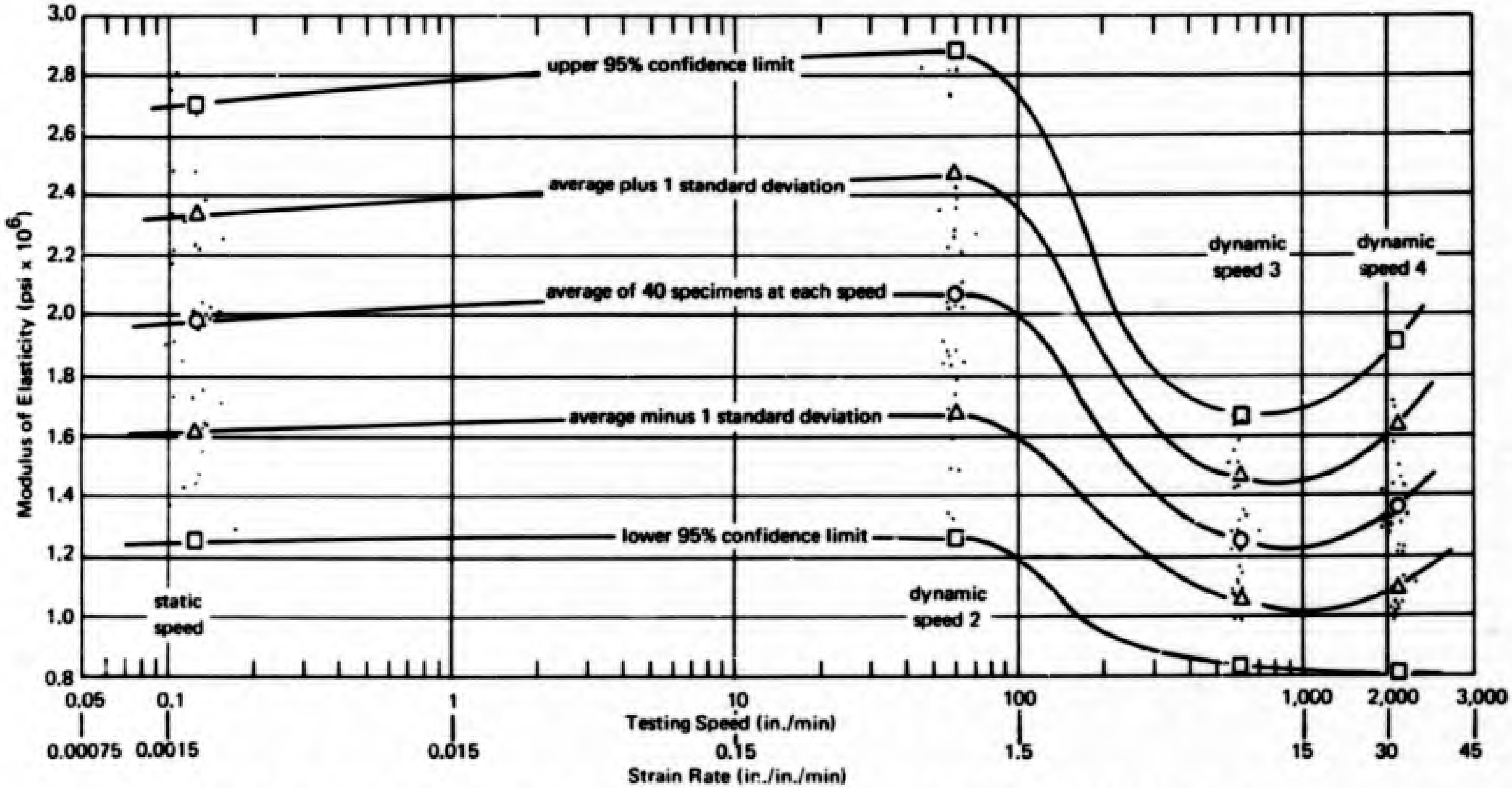


Figure 11. Relation between modulus of elasticity and testing speed (bending tests on dry specimens).

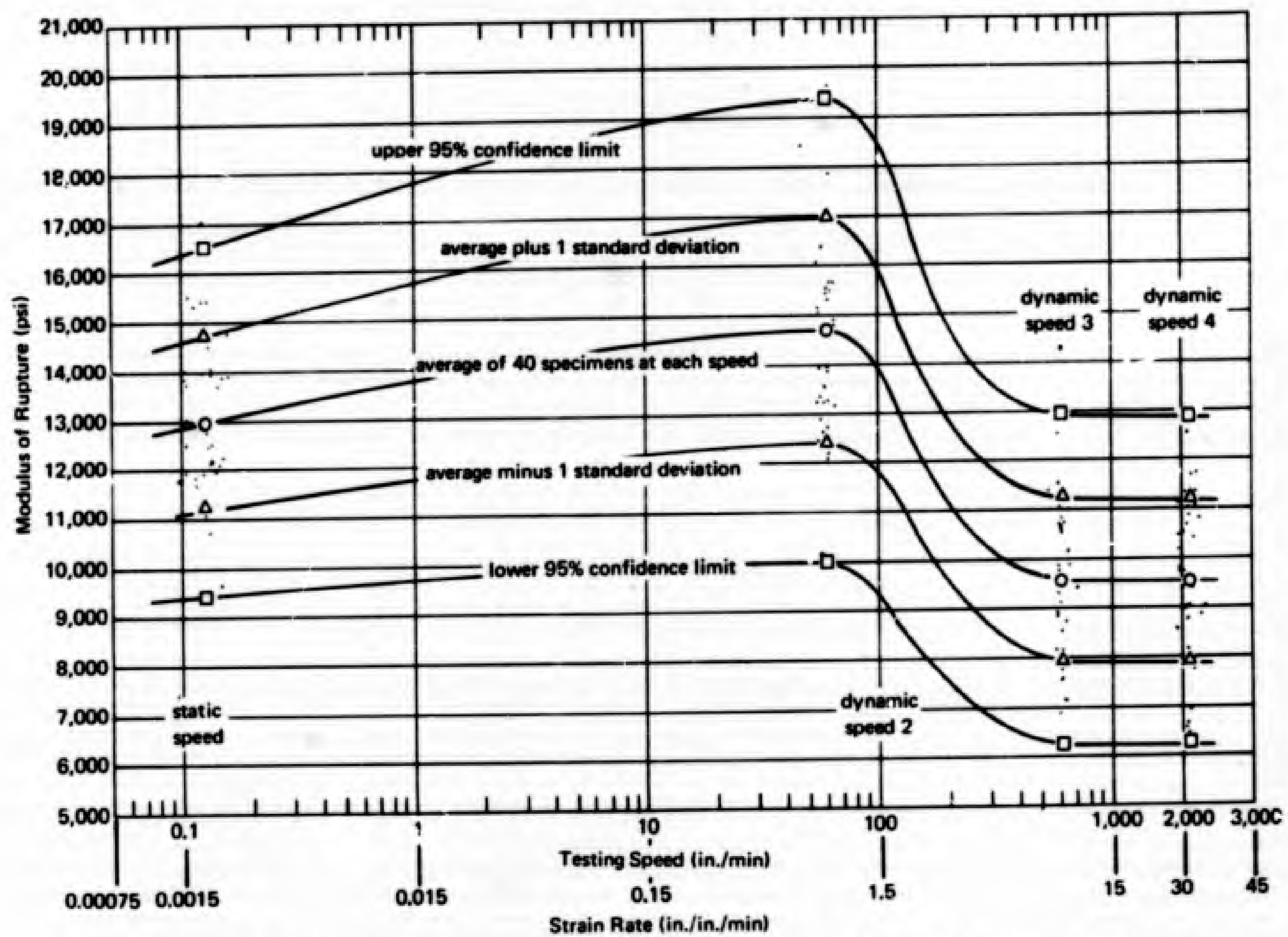


Figure 12. Relation between modulus of rupture and testing speed (bending tests on dry specimens).

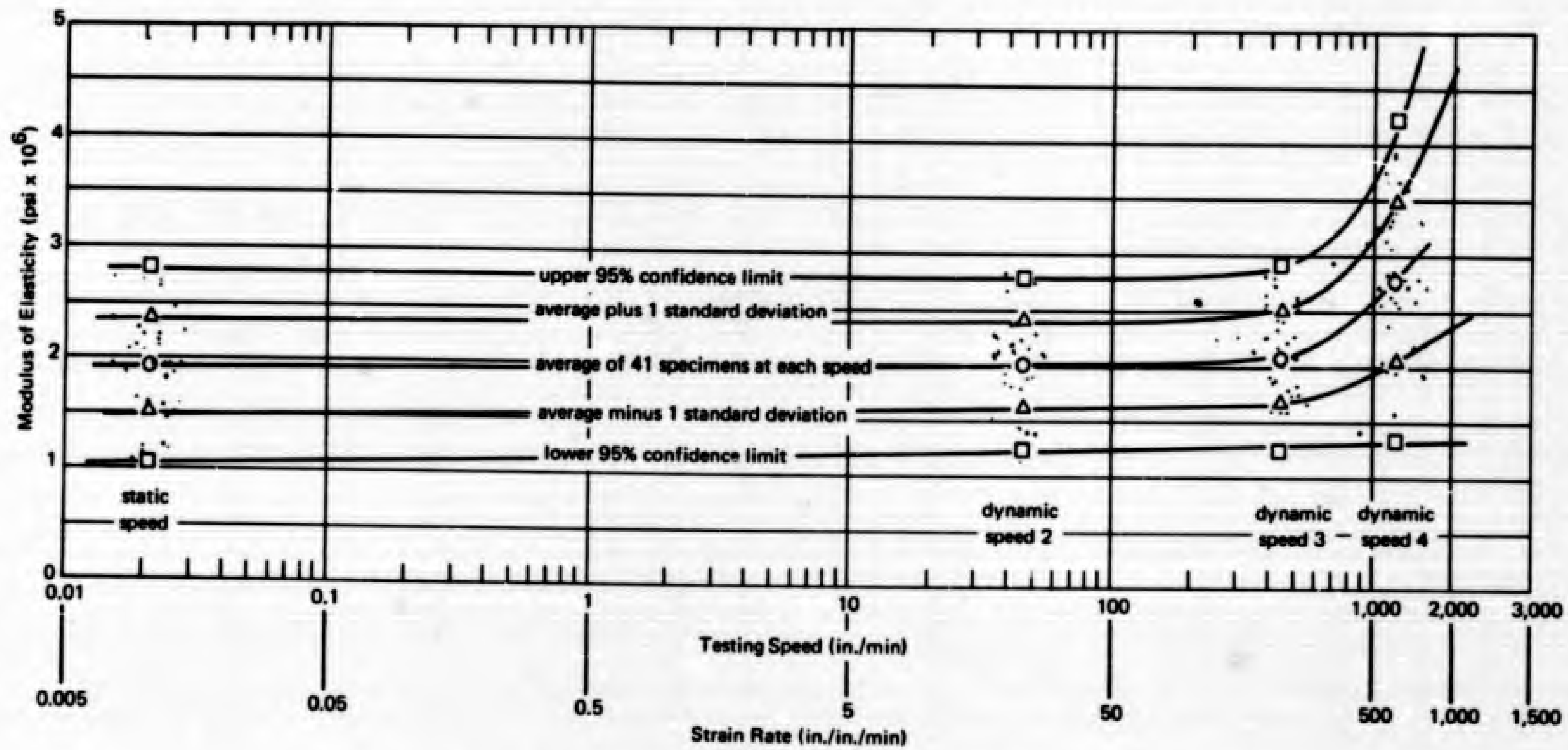


Figure 13. Relation between modulus of elasticity and testing speed (green specimens, compression parallel to grain).

**Maximum Stress.** The relationship between testing speed and maximum stress of green specimens tested in compression parallel to the grain is shown in Table 5 and in Figure 14. There is a gentle but steady increase in maximum stress as testing speed increases, with an upturn in rate of increase beyond a speed of about 500 inches per minute. At the lower 95% confidence limit, the increase in maximum stress from static speed to dynamic speed 4 was about 76%.

**Compression Parallel to Grain, Dry Specimens**

**Modulus of Elasticity.** Table 6 contains results of tests of dry specimens in compression parallel to the grain. The effect of testing speed upon **E** are shown in Figure 15. There was a slight increase in **E** at the faster testing speeds. At the lower 95% confidence limit, the increase in **E** from static speed to dynamic speed 4 was about 43%.

**Maximum Stress.** The relationship between testing speed and maximum stress of dry specimens tested in compression parallel to the grain is shown in Table 6 and in Figure 16. There is a gradual increase in maximum stress with testing speed and a rather pronounced increase beginning at a speed of about 100 inches per minute. At the lower 95% confidence limit, the increase in maximum stress from static speed to dynamic speed 4 was about 70%.

**Compression Perpendicular to Grain, Green Specimens**

The relationship between testing speed and maximum stress for green specimens tested perpendicular to the grain is shown in Table 7 and in Figure 17. Maximum stress increases as the testing speed increases, but tends to drop off at the highest speeds. At the lower 95% confidence limit, the net increase in maximum stress from static speed to dynamic speed 4 was about 40%.

**Compression Perpendicular to Grain, Dry Specimens**

The effects of testing speed upon maximum stress in compression perpendicular to grain tests on dry specimens are shown in Table 8 and in Figure 18. There is a gentle decrease in maximum stress between static speed and dynamic speed 2, followed by an increase up to dynamic speed 4. At the lower 95% confidence limit, there is a net increase in maximum stress from static speed to dynamic speed 4 of about 50%.

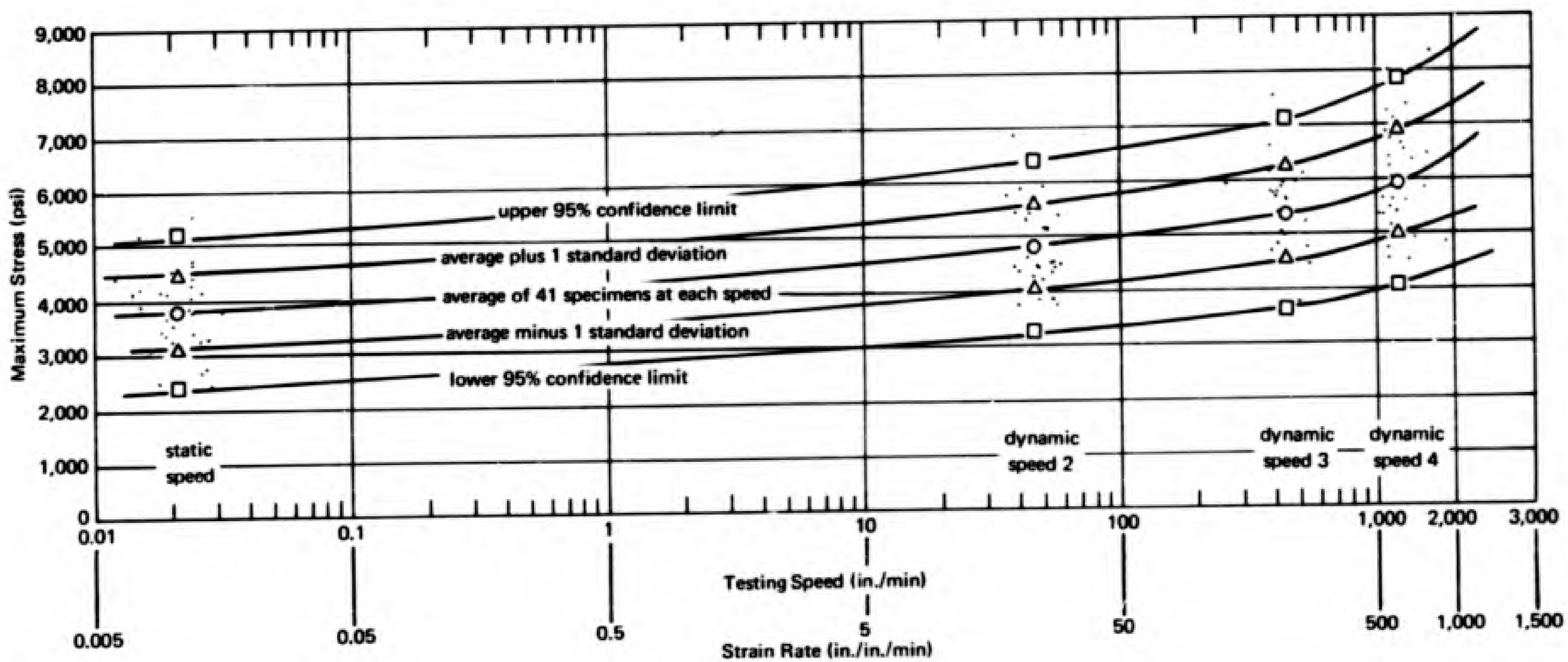


Figure 14. Relation between maximum stress and testing speed (green specimens, compression parallel to grain).

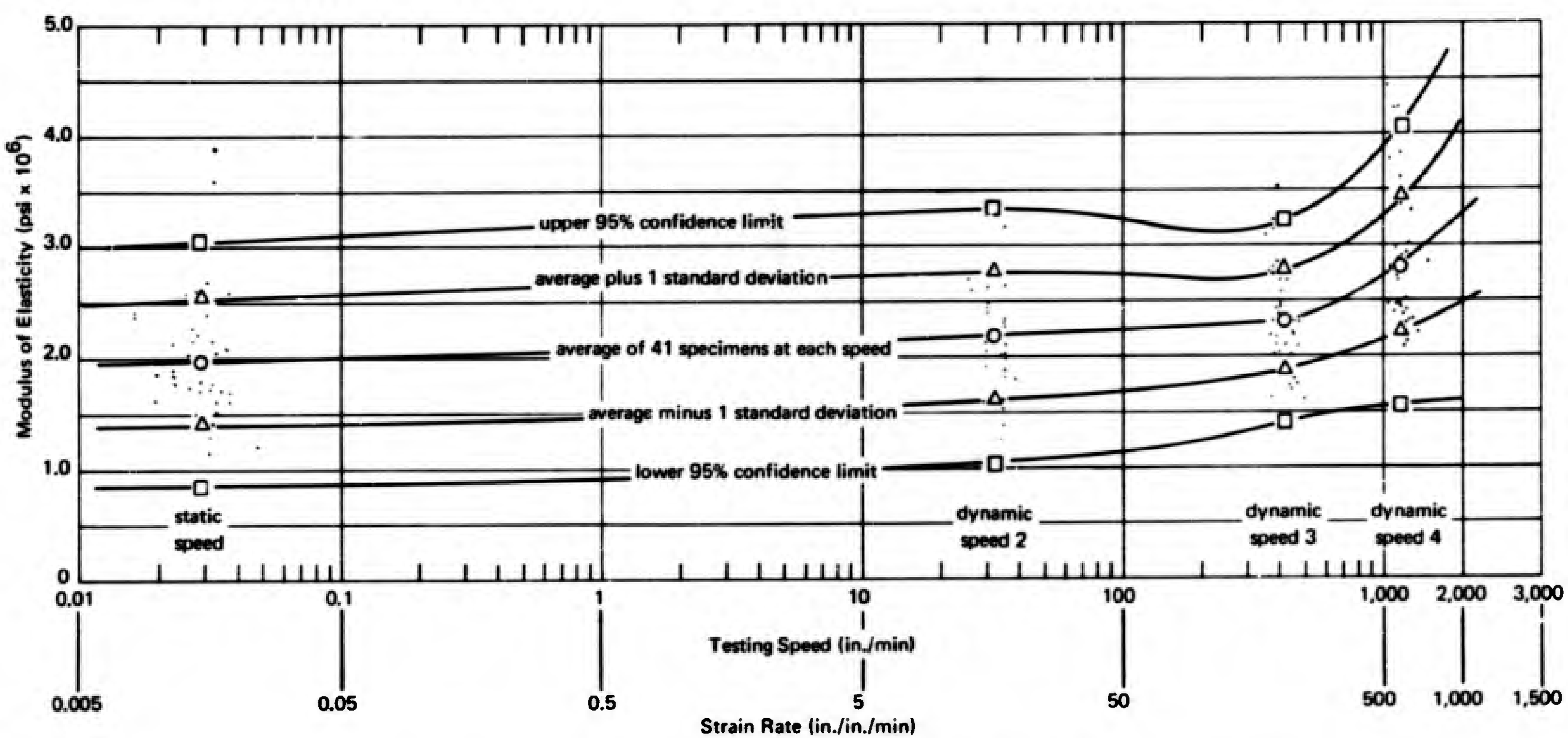


Figure 15. Relation between modulus of elasticity and testing speed (dry specimens, compression parallel to grain).

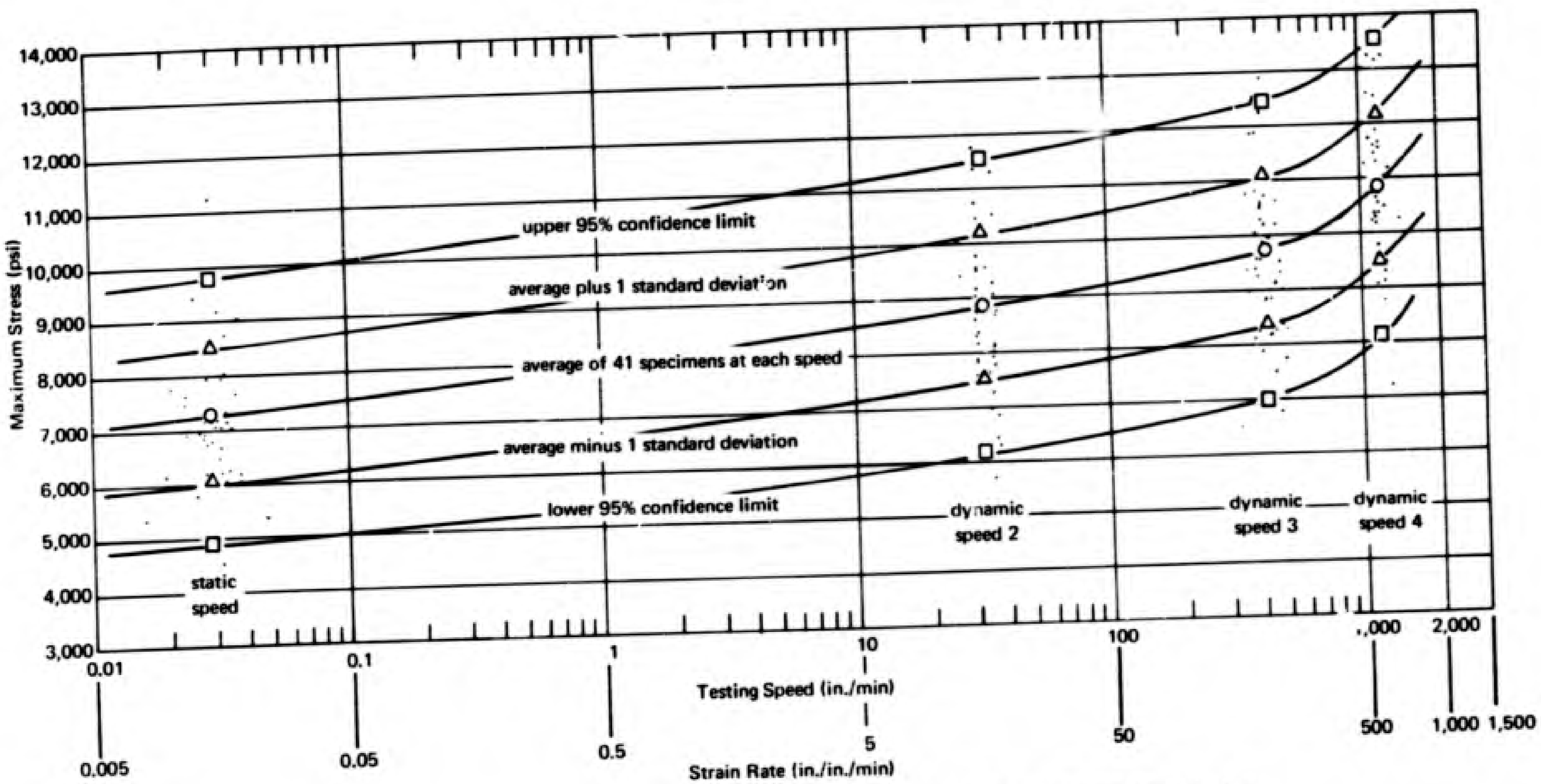


Figure 16. Relation between maximum stress and testing speed (dry specimens, compression parallel to grain).

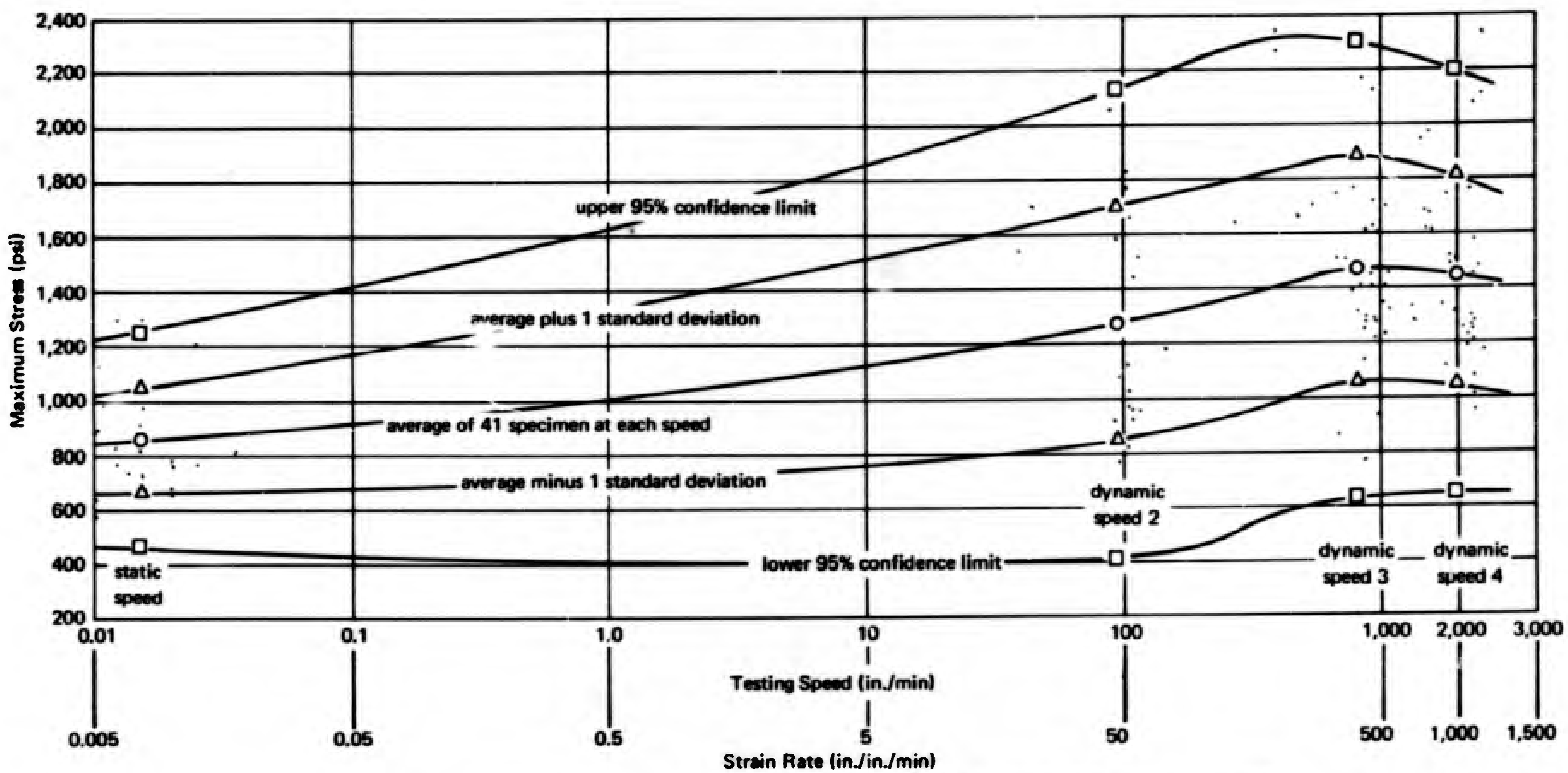


Figure 17. Relation between maximum stress and testing speed (green specimens, compression perpendicular to grain).

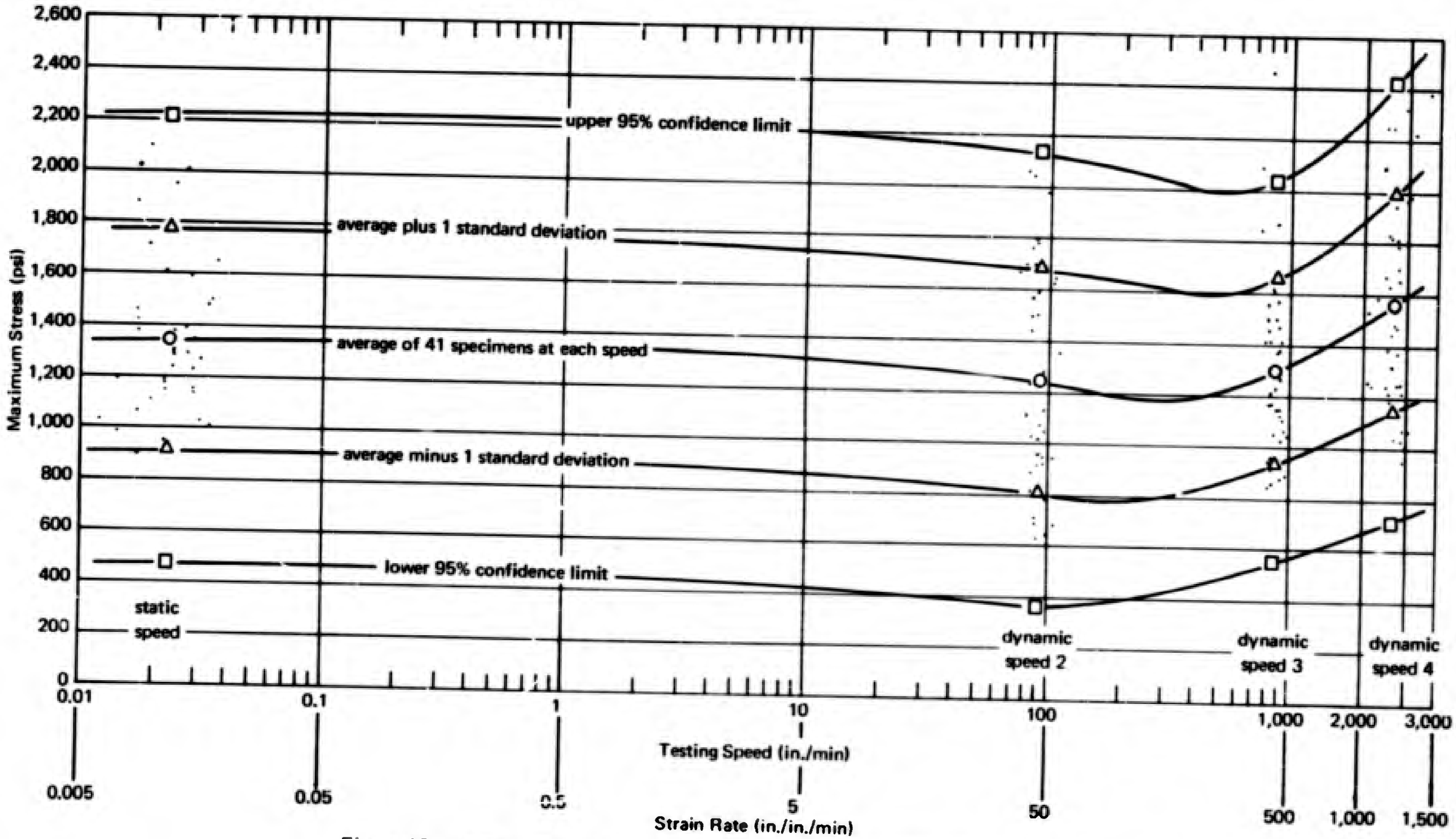


Figure 18. Relation between maximum stress and testing speed (dry specimens, compression perpendicular to grain).

## DISCUSSION

### Results of Tests on Green Specimens

Some of the most pertinent statistical observations are summarized in Table 9. In order to compare strengths at the same speed, the values were taken from Figures 6, 8, 9, 10, 13, 14, and 17 at the speeds shown in Table 9. The results in shear, compression parallel to grain, and compression perpendicular to grain show consistent increases in strength values with increases in testing speed.

The results in bending also indicate, generally, increases in strength over the static values with increases in testing speed. The exception is the modulus of elasticity in bending, which reveals a net decrease as the testing speed increases. It is significant that although the increase in proportional limit for the lower 95% confidence limit at 2,000 inches per minute is 118%, the corresponding increase in modulus of rupture is only about half as much. The modulus of rupture values are the more significant ones in timber design.

### Results of Tests on Dry Specimens

Comparisons of strength values for dry specimens at the same testing speeds, taken from Figures 7, 11, 12, 15, 16, and 18, are presented in Table 10. As was true for the green specimens, the results here indicate strength increases as the testing speed increases for tests in shear, compression parallel to grain, and compression perpendicular to grain. Again, the most significant results are in bending, where all strength values show a modest increase at the slower dynamic speeds, followed by a drastic decrease in strength at the faster testing speeds. The net strength values at the top speed are considerably lower than those at the static speed.

These results seem to parallel to some extent those reported by Liska,[6] who loaded clear, dry Douglas fir specimens (among others) in bending and in compression parallel to the grain. Liska's specimens were about half the size of those used in the study reported herein. His results in bending showed an increase in modulus of rupture of about 20% from static speed up to a top speed of 18 inches per minute with the results given as averages for the specimens tested. Corresponding results reported here (Figure 12) indicate an increase of about 12% for a testing speed of 18 inches per minute. The differences probably lie in the statistical aspects of the two research efforts and in differences of specimen sizes. In compression parallel to grain, Liska's results indicated an increase in maximum stress of about 21% from static speed up to a top speed of 2.8 inches per minute. Corresponding maximum stress values for this NCEL study (Figure 16) reveal an increase of about 13% at 2.8 inches per minute. The moisture content values for the two studies, 12% for Liska's and 11% for NCEL wood, are close enough to be comparable. Since Liska's testing speeds did not go beyond 18 inches per minute, no further comparisons can be made.

The reduction in shock resistance or toughness of dry wood in bending is mentioned in Reference 1 (page 85), although no reference is made to published data. In a bending test, the wood is oriented so that the fibers run along the length of the beam, the fibers acting as small tubes tightly bound together. It has been hypothesized that wood failure in a static bending test is most likely caused by compressive crushing of the upper fibers, with tension cracks evident in the lower fibers at the conclusion of the test.[7] The fibers of the beam near the neutral axis lend stiffening support to the fibers above them, contributing to the overall rigidity of the beam. The fibers not at the moment stressed to their proportional limit may act as columns in compression parallel to the grain in resisting the transverse loads coming from above. Buckling is impeded by the fact that the fibers are bound together.

As the rate of loading is increased, the time lag for individual fibers to reach proportional limit values throughout the beam is decreased until at some high speed there is little, if any, time lag. At this moment, all fibers tend to buckle at once. By this line of reasoning, a dry wooden beam will carry more load in flexure when all the fibers are not loaded to their proportional limits simultaneously; that is, it will be stronger when loaded slowly than when loaded rapidly.

Another possible explanation is that the fibers near the top, where the load is applied, tend to act independently when the load is applied extremely rapidly. In other words, there is simply insufficient time for the top surface fibers to gain support from those below, and they fail one by one down through the beam.

## Comparisons of Results for Green and Dry Wood

**Shear Parallel to the Grain.** To enable direct comparisons of results of shear tests of green and of dry specimens, the most pertinent statistical values were taken directly from Figures 6 and 7 at selected testing speeds. The comparisons are presented in Table 11. As expected, the drier specimens revealed consistently higher shear strengths throughout the testing range.

**Bending.** The most dramatic comparisons of the performance of green and of dry specimens under dynamic loading are revealed in the bending tests. These comparisons are presented in Table 11, the various values being taken from Figures 9, 10, 11, and 12. The relationships for the modulus of rupture at the lower 95% confidence limits are presented in Figure 19. At testing speeds up to about 60 inches per minute, dry wood has higher strength values than green wood. At speeds over 60 inches per minute, the relationship between strength of green and dry wood changes drastically. At speeds above 400 inches per minute, the green wood strength values exceed those for the dry wood. Comparisons of moduli of elasticity show the same trends. Possible reasons for these startling reductions in modulus of rupture of dry specimens in bending tests (Figure 19) were presented in "Results of Tests on Dry Specimens."

**Compression Parallel to the Grain.** Table 11 contains results of tests of green and of dry wood in compression parallel to the grain. The moduli of elasticity do not seem to be significantly different throughout the test range. The maximum stresses, on the other hand, show that the dry wood strength values are more than double the green wood strength values. The dry wood fibers, being much stiffer than their green counterparts, sustain considerably higher loads as small columns when they are loaded in compression parallel to the grain.

**Compression Perpendicular to the Grain.** As shown in Table 11, the differences between results for green wood and dry wood in compression perpendicular to the grain appear small, except for the results of the static loading tests. As testing speed increased, even these slight differences seemed to disappear. In drying, the greatest stiffening and strengthening effects upon wood fibers occur along the grain. In a compression test perpendicular to the grain, only a portion of this stiffness is realized. As the testing speed increases, there is not sufficient time for even this small increase in strength due to drying to be brought into play.

Further comparisons of results of tests on green and dry wood are presented in Table 12, which lists beam deflections at modulus of rupture. As might have been expected, the dry beams did not deflect as much at maximum load as did the green beams. On a statistical basis, the differences in deflections in the static tests were not great, but as the testing speed increased, these differences became greater and greater. In the green beams the deflection increased with increase in testing speed, whereas the deflections of the dry beams decreased with increase in testing speed. The results presented in Table 12 emphasize the inherent variability of the engineering properties of wood.

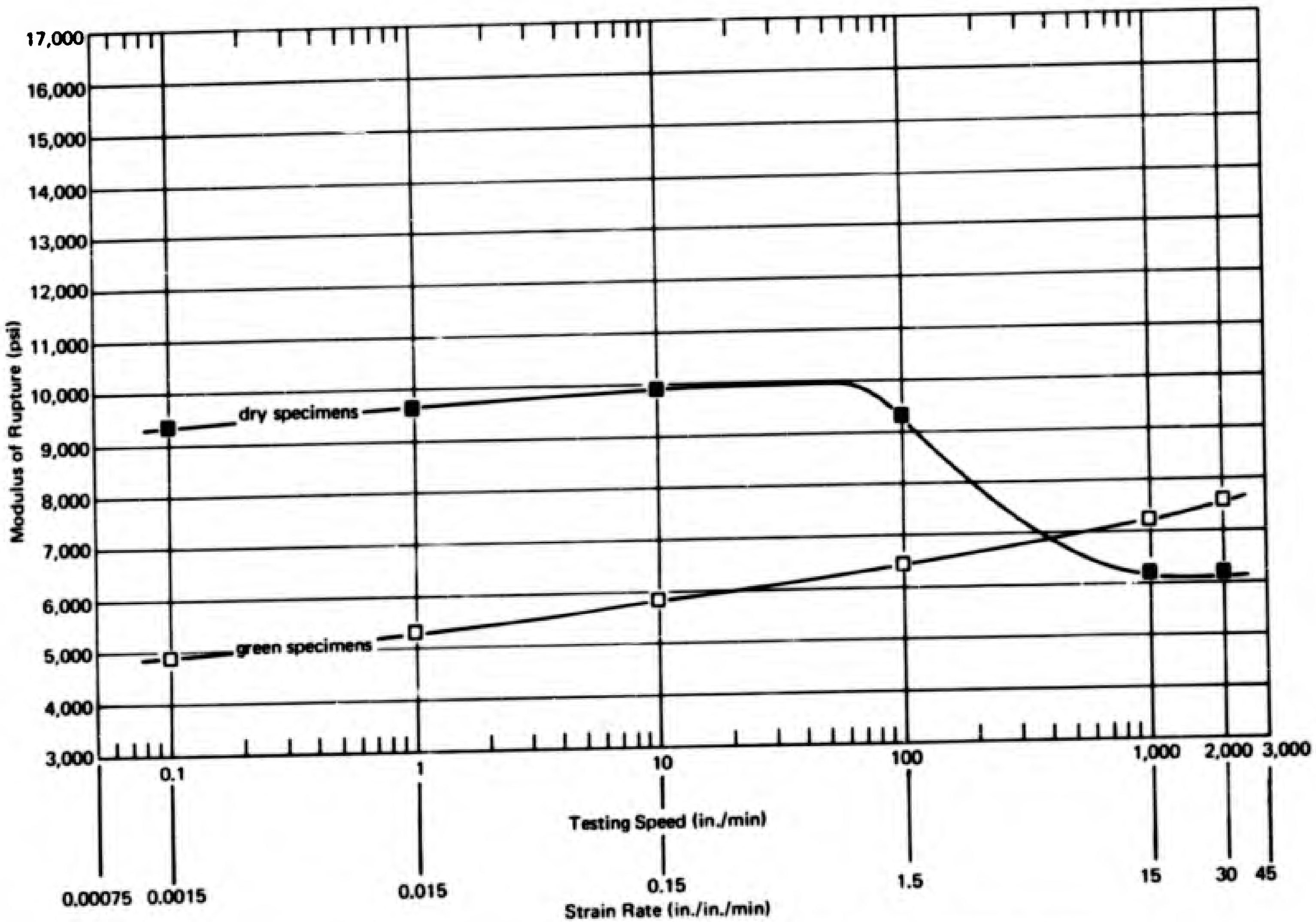


Figure 19. Comparisons of green and dry bending tests (lower 95% confidence limits).

## APPLICATION OF TEST RESULTS TO TIMBER DESIGN

The evaluation of strength properties of a given species of wood begins with static tests on small, clear specimens in accordance with ASTM D-143[4] or similar standardized test method. The results of these tests, treated statistically, are called clear wood strengths. To these clear wood strengths a factor of safety of about 2-1/2 is applied. The resulting values are called basic stresses (generalized working stresses) for the green wood of the species, free of knots or other defects. A qualified and licensed inspector, operating under grading rules established by the association he represents, designates a strength ratio for each piece.[8] In doing so, he considers location and sizes of knots, checks, splits, slope of grain, and any other strength-reducing factors. A strength ratio of 75%, for example, means that in the opinion of the grader, an allowable unit stress equal to 75% of the basic stress value is safe to use.

For most species of wood used for structural purposes, tables of allowable unit stresses have been developed.[9,10] These tables are based upon green wood strengths and are applicable to members which will be utilized in locations which are continually dry and which will be subjected to normal load duration (load life of 10 years). The tables are subdivided, by strengths and by type of member (beam, stringer, joist, etc.), into grades of timber. Allowances for dry wood, for use in locations which are continually wet, for load durations other than normal, and for other variables and limitations are contained in footnotes or in accompanying notes and appendixes.

A designer of timber structures, having determined the working stresses for the members of his structure, selects the grade of timber he needs for each member from the tables of allowable unit stresses mentioned above. The usefulness of dynamic testing data such as obtained in this study lies in the determination of the allowances for impact, earthquake, and blast loads. Certain design factors are allowed for duration of load other than normal loading.[3,9,10] For impact loads, defined as those loads acting on a structure for about 1 second, the allowable increase in design working stress is 100%. For earthquake loading, the allowable increase is 33%, with earthquake load defined as a load which acts upon the member for about 1 day. The current design specifications contain no allowable design stresses for blast loading of timber structures.

For solid sawn beams of structural size (at least 5 inches thick and 8 inches deep), the design values are based on green wood strengths, because it is believed that a timber beam never completely dries in place in a structure. Moreover, any increased strength otherwise attributable to drying is offset by formation of defects such as checks. In this study, the time to maximum load which most closely approximates the definition of impact loading duration of

1 second would be at about dynamic speed 2. The values for modulus of rupture in bending of green specimens (Table 3) indicate the increase over the static strength at dynamic speed 2 was about 13% for the average, 28% for minus 1 standard deviation, and 29% for the lower 95% confidence limit. Thus, it is seen that results in this study are considerably below the 100% allowance noted above for impact. The curve[9] from which the design allowances for duration of load are obtained indicates that for durations extrapolated to less than 1 second, allowances considerably higher than 100% might be permissible. The highest testing speed in this study approximates a load duration of about 0.026 second in bending. Even at these short durations, it is seen from Table 9 that the modulus of rupture at the top dynamic speed exceeds the static value by no more than 54%.

For a long-duration load of a blast type, the flexural elements in ordinary structures undergo strain rates in the range of 0.1 to 1.0 inch per inch per second. These strain rates correspond to testing speeds between 392 and 3,920 inches per minute as reported herein. Test results in this study do not provide designers with much confidence in the conventional increased allowances for working stresses of wood subjected to shock or impact loading, whether it be in bending, shear, or compression. Earthquake velocities may vary between even wider limits than do blast velocities, and the same lack of confidence therefore exists with regard to increased working stress allowances for structures which may be subjected to earthquake velocities of short duration. It should be emphasized, however, that current timber design specifications define earthquake loads as those which have a duration of about 1 day. Such a definition certainly removes earthquake considerations from a dynamic testing study such as this. Perhaps the definition of duration of load for earthquakes needs further examination. Dynamic analysis and determination of dynamic stresses which may act on a given structure will of course depend on the judgment of the individual designer.

Perhaps the most serious implications arising from this study lie in the results observed in the bending tests of dry specimens. While it may be true that a large solid sawn beam in place in a structure never completely dries, it will certainly dry to some extent inward from all exposed surfaces. If, in its semidry state, it is then subjected to an impact or shock load, the results could be disastrous because drying reduces dynamic bending strength. (See Figure 12 and Table 10.)

An unknown factor regarding the performance of wood under shock and impact loading is the amount of support provided to structural timber elements by fastenings such as nails, bolts, screws, and proprietary fasteners during such loading. A study of the behavior of these fasteners under dynamic loading would perhaps reveal the extent to which fastenings can be depended upon to absorb and transmit shock loadings.

The results of bending tests on dry specimens introduce another important consideration. In the production of glued-laminated beams, the individual laminations consist of predried wood planks or boards. These boards are glued together under high temperature and pressure and the resulting beams are subsequently utilized in structures in many ways. The performance of these dry members in bending when subjected to shock or impact loading may well depend solely upon the strength of the glue bond. These glue-bonded members should also be subjected to dynamic loading in the laboratory to clarify this highly important aspect of timber construction.

## FINDINGS

1. Compared with values found for static loading rates, small clear specimens of green Douglas fir, when loaded at testing speeds up to about 2,000 inches per minute (equivalent to a strain rate of about 0.5 inch per inch per minute), showed net increases in all strength values with the exception of modulus of elasticity in bending. The modulus of elasticity decreased above a speed of about 600 inches per minute (strain rate of about 0.15 inch per inch per minute).

2. Under similar conditions, small, clear specimens of dry timber showed increases in all strength values except in bending. Dramatic decreases in strength were observed in the latter.

3. The increases in dynamic strength of green specimens fell considerably below the currently allowable strengths for impact loaded timber. Dynamic strength increases at testing speeds corresponding to shock and impact loading were insignificant when compared to static values.

## CONCLUSIONS

1. Designers of timber structures should reappraise the recommended over-allowances for working stresses when structures may be subjected to impact or shock loadings; these allowances should be reduced or eliminated.

2. As a timber beam dries in place in a structure, its dynamic strength properties approach those of dry timber and it may eventually exhibit less strength under shock loading than when first installed in the structure.

## RECOMMENDATIONS

1. Because the safety of timber structures subjected to shock loading may depend more on the in-situ performance of timber fasteners (nails, screws, bolts, and proprietary devices) than on the strength of the timber itself, timber joints secured with fasteners should be tested under dynamic loading. These tests could be conducted in the NCEL dynamic testing machine.

2. The dynamic behavior of glued-laminated timbers in particular should be determined because these timbers are composed of dry wood. The dynamic efficiency of the glue line may determine the safety of this type of construction when it is subjected to shock loading. These tests could be performed in the NCEL dynamic testing machine with small 2 x 4 glued-laminated beams.

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Table 1. Results of Shear-Parallel-to-Grain Tests, Green Timber

| Timber No. | Maximum Stress (psi) | | | | | Testing Speed (in./mi | | |
|---|---|---|---|---|---|---|---|---|
| | Static Speed | Dynamic Speed 1 | Dynamic Speed 2 | Dynamic Speed 3 | Dynamic Speed 4 | Static Speed | Dynamic Speed 1 | Dynamic Speed 2 |
| 1 | 880 | 1,080 | 1,160 | 1,290 | 1,650 | 0.011 | 5.1 | 58 |
| 2 | 810 | 980 | 1,170 | 1,240 | 1,430 | 0.023 | 9.3 | 55 |
| 3 | 960 | 1,130 | 1,180 | 1,330 | 1,520 | 0.014 | 5.2 | 55 |
| 4 | 740 | 1,110 | 1,250 | 1,330 | 1,840 | 0.019 | 6.7 | 60 |
| 5 | 720 | 880 | 890 | 1,040 | 1,360 | 0.008 | 8.8 | 58 |
| 6 | 810 | 1,010 | 1,130 | 1,220 | 1,340 | 0.014 | 8.5 | 62 |
| 7 | 980 | 1,140 | 1,250 | 1,420 | 1,560 | 0.014 | 4.4 | 61 |
| 8 | 875 | 960 | 1,030 | 1,130 | 1,330 | 0.016 | 6.1 | 55 |
| 9 | 810 | 980 | 1,020 | 1,150 | 1,440 | 0.009 | 5.4 | 55 |
| 10 | 980 | 1,200 | 1,220 | 1,360 | 1,900 | 0.010 | 5.9 | 52 |
| 11 | 1,050 | 1,100 | 1,180 | 1,330 | 1,470 | 0.026 | 4.4 | 51 |
| 12 | 790 | 900 | 1,030 | 1,080 | 1,140 | 0.041 | 4.2 | 57 |
| 13 | 840 | 990 | 1,140 | 1,230 | 1,300 | 0.014 | 4.6 | 61 |
| 14 | 790 | 1,020 | 1,150 | 1,130 | 1,260 | 0.024 | 6.1 | 60 |
| 15 | 1,070 | 1,140 | 1,210 | 1,430 | 1,330 | 0.022 | 4.8 | 59 |
| 16 | 910 | 1,000 | 1,010 | 1,260 | 1,370 | 0.009 | 8.3 | 55 |
| 18 | 890 | 1,050 | 1,130 | 1,330 | 1,500 | 0.033 | 5.7 | 59 |
| 19 | 780 | 940 | 1,140 | 1,180 | 1,130 | 0.028 | 4.8 | 63 |
| 20 | 790 | 1,110 | 1,120 | 1,170 | 1,710 | 0.016 | 5.0 | 57 |
| 21 | 910 | 1,150 | 960 | 1,370 | 1,460 | 0.025 | 6.1 | 61 |
| 22 | 980 | 1,000 | 1,090 | 1,280 | 1,430 | 0.029 | 6.1 | 62 |
| 23 | 800 | 1,040 | 1,130 | 1,190 | 1,400 | 0.008 | 18.1 | 60 |
| 24 | 850 | 970 | 1,060 | 1,180 | 1,380 | 0.022 | 5.5 | 60 |
| 25 | 940 | 1,130 | 1,240 | 1,320 | 1,560 | 0.017 | 8.8 | 124 |
| 26 | 850 | 1,000 | 1,100 | 1,140 | 1,440 | 0.020 | 8.7 | 57 |
| 27 | 830 | 950 | 970 | 1,160 | 1,280 | 0.023 | 8.4 | 65 |
| 28 | 770 | 1,010 | 1,060 | 1,170 | 1,670 | 0.014 | 5.4 | 54 |
| 29 | 990 | 1,240 | 1,210 | 1,340 | 1,530 | 0.029 | 8.2 | 54 |
| 30 | 970 | 1,020 | 1,090 | 1,200 | 1,560 | 0.009 | 8.6 | 60 |
| 31 | 1,000 | 1,180 | 1,380 | 1,460 | 1,980 | 0.006 | 15.9 | 62 |
| 32 | 980 | 1,030 | 1,060 | 1,260 | 1,350 | 0.020 | 6.1 | 56 |
| 33 | 750 | 960 | 1,090 | 1,260 | 1,420 | 0.006 | 8.6 | 54 |
| 34 | 1,030 | 1,230 | 1,110 | 1,330 | 1,690 | 0.012 | 9.0 | 58 |
| 35 | 1,080 | 1,190 | 1,220 | 1,430 | 1,600 | 0.018 | 5.5 | 61 |
| 36 | 790 | 990 | 1,020 | 1,140 | 1,430 | 0.017 | 6.1 | 55 |
| 37 | 890 | 1,090 | 1,130 | 1,360 | 1,270 | 0.024 | 5.7 | 61 |
| 38 | 1,050 | 920 | 1,100 | 1,430 | 1,340 | 0.023 | 5.9 | 63 |
| 39 | 760 | 860 | 990 | 1,120 | 1,200 | 0.017 | 5.3 | 58 |
| 40 | 950 | 1,140 | 1,220 | 1,440 | 1,740 | 0.014 | 4.5 | 49 |
| 41 | 930 | 1,130 | 1,120 | 1,290 | 1,570 | 0.006 | 17.3 | 62 |
| 42 | 1,050 | 1,230 | 1,410 | 1,560 | 2,120 | 0.022 | 5.4 | 54 |
| Average | 893 | 1,053 | 1,126 | 1,270 | 1,488 | 0.018 | 7.1 | 60 |
| Standard deviation | 104 | 100 | 105 | 119 | 217 | | | |
| 95% confidence interval | 210 | 202 | 212 | 241 | 439 | | | |
| Upper 95% confidence limit | 1,103 | 1,255 | 1,338 | 1,511 | 1,927 | | | |
| Lower 95% confidence limit | 683 | 851 | 914 | 1,029 | 1,049 | | | |
| Plus 1 standard deviation | 997 | 1,153 | 1,231 | 1,389 | 1,705 | | | |
| Minus 1 standard deviation | 789 | 953 | 1,021 | 1,151 | 1,271 | | | |

Note: 95% confidence interval = standard deviation x 2.021.

Table 1. Results of Shear Parallel-to-Grain Tests, Green Timber

| Maximum Stress (psi) | | | | | Testing Speed (in./min) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Static Speed | Dynamic Speed 1 | Dynamic Speed 2 | Dynamic Speed 3 | Dynamic Speed 4 | Static Speed | Dynamic Speed 1 | Dynamic Speed 2 | Dynamic Speed 3 | Dynamic Speed 4 |
| 880 | 1,080 | 1,160 | 1,290 | 1,650 | 0.011 | 5.1 | 58 | 569 | 1,410 |
| 810 | 980 | 1,170 | 1,240 | 1,430 | 0.023 | 9.3 | 55 | 435 | 1,813 |
| 960 | 1,130 | 1,180 | 1,330 | 1,520 | 0.014 | 5.2 | 55 | 584 | 1,600 |
| 740 | 1,110 | 1,250 | 1,330 | 1,840 | 0.019 | 6.7 | 60 | 591 | 2,136 |
| 720 | 880 | 890 | 1,040 | 1,360 | 0.008 | 8.8 | 58 | 584 | 2,017 |
| 810 | 1,010 | 1,130 | 1,220 | 1,340 | 0.014 | 8.5 | 62 | 476 | 1,807 |
| 980 | 1,140 | 1,250 | 1,420 | 1,560 | 0.014 | 4.4 | 61 | 599 | 2,125 |
| 875 | 960 | 1,030 | 1,130 | 1,330 | 0.016 | 6.1 | 55 | 493 | 1,450 |
| 810 | 980 | 1,020 | 1,150 | 1,440 | 0.009 | 5.4 | 55 | 436 | 1,430 |
| 980 | 1,200 | 1,220 | 1,360 | 1,900 | 0.010 | 5.9 | 52 | 421 | 1,290 |
| 1,050 | 1,100 | 1,180 | 1,330 | 1,470 | 0.026 | [illegible] | 51 | 337 | 1,570 |
| 790 | 900 | 1,030 | 1,080 | 1,140 | 0.041 | 4.2 | 57 | 535 | 1,211 |
| 840 | 990 | 1,140 | 1,230 | 1,300 | 0.014 | 4.6 | 61 | 599 | 1,855 |
| 790 | 1,020 | 1,150 | 1,130 | 1,260 | 0.024 | 6.1 | 60 | 562 | 1,240 |
| 1,070 | 1,140 | 1,210 | 1,430 | 1,330 | 0.022 | 4.8 | 59 | 588 | 1,202 |
| 910 | 1,000 | 1,010 | 1,260 | 1,370 | 0.009 | 8.3 | 55 | 670 | 2,159 |
| 890 | 1,050 | 1,130 | 1,330 | 1,500 | 0.033 | 5.7 | 59 | 588 | 1,117 |
| 780 | 940 | [illegible] | 1,180 | 1,130 | 0.028 | 4.8 | 63 | 580 | 1,082 |
| 790 | 1,110 | 1,120 | 1,170 | 1,710 | 0.016 | 5.0 | 57 | 410 | 1,810 |
| 910 | 1,150 | 960 | 1,370 | 1,460 | 0.025 | 6.1 | 61 | 550 | 1,760 |
| 980 | 1,000 | 1,090 | 1,280 | 1,430 | 0.029 | 6.1 | 62 | 505 | 2,140 |
| 800 | 1,040 | 1,130 | 1,190 | 1,400 | 0.008 | 18.1 | 60 | 636 | 2,070 |
| 850 | 970 | 1,060 | 1,180 | 1,380 | 0.022 | 5.5 | 60 | 580 | 2,120 |
| 940 | 1,130 | 1,240 | 1,320 | 1,560 | 0.017 | 8.8 | 124 | 629 | 2,262 |
| 850 | 1,000 | 1,100 | 1,140 | 1,440 | 0.020 | 8.7 | 57 | 407 | 2,288 |
| 830 | 950 | 970 | 1,160 | 1,280 | 0.023 | 8.4 | 65 | 570 | 1,760 |
| 770 | 1,010 | 1,060 | 1,170 | 1,670 | 0.014 | 5.4 | 54 | 478 | 1,940 |
| 990 | 1,240 | 1,210 | 1,340 | 1,530 | 0.029 | 8.2 | 54 | 466 | 2,136 |
| 970 | 1,020 | 1,090 | 1,200 | 1,560 | 0.009 | 8.6 | 60 | 439 | 1,803 |
| 1,000 | 1,180 | 1,380 | 1,460 | 1,980 | 0.006 | 15.9 | 62 | 636 | 1,780 |
| 980 | 1,030 | 1,060 | 1,260 | 1,350 | 0.020 | 6.1 | 56 | 580 | 1,870 |
| 750 | 960 | 1,090 | 1,260 | 1,420 | 0.006 | 8.6 | 54 | 719 | 2,037 |
| 1,030 | 1,230 | 1,110 | 1,330 | 1,690 | 0.012 | 9.0 | 58 | 350 | 2,211 |
| 1,080 | 1,190 | 1,220 | 1,430 | 1,600 | 0.018 | 5.5 | 61 | 562 | 2,276 |
| 790 | 990 | 1,020 | 1,140 | 1,430 | 0.017 | 6.1 | 55 | 576 | 2,415 |
| 890 | 1,090 | 1,130 | 1,360 | 1,270 | 0.024 | 5.7 | 61 | 566 | 1,750 |
| 1,050 | 920 | 1,100 | 1,430 | 1,340 | 0.023 | 5.9 | 63 | 504 | 2,275 |
| 760 | 860 | 990 | 1,120 | 1,200 | 0.017 | 5.3 | 58 | 571 | 1,215 |
| 950 | 1,140 | 1,220 | 1,440 | 1,740 | 0.014 | 4.5 | 49 | 582 | 1,810 |
| 930 | 1,130 | 1,120 | 1,290 | 1,570 | 0.006 | 17.3 | 62 | 642 | 2,041 |
| 1,050 | 1,230 | 1,410 | 1,560 | 2,120 | 0.022 | 5.4 | 54 | 577 | 2,131 |
| 893 | 1,053 | 1,126 | 1,270 | 1,488 | 0.018 | 7.1 | 60 | 541 | 1,815 |
| 104 | 100 | 105 | 119 | 217 | | | | | |
| 210 | 202 | 212 | 241 | 439 | | | | | |
| 1,103 | 1,255 | 1,338 | 1,511 | 1,927 | | | | | |
| 683 | 851 | 914 | 1,029 | [illegible] | | | | | |
| 997 | 1,153 | 1,231 | 1,389 | 1,705 | | | | | |
| 789 | 953 | 1,021 | 1,151 | 1,271 | | | | | |

standard deviation x 2.021.



B

Table 2. Results of Shear-Parallel-to-Grain Tests, Dry Timber

| Timber No. | Maximum Stress (psi) | | | | Testing Speed (in./min) | | | |
|---|---|---|---|---|---|---|---|---|
| | Static Speed | Dynamic Speed 2 | Dynamic Speed 3 | Dynamic Speed 4 | Static Speed | Dynamic Speed 2 | Dynamic Speed 3 | Dynamic Speed 4 |
| 1 | 1,200 | 1,270 | 1,740 | 1,870 | 0.014 | 57 | 480 | 2,060 |
| 2 | 1,280 | 1,600 | 1,810 | 2,000 | 0.016 | 45 | 660 | 2,090 |
| 3 | 1,330 | 1,530 | 1,750 | 1,910 | 0.018 | 49 | 720 | 1,760 |
| 4 | 1,410 | 1,650 | 1,770 | 1,770 | 0.021 | 59 | 510 | 1,820 |
| 5 | 1,130 | 1,420 | 1,530 | 2,060 | 0.013 | 39 | 730 | 1,240 |
| 6 | 1,400 | 1,590 | 1,620 | 1,860 | 0.028 | 48 | 610 | 2,180 |
| 7 | 1,520 | 1,750 | 1,710 | 1,990 | 0.030 | 62 | 500 | 1,590 |
| 8 | 1,200 | 1,700 | 1,600 | 1,730 | 0.034 | [illegible] | 580 | 1,870 |
| 9 | 1,660 | 1,720 | 1,670 | 1,680 | 0.027 | 56 | 520 | 1,820 |
| 10 | 1,600 | 1,850 | 1,800 | 2,460 | 0.023 | 62 | 520 | 1,880 |
| 11 | 1,550 | 1,600 | 1,800 | 2,750 | 0.023 | 57 | 500 | 1,740 |
| 12 | 1,210 | 1,400 | 1,510 | 1,970 | 0.021 | 62 | 520 | 1,720 |
| 13 | 1,140 | 1,420 | 1,480 | 2,000 | 0.023 | 59 | 540 | 1,920 |
| 14 | 1,360 | 1,480 | 1,650 | 1,960 | 0.023 | 61 | 500 | 1,720 |
| 15 | 1,380 | 1,670 | 1,780 | 2,330 | 0.032 | 58 | 560 | 1,840 |
| 16 | 1,460 | 1,540 | 1,910 | 2,390 | 0.027 | 60 | 500 | 1,940 |
| 18 | 1,230 | 1,780 | 1,520 | 2,240 | 0.035 | 59 | 540 | 1,810 |
| 19 | 1,210 | 1,560 | 1,630 | 1,900 | 0.030 | 59 | 510 | 1,620 |
| 20 | 1,280 | 1,650 | 1,770 | 1,970 | 0.025 | 50 | 590 | 1,980 |
| 21 | 960 | 1,720 | 1,940 | 2,170 | 0.023 | 60 | 500 | 1,730 |
| 22 | — | — | — | — | — | — | — | — |
| 23 | 1,170 | 1,450 | 1,810 | 2,120 | 0.028 | 60 | 710 | 1,790 |
| 24 | 1,380 | 1,660 | 1,980 | 2,290 | 0.025 | 61 | 480 | 1,370 |
| 25 | 1,380 | 1,690 | 1,810 | 2,380 | 0.039 | 60 | 530 | 1,900 |
| 26 | 1,340 | 1,690 | 1,800 | 2,170 | 0.023 | 59 | 480 | 1,760 |
| 27 | 1,320 | 1,610 | 1,680 | 2,580 | 0.026 | 63 | 490 | 1,750 |
| 28 | 1,320 | 1,510 | 1,540 | 2,320 | 0.021 | 53 | 590 | 1,740 |
| 29 | 1,790 | 2,020 | 2,170 | 2,770 | 0.023 | 62 | 490 | 1,720 |
| 30 | 1,460 | 2,030 | 2,050 | 2,090 | 0.014 | 63 | 480 | 1,830 |
| 31 | 1,260 | 1,730 | 2,170 | 3,070 | 0.025 | 62 | 500 | 1,790 |
| 32 | 1,540 | 1,900 | 1,800 | 2,620 | 0.025 | 60 | 500 | 1,760 |
| 33 | 1,490 | 1,830 | 1,890 | 2,920 | 0.021 | 62 | 490 | 1,780 |
| 34 | 1,510 | 1,850 | 1,950 | 2,720 | 0.025 | 57 | 510 | 1,760 |
| 35 | 1,920 | 2,600 | 2,280 | 3,460 | 0.021 | 58 | 490 | 1,690 |
| 36 | 1,220 | 1,650 | 1,550 | 2,090 | 0.021 | 60 | 510 | 1,650 |
| 37 | 1,490 | 1,820 | 1,650 | 2,110 | 0.032 | 60 | 510 | 1,690 |
| 38 | 1,510 | 2,180 | 2,090 | 2,300 | 0.020 | 60 | 500 | 1,750 |
| 39 | 1,240 | 1,300 | 1,410 | 1,780 | 0.012 | 60 | 500 | 1,800 |
| 40 | 1,420 | 1,500 | 1,630 | 2,200 | 0.039 | 60 | 555 | 1,890 |
| 41 | 1,440 | 1,610 | 2,020 | — | 0.017 | 63 | 500 | — |
| 42 | 1,490 | 1,940 | 1,690 | 2,730 | 0.021 | 61 | 510 | 1,780 |
| Average | 1,380 | 1,687 | 1,774 | 2,249 | 0.024 | 58 | 535 | 1,796 |
| Standard deviation | 184 | 245 | 204 | 399 | | | | |
| 95% confidence interval | 372 | 495 | 413 | 807 | | | | |
| Upper 95% confidence limit | 1,752 | 2,182 | 2,187 | 3,056 | | | | |
| Lower 95% confidence limit | 1,008 | 1,192 | 1,361 | 1,442 | | | | |
| Plus 1 standard deviation | 1,564 | 1,932 | 1,978 | 2,648 | | | | |
| Minus 1 standard deviation | 1,196 | 1,442 | 1,570 | 1,850 | | | | |

Note: 95% confidence interval = standard deviation x 2.021.

Table 3. Results of Bending Tests, Green Tim

| Timber No. | Stress at Proportional Limit (psi) | | | | Modulus of Elasticity, (psi x $10^6$) | | | |
|---|---|---|---|---|---|---|---|---|
| | Static Speed | Dynamic Speed 2 | Dynamic Speed 3 | Dynamic Speed 4 | Static Speed | Dynamic Speed 2 | Dynamic Speed 3 | Dynamic Speed 4 |
| 1 | 3,840 | 4,460 | 5,050 | 5,620 | 1.51 | 1.34 | 1.58 | 1.50 |
| 2 | 2,840 | 3,780 | 4,410 | 4,990 | 1.39 | 1.67 | 1.44 | 1.42 |
| 3 | 2,260 | 3,730 | 4,460 | 4,940 | 1.27 | 1.30 | 1.33 | 1.22 |
| 4 | 3,100 | 3,980 | 4,520 | 5,250 | 1.82 | 1.90 | 1.73 | 1.42 |
| 5 | 2,620 | 3,880 | 4,460 | 5,040 | 1.05 | 1.60 | 1.38 | 1.24 |
| 6 | 2,520 | 3,100 | 3,570 | 4,110 | 1.16 | 1.27 | 1.59 | 1.34 |
| 7 | 2,940 | 5,300 | 6,450 | 7,350 | 1.92 | 1.82 | 1.80 | 1.72 |
| 8 | 2,620 | 3,360 | 3,780 | 4,560 | 1.40 | 1.53 | 1.77 | 1.42 |
| 9 | 4,410 | 5,250 | 5,780 | 6,200 | 2.16 | 1.97 | 2.28 | 2.47 |
| 10 | 4,560 | 5,990 | 6,550 | 7,350 | 2.61 | 2.75 | 2.72 | 2.55 |
| 11 | 5,150 | 6,450 | 7,600 | 8,300 | 2.21 | 2.58 | 2.03 | 1.55 |
| 12 | 2,780 | 4,040 | 4,930 | 6,300 | 1.78 | 1.49 | 1.36 | 1.34 |
| 13 | 2,840 | 3,680 | 4,510 | 5,510 | 1.76 | 1.58 | 1.48 | — |
| 14 | 2,260 | 3,260 | 3,930 | 5,360 | 1.27 | 1.44 | 1.50 | 1.42 |
| 15 | 4,040 | 4,980 | 5,780 | 6,820 | 1.71 | 1.80 | 1.86 | 1.25 |
| 16 | 3,700 | 4,410 | 5,040 | 6,250 | 2.00 | 1.64 | 1.85 | 1.81 |
| 18 | 4,150 | 4,620 | 5,400 | 6,400 | 1.93 | 1.86 | 1.60 | 1.49 |
| 19 | 3,520 | 4,670 | 5,460 | 6,460 | 1.61 | 1.64 | 1.73 | 1.62 |
| 20 | 3,460 | 5,300 | 6,510 | 7,030 | 2.26 | 2.29 | 2.38 | 2.28 |
| 21 | 3,520 | 4,460 | 5,200 | 6,250 | 1.84 | 1.94 | 1.86 | 1.92 |
| 22 | 3,150 | 3,730 | 4,250 | 4,880 | 1.56 | 1.54 | 1.65 | 1.40 |
| 23 | 2,780 | 3,360 | 3,940 | 4,410 | 0.99 | 1.10 | 1.29 | 1.02 |
| 24 | 2,520 | 3,100 | 3,680 | 4,460 | 1.14 | 1.00 | 0.92 | 1.03 |
| 25 | 3,460 | 4,730 | 5,510 | 6,360 | 1.38 | 2.28 | 1.65 | 2.47 |
| 26 | 3,310 | 4,250 | 5,100 | 6,050 | 2.23 | 1.61 | 1.72 | 1.78 |
| 27 | 3,050 | 3,730 | 4,050 | 4,780 | 1.89 | 1.78 | 2.06 | 1.70 |
| 28 | 4,100 | 4,720 | 5,460 | 6,720 | 1.99 | 1.96 | 1.76 | 1.62 |
| 29 | 3,940 | 5,000 | 5,830 | 6,890 | 1.98 | 2.30 | 2.31 | 1.92 |
| 30 | 2,730 | 4,050 | 4,880 | 6,000 | 1.40 | 1.81 | 2.84 | 1.64 |
| 31 | — | — | — | — | — | — | — | — |
| 32 | 2,200 | 4,100 | 5,050 | 5,780 | 1.92 | 1.78 | 1.77 | 1.72 |
| 33 | 3,100 | 4,150 | 4,940 | 6,300 | 1.80 | 1.93 | 1.93 | 1.43 |
| 34 | 2,360 | 4,250 | 5,360 | 6,520 | 1.84 | 1.70 | 2.10 | 1.88 |
| 35 | 3,310 | 4,360 | 5,610 | 8,250 | 2.04 | 2.17 | 1.88 | 1.52 |
| 36 | 2,000 | 3,260 | 4,040 | 4,990 | 1.52 | 1.49 | 1.47 | 1.33 |
| 37 | 2,840 | 4,100 | 4,940 | 6,200 | 1.80 | 1.87 | 2.29 | 1.47 |
| 38 | 4,620 | 5,680 | 6,350 | 7,000 | 1.91 | 2.07 | 2.32 | 2.51 |
| 39 | 4,040 | 4,560 | 5,250 | 5,990 | 1.62 | 0.81 | 1.32 | 1.29 |
| 40 | 3,420 | 4,730 | 5,570 | 6,720 | 1.84 | 1.42 | 1.52 | 1.31 |
| 41 | 3,940 | 4,830 | 5,720 | 7,150 | 2.38 | 1.93 | 2.10 | 1.58 |
| 42 | 3,360 | 4,410 | 5,250 | 7,090 | 1.44 | 1.52 | 1.49 | 0.84 |
| Average | 3,276 | 4,345 | 5,105 | 6,066 | 1.73 | 1.74 | 1.79 | 1.56 |
| Standard deviation (interval) | 737 | 773 | 885 | 1,023 | 0.37 | 0.40 | 0.40 | 0.48 |
| 95% confidence interval | 1,490 | 1,563 | 1,789 | 2,070 | 0.75 | 0.81 | 0.81 | 0.97 |
| Upper 95% confidence limit | 4,766 | 5,908 | 6,894 | 8,136 | 2.48 | 2.55 | 2.60 | 2.53 |
| Lower 95% confidence limit | 1,786 | 2,782 | 3,316 | 3,996 | 0.98 | 0.93 | 0.98 | 0.59 |
| Plus 1 standard deviation | 4,013 | 5,118 | 5,990 | 7,089 | 2.10 | 2.14 | 2.19 | 2.04 |
| Minus 1 standard deviation | 2,539 | 3,572 | 4,220 | 5,043 | 1.36 | 1.34 | 1.39 | 1.08 |

Note: 95% confidence interval = standard deviation x 2.021.

A

e 3. **Results of Bending Tests, Green Timber**

| lus of Elasticity, (psi x $10^6$) | | | Modulus of Rupture (psi) | | | | Testing Speed (in./min) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| namic eed 2 | Dynamic Speed 3 | Dynamic Speed 4 | Static Speed | Dynamic Speed 2 | Dynamic Speed 3 | Dynamic Speed 4 | Static Speed | Dynamic Speed 2 | Dynamic Speed 3 | Dynamic Speed 4 |
| .34 | 1.58 | 1.50 | 7,090 | 8,370 | 9,870 | 9,750 | 0.097 | 65 | 695 | 2,380 |
| .67 | 1.44 | 1.42 | 6,830 | 9,020 | 9,400 | 9,450 | 0.118 | 74 | 870 | 2,470 |
| .30 | 1.33 | 1.22 | 5,570 | 7,400 | 7,980 | 8,560 | 0.104 | 65 | 660 | 2,110 |
| .90 | 1.73 | 1.42 | 6,450 | 8,610 | 10,920 | 9,130 | 0.103 | 66 | 700 | 2,380 |
| .60 | 1.38 | 1.24 | 5,780 | 7,750 | 8,300 | 7,770 | 0.110 | 70 | 600 | 2,270 |
| .27 | 1.59 | 1.34 | 6,510 | 7,890 | 9,200 | 9,550 | 0.109 | 67 | 700 | 2,320 |
| .82 | 1.80 | 1.72 | 7,980 | 10,130 | 10,130 | 11,530 | 0.107 | 69 | 640 | 2,230 |
| .53 | 1.77 | 1.42 | 6,220 | 7,880 | 8,450 | 8,870 | 0.112 | 58 | 450 | 1,970 |
| .97 | 2.28 | 2.47 | 8,140 | 9,600 | 10,810 | 11,220 | 0.096 | 58 | 580 | 1,960 |
| .75 | 2.72 | 2.55 | 9,660 | 11,600 | 13,120 | 13,200 | 0.103 | 62 | 420 | 2,290 |
| .58 | 2.03 | 1.55 | 8,400 | 11,000 | 12,900 | 12,400 | 0.110 | 56 | 720 | 2,390 |
| .49 | 1.36 | 1.34 | 5,150 | 7,040 | 7,780 | 9,550 | 0.111 | 62 | 640 | 2,340 |
| .58 | 1.48 | – | 6,090 | 8,250 | 8,300 | 9,770 | 0.124 | 36 | 660 | 2,460 |
| .44 | 1.50 | 1.42 | 5,940 | 8,770 | 8,610 | 9,570 | 0.112 | 66 | 670 | 2,390 |
| .80 | 1.86 | 1.25 | 7,650 | 9,500 | 10,500 | 10,700 | 0.121 | 64 | 705 | 2,340 |
| .64 | 1.85 | 1.81 | 6,670 | 8,140 | 9,400 | 10,190 | 0.102 | 60 | 630 | 2,140 |
| .86 | 1.60 | 1.49 | 6,900 | 9,240 | 10,400 | 10,400 | 0.112 | 82 | 740 | 2,370 |
| .64 | 1.73 | 1.62 | 6,300 | 8,250 | 9,400 | 9,450 | 0.105 | 65 | 685 | 2,220 |
| .29 | 2.36 | 2.28 | 7,450 | 9,550 | 10,800 | 11,500 | 0.126 | 63 | 660 | 2,175 |
| .94 | 1.86 | 1.92 | 8,930 | 9,660 | 10,100 | 10,500 | 0.104 | 67 | 650 | 2,270 |
| .54 | 1.65 | 1.40 | 6,620 | 7,720 | 8,900 | 9,290 | 0.118 | 63 | 645 | 2,310 |
| .10 | 1.29 | 1.02 | 5,410 | 6,450 | 7,820 | 7,710 | 0.118 | 67 | 650 | 2,200 |
| .00 | 0.92 | 1.03 | 5,140 | 6,510 | 7,500 | 8,300 | 0.108 | 64 | 655 | 2,275 |
| .28 | 1.65 | 2.47 | 7,770 | 11,450 | 11,020 | 11,020 | 0.100 | 64 | 655 | 2,240 |
| .61 | 1.72 | 1.78 | 7,150 | 8,400 | 9,610 | 9,610 | 0.104 | 67 | 810 | 2,260 |
| .78 | 2.06 | 1.70 | 7,150 | 7,880 | 8,980 | 10,100 | 0.106 | 73 | 645 | 2,300 |
| .96 | 1.76 | 1.62 | 6,300 | 8,300 | 9,600 | 9,970 | 0.100 | 59 | 675 | 2,110 |
| 30 | 2.31 | 1.92 | 8,500 | 10,650 | 11,600 | 11,780 | 0.100 | 69 | 730 | 2,240 |
| .81 | 2.84 | 1.64 | 7,460 | 9,250 | 9,810 | 10,780 | 0.112 | 60 | 620 | 2,350 |
| – | – | – | – | – | – | – | – | – | – | – |
| 78 | 1.77 | 1.72 | 7,200 | 9,660 | 10,040 | 11,070 | 0.094 | 69 | 590 | 2,310 |
| 93 | 1.93 | 1.43 | 6,200 | 9,400 | 9,780 | 10,200 | 0.105 | 67 | 580 | 2,040 |
| 70 | 2.10 | 1.88 | 7,900 | 9,670 | 10,600 | 11,350 | 0.104 | 61 | 720 | 2,260 |
| 17 | 1.88 | 1.52 | 8,450 | 11,550 | 12,120 | 12,800 | 0.108 | 58 | 670 | 2,320 |
| 49 | 1.47 | 1.33 | 6,300 | 6,940 | 8,040 | 8,700 | 0.112 | 69 | 670 | 2,440 |
| 37 | 2.29 | 1.47 | 7,150 | 9,500 | 9,920 | 10,350 | 0.104 | 70 | 645 | 2,360 |
| 07 | 2.32 | 2.51 | 8,880 | 10,880 | 11,500 | 11,910 | 0.116 | 69 | 700 | 2,075 |
| 81 | 1.32 | 1.29 | 6,830 | 8,610 | 8,710 | 8,550 | 0.099 | 64 | 620 | 2,400 |
| 42 | 1.52 | 1.31 | 7,660 | 9,820 | 10,600 | 10,600 | 0.108 | 62 | 645 | 2,200 |
| 93 | 2.10 | 1.58 | 7,940 | 9,980 | 11,440 | 11,130 | 0.102 | 57 | 670 | 2,270 |
| 52 | 1.49 | 0.84 | 6,880 | 9,750 | 9,660 | 10,200 | 0.115 | 54 | 635 | 2,235 |
| 74 | 1.79 | 1.56 | 7,066 | 8,000 | 9,838 | 10,212 | 0.108 | 64 | 658 | 2,267 |
| 40 | 0.40 | 0.48 | 1,074 | 1,337 | 1,368 | 1,294 | | | | |
| 81 | 0.81 | 0.97 | 2,172 | 2,705 | 2,760 | 2,620 | | | | |
| 55 | 2.60 | 2.53 | 9,238 | 11,705 | 12,598 | 12,832 | | | | |
| 93 | 0.98 | 0.59 | 4,894 | 6,295 | 7,078 | 7,592 | | | | |
| 14 | 2.19 | 2.04 | 8,140 | 10,337 | 11,206 | 11,506 | | | | |
| 34 | 1.39 | 1.08 | 5,992 | 7,663 | 8,470 | 8,918 | | | | |

Table 4. Results of Bending Tests, Dry Timber

| Timber No. | Modulus of Elasticity (psi x $10^6$) | | | | Modulus of Rupture (psi) | | | | Testi | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Static Speed | Dynamic Speed 2 | Dynamic Speed 3 | Dynamic Speed 4 | Static Speed | Dynamic Speed 2 | Dynamic Speed 3 | Dynamic Speed 4 | Static Speed | Dynami Speed 2 |
| 1 | 1.90 | 1.84 | 1.17 | 1.14 | 11,780 | 13,100 | 8,050 | 8,830 | 0.097 | 58 |
| 2 | 1.44 | 1.59 | 1.17 | 0.99 | 11,090 | 12,330 | 7,880 | 6,540 | 0.125 | 61 |
| 3 | 1.64 | 1.46 | 0.90 | 1.01 | 11,930 | 12,440 | 6,940 | 7,830 | 0.139 | 55 |
| 4 | 2.17 | 2.42 | 1.63 | 1.44 | 13,650 | 16,950 | 11,500 | 10,700 | 0.104 | 61 |
| 5 | 1.63 | 1.79 | 1.12 | 1.03 | 9,640 | 12,130 | 8,140 | 6,930 | 0.145 | 62 |
| 6 | 1.43 | 1.34 | 0.87 | 0.94 | 11,700 | 12,880 | 8,140 | 6,610 | 0.114 | 57 |
| 7 | 2.36 | 2.39 | 1.43 | 1.69 | 14,080 | 15,650 | 10,860 | 10,660 | 0.132 | 62 |
| 8 | 1.91 | 2.04 | 1.28 | 1.31 | 11,910 | 13,230 | 9,400 | 9,610 | 0.104 | 59 |
| 9 | 2.24 | 2.35 | 1.51 | 1.47 | 14,500 | 16,020 | 11,400 | 11,340 | 0.098 | 54 |
| 10 | 2.63 | 2.80 | 1.56 | 1.65 | 15,500 | 17,870 | 11,090 | 11,340 | 0.108 | 62 |
| 11 | 2.48 | 2.81 | 1.66 | 1.89 | 13,500 | 19,300 | 12,550 | 12,550 | 0.103 | 58 |
| 12 | 1.75 | 1.88 | 1.06 | 1.09 | 12,180 | 13,960 | 7,720 | 7,980 | 0.134 | 57 |
| 13 | 1.96 | 1.92 | 1.22 | 1.84 | 12,760 | 13,230 | 8,820 | 8,980 | 0.128 | 55 |
| 14 | 1.47 | 1.73 | 1.09 | 1.21 | 10,700 | 12,700 | 7,510 | 8,130 | 0.130 | 61 |
| 15 | 2.21 | 2.21 | 1.14 | 1.46 | 13,750 | 16,400 | 10,550 | 10,400 | 0.105 | 57 |
| 16 | 1.74 | 2.03 | 1.07 | 1.06 | 11,920 | 13,960 | 8,870 | 9,400 | 0.123 | 61 |
| 18 | – | – | – | – | – | – | – | – | – | – |
| 19 | 2.04 | 2.60 | 1.28 | 1.27 | 13,910 | 14,900 | 9,290 | 9,760 | 0.134 | 65 |
| 20 | 2.74 | 2.28 | 1.51 | 1.56 | 14,000 | 15,440 | 10,500 | 10,500 | 0.102 | 61 |
| 21 | 2.22 | 2.11 | 1.42 | 1.61 | 14,500 | 14,700 | 9,140 | 10,190 | 0.129 | 64 |
| 22 | 1.99 | 1.84 | 1.22 | 1.35 | 12,230 | 13,120 | 8,720 | 8,560 | 0.149 | 65 |
| 23 | 1.29 | 1.32 | 0.79 | 0.83 | 10,000 | 10,100 | 7,150 | 6,410 | 0.172 | 60 |
| 24 | 1.38 | 1.48 | 0.98 | 0.98 | 10,400 | 12,450 | 7,940 | 8,730 | 0.100 | 64 |
| 25 | 1.71 | 1.87 | 1.33 | 1.49 | 13,910 | 13,330 | 10,200 | 11,020 | 0.158 | 57 |
| 26 | 1.97 | 2.16 | 1.26 | 1.43 | 12,500 | 14,800 | 11,190 | 9,450 | 0.132 | 65 |
| 27 | 2.08 | 2.21 | 1.34 | 1.26 | 13,880 | 15,650 | 9,880 | 7,730 | 0.150 | 65 |
| 28 | 1.98 | 2.02 | 1.09 | 1.29 | 12,910 | 13,550 | 9,660 | 9,030 | 0.101 | 58 |
| 29 | 2.68 | 2.73 | 1.63 | 1.66 | 17,000 | 20,200 | 11,020 | 11,680 | 0.122 | 59 |
| 30 | 1.55 | 1.85 | 1.26 | 1.36 | 12,980 | 15,180 | 10,130 | 10,500 | 0.132 | 56 |
| 31 | 1.64 | 1.49 | 1.04 | 1.53 | 8,650 | 12,400 | 7,570 | 9,570 | 0.136 | 60 |
| 32 | 2.02 | 2.26 | 1.26 | 1.35 | 12,430 | 15,530 | 10,710 | 9,550 | 0.130 | 61 |
| 33 | 2.12 | 2.26 | 1.32 | 1.03 | 13,700 | 14,910 | 10,600 | 10,660 | 0.144 | 75 |
| 34 | 2.05 | 2.07 | 1.24 | 1.25 | 13,970 | 15,490 | 9,450 | 11,020 | 0.12[illegible] | 63 |
| 35 | 2.30 | 2.36 | 1.59 | 1.70 | 15,330 | 19,640 | 14,280 | 11,710 | 0.112 | 62 |
| 36 | 1.90 | 2.08 | 1.11 | 1.18 | 12,070 | 13,240 | 6,100 | 5,780 | 0.146 | 61 |
| 37 | 2.05 | 1.88 | 1.23 | 1.28 | 12,130 | 10,090 | 9,760 | 9,710 | 0.134 | 57 |
| 38 | 2.47 | 2.42 | 1.55 | 1.76 | 15,440 | 16,870 | 11,090 | 11,350 | 0.123 | 62 |
| 39 | 1.85 | 2.08 | 1.18 | 1.44 | 11,800 | 13,880 | 8,500 | 9,000 | 0.112 | 61 |
| 40 | 2.26 | 2.41 | 1.29 | 1.79 | 14,800 | 15,330 | 9,450 | 9,710 | 0.158 | 61 |
| 41 | 2.23 | 2.82 | 1.35 | 1.52 | 15,430 | 18,440 | 10,710 | 11,130 | 0.128 | 47 |
| 42 | 1.73 | 1.65 | 1.15 | 1.18 | 13,020 | 15,020 | 9,870 | 10,820 | 0.104 | 57 |
| Average | 1.98 | 2.07 | 1.25 | 1.36 | 12,941 | 14,658 | 9,558 | 9,535 | 0.125 | 60 |
| Standard deviation (interval) | 0.36 | 0.40 | 0.21 | 0.27 | 1,759 | 2,336 | 1,658 | 1,645 | | |
| 95% confidence interval | 0.73 | 0.81 | 0.42 | 0.55 | 3,555 | 4,720 | 3,350 | 3,325 | | |
| Upper 95% confidence limit | 2.71 | 2.88 | 1.67 | 1.91 | 16,496 | 19,378 | 12,908 | 12,860 | | |
| Lower 95% confidence limit | 1.25 | 1.26 | 0.83 | 0.81 | 9,386 | 9,938 | 6,208 | 6,210 | | |
| Plus 1 standard deviation | 2.34 | 2.47 | 1.46 | 1.63 | 14,700 | 16,994 | 11,216 | 11,180 | | |
| Minus 1 standard deviation | 1.62 | 1.67 | 1.04 | 1.09 | 11,182 | 12,322 | 7,900 | 7,890 | | |

Note: 95% confidence interval = standard deviation interval x 2.021.



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Table 4. Results of Bending Tests, Dry Timber

| (psi x $10^6$) | | Modulus of Rupture (psi) | | | | Testing Speed (in./min) | | | |
|---|---|---|---|---|---|---|---|---|---|
| …mic …d 3 | Dynamic Speed 4 | Static Speed | Dynamic Speed 2 | Dynamic Speed 3 | Dynamic Speed 4 | Static Speed | Dynamic Speed 2 | Dynamic Speed 3 | Dynamic Speed 4 |
| 7 | 1.14 | 11,780 | 13,100 | 8,050 | 8,830 | 0.097 | 58 | 610 | 2,460 |
| 7 | 0.99 | 11,090 | 12,330 | 7,880 | 6,540 | 0.125 | 61 | 610 | 2,100 |
| 0 | 1.01 | 11,930 | 12,440 | 6,940 | 7,830 | 0.139 | 55 | 600 | 2,140 |
| 3 | 1.44 | 13,650 | 16,950 | 11,500 | 10,700 | 0.104 | 61 | 590 | 2,350 |
| 2 | 1.03 | 9,640 | 12,130 | 8,140 | 6,930 | 0.145 | 62 | 610 | 2,190 |
| 7 | 0.94 | 11,700 | 12,880 | 8,140 | 6,610 | 0.114 | 57 | 580 | 2,170 |
| 3 | 1.69 | 14,080 | 15,650 | 10,860 | 10,660 | 0.132 | 62 | 610 | 2,130 |
| 3 | 1.31 | 11,910 | 13,230 | 9,400 | 9,610 | 0.104 | 59 | 710 | 2,220 |
| 1 | 1.47 | 14,500 | 16,020 | 11,400 | 11,340 | 0.098 | 54 | 550 | 2,190 |
| 5 | 1.65 | 15,500 | 17,870 | 11,090 | 11,340 | 0.108 | 62 | 600 | 2,080 |
| 5 | 1.89 | 13,500 | 19,300 | 12,550 | 12,550 | 0.103 | 58 | 590 | 2,150 |
| 6 | 1.09 | 12,180 | 13,960 | 7,720 | 7,980 | 0.134 | 57 | 610 | 2,290 |
| 2 | 1.84 | 12,760 | 13,230 | 8,820 | 8,980 | 0.128 | 55 | 590 | 2,080 |
| 0 | 1.21 | 10,700 | 12,700 | 7,510 | 8,130 | 0.130 | 61 | 590 | 2,120 |
| 3 | 1.46 | 13,750 | 16,400 | 10,550 | 10,400 | 0.105 | 57 | 620 | 2,280 |
| | 1.06 | 11,920 | 13,960 | 8,870 | 9,400 | 0.123 | 61 | 590 | 2,230 |
| | – | – | – | – | – | – | – | – | – |
| | 1.27 | 13,910 | 14,900 | 9,290 | 9,760 | 0.134 | 65 | 590 | 1,990 |
| | 1.56 | 14,000 | 15,440 | 10,500 | 10,500 | 0.102 | 61 | 620 | 2,000 |
| | 1.61 | 14,500 | 14,700 | 9,140 | 10,190 | 0.129 | 64 | 590 | 1,920 |
| | 1.35 | 12,230 | 13,120 | 8,720 | 8,560 | 0.149 | 65 | 630 | 1,940 |
| | 0.83 | 10,000 | 10,100 | 7,150 | 6,410 | 0.172 | 60 | 630 | 2,180 |
| | 0.98 | 10,400 | 12,450 | 7,940 | 8,730 | 0.100 | 64 | 620 | 2,140 |
| | 1.49 | 13,910 | 13,330 | 10,200 | 11,020 | 0.158 | 57 | 650 | 2,150 |
| | 1.43 | 12,500 | 14,800 | 11,190 | 9,450 | 0.132 | 65 | 600 | 2,040 |
| | 1.26 | 13,880 | 15,650 | 9,880 | 7,730 | 0.150 | 65 | 650 | 2,220 |
| | 1.29 | 12,910 | 13,550 | 9,660 | 9,030 | 0.101 | 58 | 630 | 2,140 |
| | 1.66 | 17,000 | 20,200 | 11,020 | 11,680 | 0.122 | 59 | 640 | 2,210 |
| | 1.36 | 12,980 | 15,180 | 10,130 | 10,500 | 0.132 | 56 | 650 | 1,970 |
| | 1.53 | 8,650 | 12,400 | 7,570 | 9,570 | 0.136 | 60 | 600 | 2,230 |
| | 1.35 | 12,430 | 15,530 | 10,710 | 9,550 | 0.130 | 61 | 600 | 2,090 |
| | 1.03 | 13,700 | 14,910 | 10,600 | 10,660 | 0.144 | 75 | 610 | 2,100 |
| | 1.25 | 13,970 | 15,490 | 9,450 | 11,020 | 0.122 | 63 | 600 | 2,280 |
| | 1.70 | 15,330 | 19,640 | 14,280 | 11,710 | 0.112 | 62 | 620 | 2,300 |
| | 1.18 | 12,070 | 13,240 | 6,100 | 5,780 | 0.146 | 61 | 610 | 2,220 |
| | 1.28 | 12,130 | 10,090 | 9,760 | 9,710 | 0.134 | 57 | 600 | 2,020 |
| | 1.76 | 15,440 | 16,870 | 11,090 | 11,350 | 0.123 | 62 | 600 | 2,290 |
| | 1.44 | 11,800 | 13,880 | 8,500 | 9,000 | 0.112 | 61 | 610 | 2,520 |
| | 1.79 | 14,800 | 15,330 | 9,450 | 9,710 | 0.158 | 61 | 600 | 1,990 |
| | 1.52 | 15,430 | 18,440 | 10,710 | 11,130 | 0.128 | 47 | 630 | 1,980 |
| | 1.18 | 13,020 | 15,020 | 9,870 | 10,820 | 0.104 | 57 | 600 | 2,120 |
| | 1.36 | 12,941 | 14,658 | 9,558 | 9,535 | 0.125 | 60 | 611 | 2,156 |
| | 0.27 | 1,759 | 2,336 | 1,658 | 1,645 | | | | |
| | 0.55 | 3,555 | 4,720 | 3,350 | 3,325 | | | | |
| | 1.91 | 16,496 | 19,378 | 12,908 | 12,860 | | | | |
| | 0.81 | 9,386 | 9,938 | 6,208 | 6,210 | | | | |
| | 1.63 | 14,700 | 16,994 | 11,216 | 11,180 | | | | |
| | 1.09 | 11,182 | 12,322 | 7,900 | 7,890 | | | | |

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B

Table 5. Results of Compression-Parallel-to-Grain Tests, Green Tim

| Timber No. | Modulus of Elasticity (psi x $10^6$) | | | | Maximum Stress (psi) | | |
|---|---|---|---|---|---|---|---|
| | Static Speed | Dynamic Speed 2 | Dynamic Speed 3 | Dynamic Speed 4 | Static Speed | Dynamic Speed 2 | Dynamic Speed 3 |
| 1 | 1.64 | 1.82 | – | 1.96 | 3,700 | 4,700 | – |
| 2 | 1.78 | 1.79 | 1.56 | 2.36 | 3,440 | 4,560 | 4,670 |
| 3 | 1.20 | 1.37 | 1.68 | 3.16 | 2,690 | 3,710 | 4,450 |
| 4 | 1.90 | 2.12 | 2.29 | 3.40 | 3,290 | 4,490 | 5,200 |
| 5 | 1.50 | 1.59 | 1.71 | 2.22 | 2,750 | 3,870 | 3,960 |
| 6 | 1.23 | 1.42 | 1.31 | 1.91 | 3,260 | 4,250 | 4,820 |
| 7 | 2.10 | 2.23 | 2.30 | 3.76 | 4,170 | 5,130 | 6,030 |
| 8 | 1.83 | 1.89 | 1.77 | 2.02 | 3,050 | 4,030 | 3,930 |
| 9 | 2.20 | 2.58 | 2.29 | 2.90 | 4,280 | 5,400 | 5,960 |
| 10 | 2.52 | 2.64 | 2.59 | 3.38 | 5,580 | 7,000 | 7,520 |
| 11 | 2.73 | 2.76 | 2.84 | 3.92 | 5,180 | 6,200 | 7,210 |
| 12 | 1.69 | 1.71 | 1.76 | 2.71 | 3,000 | 3,850 | 4,310 |
| 13 | 1.93 | 1.86 | 2.23 | 3.17 | 3,320 | 4,400 | 5,070 |
| 14 | 1.46 | 1.66 | 1.55 | 2.50 | 3,110 | 4,070 | 4,530 |
| 15 | 2.14 | 2.10 | 2.26 | 3.34 | 3,920 | 5,100 | 5,890 |
| 16 | 1.93 | 2.04 | 2.07 | 3.24 | 3,760 | 4,310 | 4,980 |
| 18 | 2.45 | 2.36 | 2.51 | 3.73 | 4,190 | 5,340 | 5,940 |
| 19 | 2.20 | 2.06 | 2.10 | 3.22 | 3,210 | 4,500 | 4,750 |
| 20 | 2.55 | 2.37 | 2.38 | 3.25 | 4,550 | 5,400 | 5,910 |
| 21 | 1.61 | 2.20 | 2.31 | 2.48 | 4,430 | 4,750 | 5,400 |
| 22 | 1.93 | 1.89 | 1.89 | 2.55 | 3,710 | 4,250 | 5,190 |
| 23 | 1.06 | 1.38 | 1.25 | 2.10 | 2,510 | 3,410 | 3,620 |
| 24 | 1.15 | 1.13 | 1.52 | 2.86 | 2,500 | 3,280 | 3,760 |
| 25 | 2.34 | 1.82 | 1.56 | 2.59 | 4,220 | 4,380 | 5,770 |
| 26 | 2.27 | 1.89 | 2.13 | 2.52 | 3,670 | 4,420 | 4,970 |
| 27 | 2.19 | 2.16 | 2.68 | 2.83 | 3,770 | 4,530 | 5,550 |
| 28 | 1.92 | 1.87 | 2.07 | 1.86 | 3,790 | 4,900 | 5,570 |
| 29 | 2.60 | 2.61 | 2.85 | 3.63 | 4,730 | 5,870 | 6,580 |
| 30 | 1.70 | 2.24 | 2.38 | 2.64 | 3,720 | 4,470 | 5,600 |
| 31 | 1.15 | 1.51 | 1.82 | 2.80 | 4,430 | 5,730 | 5,810 |
| 32 | 1.57 | 2.15 | 2.17 | 2.83 | 3,860 | 4,870 | 6,010 |
| 33 | 2.06 | 2.14 | 2.38 | 3.12 | 3,460 | 5,070 | 5,650 |
| 34 | 2.13 | 2.12 | 2.24 | 2.87 | 4,420 | 5,030 | 5,820 |
| 35 | 2.15 | 2.21 | 2.56 | 3.64 | 4,570 | 5,980 | 5,670 |
| 36 | 1.58 | 1.90 | 1.86 | 2.64 | 3,310 | 4,210 | 5,030 |
| 37 | 1.93 | 2.17 | 2.23 | 2.76 | 4,100 | 5,080 | 5,760 |
| 38 | 2.61 | 2.79 | 2.50 | – | 4,670 | 6,000 | 5,900 |
| 39 | 2.02 | 1.87 | 1.79 | 3.08 | 3,550 | 4,460 | 4,760 |
| 40 | 1.88 | 1.66 | 2.12 | 3.15 | 4,210 | 5,330 | 6,180 |
| 41 | 2.10 | 2.37 | 2.33 | 2.81 | 4,170 | 5,280 | 6,100 |
| 42 | 1.63 | 2.05 | 1.42 | 1.57 | 3,380 | 4,630 | 4,710 |
| Average | 1.92 | 2.01 | 2.08 | 2.77 | 3,796 | 4,786 | 5,364 |
| Standard deviation (interval) | 0.43 | 0.38 | 0.41 | 0.71 | 696 | 777 | 862 |
| 95% confidence interval | 0.87 | 0.77 | 0.83 | 1.44 | 1,408 | 1,570 | 1,742 |
| Upper 95% confidence limit | 2.79 | 2.78 | 2.91 | 4.21 | 5,204 | 6,356 | 7,106 |
| Lower 95% confidence limit | 1.05 | 1.24 | 1.25 | 1.33 | 2,388 | 3,216 | 3,622 |
| Plus 1 standard deviation | 2.35 | 2.39 | 2.49 | 3.48 | 4,492 | 5,563 | 6,226 |
| Minus 1 standard deviation | 1.49 | 1.63 | 1.67 | 2.06 | 3,100 | 4,009 | 4,502 |

Note: 95% confidence interval = standard deviation x 2.021.

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Table 5. Results of Compression-Parallel-to-Grain Tests, Green Timber

| ty (psi x $10^6$) | | Maximum Stress (psi) | | | | Testing Speed (in./min) | | | |
|---|---|---|---|---|---|---|---|---|---|
| Dynamic Speed 3 | Dynamic Speed 4 | Static Speed | Dynamic Speed 2 | Dynamic Speed 3 | Dynamic Speed 4 | Static Speed | Dynamic Speed 2 | Dynamic Speed 3 | Dynamic Speed 4 |
| – | 1.96 | 3,700 | 4,700 | – | 5,470 | 0.021 | 42 | – | 1,100 |
| 1.56 | 2.36 | 3,440 | 4,560 | 4,670 | 5,080 | 0.024 | 45 | 400 | 1,130 |
| 1.68 | 3.16 | 2,690 | 3,710 | 4,450 | 4,970 | 0.026 | 56 | 550 | 1,140 |
| 2.29 | 3.40 | 3,290 | 4,490 | 5,200 | 5,650 | 0.026 | 39 | 535 | 1,180 |
| 1.71 | 2.22 | 2,750 | 3,870 | 3,960 | 4,570 | 0.027 | 48 | 500 | 1,200 |
| 1.31 | 1.91 | 3,260 | 4,250 | 4,820 | 5,150 | 0.020 | 45 | 410 | 1,130 |
| 2.30 | 3.76 | 4,170 | 5 130 | 6,030 | 6,230 | 0.014 | 51 | 330 | 1,110 |
| 1.77 | 2.02 | 3,050 | 4,030 | 3,930 | 4,750 | 0.025 | 44 | 400 | 1,100 |
| 2.29 | 2.90 | 4,280 | 5,400 | 5,960 | 6,400 | 0.024 | 39 | 260 | 675 |
| 2.59 | 3.38 | 5,580 | 7,000 | 7,520 | 8,300 | 0.024 | 39 | 400 | 1,650 |
| 2.84 | 3.92 | 5,180 | 6,200 | 7,210 | 8,080 | 0.015 | 48 | 420 | 1,120 |
| 1.76 | 2.71 | 3,000 | 3,850 | 4,310 | 5,030 | 0.014 | 54 | 460 | 1,040 |
| 2.23 | 3.17 | 3,320 | 4,400 | 5,070 | 5,370 | 0.028 | 55 | 490 | 1,080 |
| 1.55 | 2.50 | 3,110 | 4,070 | 4,530 | 4,900 | 0.024 | 45 | 465 | 1,400 |
| 2.26 | 3.34 | 3,920 | 5,100 | 5,890 | 6,010 | 0.015 | 52 | 480 | 1,140 |
| 2.07 | 3.24 | 3,760 | 4,310 | 4,980 | 5,600 | 0.022 | 54 | 435 | 1,030 |
| 2.51 | 3.73 | 4,190 | 5,340 | 5,940 | 5,790 | 0.026 | 57 | 480 | 1,250 |
| 2.10 | 3.22 | 3,210 | 4,500 | 4,750 | 5,350 | 0.020 | 58 | 470 | 1,020 |
| 2.38 | 3.25 | 4,550 | 5,400 | 5,910 | 6,890 | 0.020 | 44 | 430 | 1,100 |
| 2.31 | 2.48 | 4,430 | 4,750 | 5,400 | 6,630 | 0.012 | 44 | 400 | 1,250 |
| 1.89 | 2.55 | 3,710 | 4,250 | 5,190 | 5,480 | 0.015 | 40 | 410 | 1,200 |
| 1.25 | 2.10 | 2,510 | 3,410 | 3,620 | 4,500 | 0.018 | 48 | 440 | 1,320 |
| 1.52 | 2.86 | 2,500 | 3,280 | 3,760 | 4,800 | 0.028 | 44 | 490 | 1,830 |
| 1.56 | 2.59 | 4,220 | 4,380 | 5,770 | 6,740 | 0.015 | 40 | 410 | 1,030 |
| 2.13 | 2.52 | 3,670 | 4,420 | 4,970 | 5,070 | 0.019 | 48 | 410 | 1,345 |
| 2.68 | 2.83 | 3,770 | 4,530 | 5,550 | 5,600 | 0.032 | 54 | 410 | 1,300 |
| 2.07 | 1.86 | 3,790 | 4,900 | 5,570 | 5,980 | 0.024 | 46 | 330 | 1,585 |
| 2.85 | 3.63 | 4,730 | 5,870 | 6,580 | 7,070 | 0.024 | 41 | 380 | 1,390 |
| 2.38 | 2.64 | 3,720 | 4,470 | 5,600 | 5,820 | 0.007 | 47 | 440 | 1,540 |
| 1.82 | 2.80 | 4,430 | 5,730 | 5,810 | 7,080 | 0.020 | 36 | 410 | 1,150 |
| 2.17 | 2.83 | 3,860 | 4,870 | 6,010 | 5,910 | 0.023 | 44 | 420 | 1,200 |
| 2.38 | 3.12 | 3,460 | 5,070 | 5,650 | 5,990 | 0.018 | 38 | 440 | 960 |
| 2.24 | 2.87 | 4,420 | 5,030 | 5,820 | 6,470 | 0.024 | 41 | 420 | 1,585 |
| 2.56 | 3.64 | 4,570 | 5,980 | 5,670 | 7,210 | 0.024 | 50 | 500 | 1,100 |
| 1.86 | 2.64 | 3,310 | 4,210 | 5,030 | 4,900 | 0.028 | 50 | 430 | 1,150 |
| 2.23 | 2.76 | 4,100 | 5,080 | 5,760 | 6,330 | 0.024 | 50 | 390 | 1,390 |
| 2.50 | – | 4,670 | 6,000 | 5,900 | 7,390 | 0.024 | 37 | 400 | 1,300 |
| 1.79 | 3.08 | 3,550 | 4,460 | 4,760 | 5,060 | 0.020 | 39 | 530 | 1,200 |
| 2.12 | 3.15 | 4,210 | 5,330 | 6,180 | 6,740 | 0.018 | 47 | 380 | 1,150 |
| 2.33 | 2.81 | 4,170 | 5,280 | 6,100 | 6,530 | 0.019 | 43 | 505 | 1,290 |
| 1.42 | 1.57 | 3,380 | 4,630 | 4,710 | 5,910 | 0.019 | 43 | 840 | 1,200 |
| 2.08 | 2.77 | 3,796 | 4,786 | 5,364 | 5,922 | 0.021 | 46 | 442 | 1,221 |
| 0.41 | 0.71 | 696 | 777 | 862 | 937 | | | | |
| 0.83 | 1.44 | 1,408 | 1,570 | 1,742 | 1,894 | | | | |
| 2.91 | 4.21 | 5,704 | 6,356 | 7,106 | 7,816 | | | | |
| 1.25 | 1.33 | 2,388 | 3,216 | 3,622 | 4,028 | | | | |
| 2.49 | 3.48 | 4,492 | 5,563 | 6,226 | 6,859 | | | | |
| 1.67 | 2.06 | 3,100 | 4,009 | 4,502 | 4,985 | | | | |

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Table 6. Results of Compression-Parallel-to-Grain Tests, Dry Timber

| Timber No. | Modulus of Elasticity (psi x $10^6$) | | | | Maximum Stress (psi) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Static Speed | Dynamic Speed 2 | Dynamic Speed 3 | Dynamic Speed 4 | Static Speed | Dynamic Speed 2 | Dynamic Speed 3 | Dynamic Speed 4 | Static Speed |
| 1 | 1.76 | 2.01 | 2.01 | 2.80 | 6,950 | 8,570 | 9,060 | 10,910 | 0.023 |
| 2 | 1.68 | 1.68 | 2.01 | 2.30 | 6,220 | 7,630 | 9,180 | 9,450 | 0.037 |
| 3 | 1.48 | 1.78 | 1.77 | 2.07 | 5,780 | 6,930 | 7,450 | 8,760 | 0.025 |
| 4 | 2.22 | 2.57 | 2.72 | 2.94 | 7,660 | 9,400 | 10,700 | 12,160 | 0.023 |
| 5 | 1.62 | 2.06 | 2.02 | 2.25 | 6,030 | 7,560 | 7,890 | 8,930 | 0.037 |
| 6 | 1.26 | 1.41 | 1.60 | 2.11 | 6,180 | 7,230 | 8,330 | 9,150 | 0.028 |
| 7 | 1.85 | 2.80 | 2.71 | 2.45 | 7,780 | 10,110 | 10,510 | 11,300 | 0.020 |
| 8 | 1.74 | 2.14 | 2.19 | 2.83 | 6,950 | 7,530 | 8,780 | 10,290 | 0.026 |
| 9 | 2.44 | 2.72 | 2.83 | 3.60 | 5,350 | 10,020 | 10,800 | 10,130 | 0.016 |
| 10 | 2.61 | 2.96 | 2.77 | 3.76 | 11,250 | 11,350 | 11,870 | 12,540 | 0.029 |
| 11 | 2.58 | 3.39 | 3.51 | 4.43 | 9,430 | 11,780 | 12,520 | 13,030 | 0.025 |
| 12 | 1.60 | 2.16 | 1.88 | 2.19 | 6,200 | 8,120 | 7,780 | 9,230 | 0.019 |
| 13 | 1.95 | 2.16 | 2.30 | 2.86 | 7,170 | 8,220 | 9,370 | 10,950 | 0.027 |
| 14 | 1.62 | 1.86 | 1.92 | 2.29 | 6,030 | 7,940 | 8,820 | 9,570 | 0.033 |
| 15 | 2.16 | 2.44 | 2.47 | 3.33 | 7,940 | 9,550 | 9,810 | 11,150 | 0.032 |
| 16 | 2.17 | 2.21 | 2.30 | 2.98 | 6,810 | 9,150 | 9,560 | 11,460 | 0.027 |
| 18 | 2.38 | 2.76 | 2.71 | 3.37 | 8,420 | 9,720 | 10,200 | 11,610 | 0.031 |
| 19 | 1.91 | 2.06 | 2.11 | 2.78 | 7,340 | 9,020 | 9,530 | 10,700 | 0.029 |
| 20 | 2.68 | – | 3.09 | 3.84 | 9,180 | 9,540 | 10,790 | 12,460 | 0.031 |
| 21 | 2.20 | 1.98 | 2.58 | 3.43 | 7,930 | 6,430 | 10,590 | 11,560 | 0.028 |
| 22 | 1.68 | 2.01 | 2.22 | 2.45 | 6,780 | 8,030 | 9,330 | 10,230 | 0.029 |
| 23 | 1.14 | 1.38 | 1.41 | 2.30 | 4,510 | 5,650 | 6,740 | 7,230 | 0.031 |
| 24 | 1.20 | 1.50 | 1.63 | 2.16 | 5,370 | 6,870 | 8,030 | 9,430 | 0.048 |
| 25 | 1.48 | 1.90 | 2.28 | 2.37 | 6,700 | 7,800 | 9,820 | 10,350 | 0.028 |
| 26 | 3.87 | 2.34 | 2.08 | 2.39 | 7,120 | 8,750 | 9,530 | 10,880 | 0.033 |
| 27 | 1.87 | 2.12 | 2.46 | 2.46 | 7,470 | 9,000 | 10,500 | 10,340 | 0.023 |
| 28 | 2.00 | 2.24 | 2.19 | 2.27 | 7,070 | 8,750 | 9,230 | 9,780 | 0.030 |
| 29 | 2.57 | 3.25 | 3.16 | 4.23 | 9,070 | 11,300 | 12,510 | 13,170 | 0.037 |
| 30 | 1.33 | 2.28 | 2.30 | 2.86 | 6,490 | 9,050 | 10,150 | 11,550 | 0.031 |
| 31 | 1.40 | 1.50 | 1.70 | 2.41 | 6,680 | 8,140 | 9,970 | 11,050 | 0.032 |
| 32 | 1.80 | 2.27 | 2.43 | 2.48 | 7,500 | 9,240 | 9,890 | 10,850 | 0.023 |
| 33 | 2.09 | 2.39 | 2.36 | 2.65 | 7,650 | 9,500 | 10,300 | 10,560 | 0.036 |
| 34 | 2.03 | 2.20 | 2.41 | 2.74 | 7,280 | 9,100 | 10,060 | 11,830 | 0.026 |
| 35 | 2.06 | 2.63 | 2.84 | 3.00 | 8,000 | 10,780 | 11,850 | 13,260 | 0.033 |
| 36 | 1.71 | 2.12 | 2.01 | 2.21 | 7,070 | 8,340 | 8,280 | 9,010 | 0.035 |
| 37 | 1.52 | 2.25 | 2.33 | 2.88 | 7,300 | 8,650 | 9,850 | 10,610 | 0.033 |
| 38 | 3.58 | 2.64 | 2.81 | 4.24 | 8,700 | 10,520 | 12,300 | 13,210 | 0.033 |
| 39 | 1.71 | 2.15 | 2.10 | 2.42 | 7,130 | 8,620 | 8,860 | 11,590 | 0.031 |
| 40 | 1.78 | 2.47 | 2.08 | 2.49 | 7,170 | 9,350 | 9,320 | 11,260 | 0.029 |
| 41 | 2.27 | 2.66 | 2.70 | 3.23 | 8,490 | 10,470 | 9,830 | 11,780 | 0.027 |
| 42 | 1.76 | 1.80 | 1.74 | 2.50 | 7,500 | 8,270 | 8,140 | 10,460 | 0.032 |
| Average | 1.97 | 2.18 | 2.31 | 2.81 | 7,264 | 8,829 | 9,708 | 10,824 | 0.029 |
| Standard deviation (interval) | 0.56 | 0.57 | 0.45 | 0.62 | 1,229 | 1,342 | 1,343 | 1,345 | |
| 95% confidence interval | 1.13 | 1.15 | 0.91 | 1.25 | 2,485 | 2,715 | 2,718 | 2,720 | |
| Upper 95% confidence limit | 3.10 | 3.33 | 3.22 | 4.06 | 9,749 | 11,544 | 12,426 | 13,544 | |
| Lower 95% confidence limit | 0.84 | 1.03 | 1.40 | 1.56 | 4,779 | 6,114 | 6,990 | 8,104 | |
| Plus 1 standard deviation | 2.53 | 2.75 | 2.76 | 3.43 | 8,493 | 10,171 | 11,051 | 12,169 | |
| Minus 1 standard deviation | 1.41 | 1.61 | 1.86 | 2.19 | 6,035 | 7,487 | 8,365 | 9,479 | |

Note: 95% confidence interval = standard deviation x 2.021.



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le 6. Results of Compression-Parallel-to-Grain Tests, Dry Timber

| 0⁶) | Maximum Stress (psi) | | | | Testing Speed (in./min) | | | |
|---|---|---|---|---|---|---|---|---|
| Dynamic Speed 4 | Static Speed | Dynamic Speed 2 | Dynamic Speed 3 | Dynamic Speed 4 | Static Speed | Dynamic Speed 2 | Dynamic Speed 3 | Dynamic Speed 4 |
| 2.80 | 6,950 | 8,570 | 9,060 | 10,910 | 0.023 | 30 | 380 | 1,150 |
| 2.30 | 6,220 | 7,630 | 9,180 | 9,450 | 0.037 | 34 | 448 | 1,250 |
| 2.07 | 5,780 | 6,930 | 7,450 | 8,760 | 0.025 | 34 | 448 | 1,200 |
| 2.94 | 7,660 | 9,400 | 10,700 | 12,160 | 0.023 | 26 | 416 | 1,200 |
| 2.25 | 6,030 | 7,560 | 7,890 | 8,930 | 0.037 | 30 | 400 | 1,390 |
| 2.11 | 6,180 | 7,230 | 8,330 | 9,150 | 0.028 | 35 | 480 | 1,225 |
| 2.45 | 7,780 | 10,110 | 10,510 | 11,300 | 0.020 | 25 | 400 | 1,105 |
| 2.83 | 6,950 | 7,530 | 8,780 | 10,290 | 0.026 | 30 | 370 | 1,415 |
| 3.60 | 5,350 | 10,020 | 10,800 | 10,130 | 0.016 | 25 | 385 | 1,150 |
| 3.76 | 11,250 | 11,350 | 11,870 | 12,540 | 0.029 | 30 | 370 | 1,055 |
| 4.43 | 9,430 | 11,780 | 12,520 | 13,030 | 0.025 | 30 | 385 | 1,010 |
| 2.19 | 6,200 | 8,120 | 7,780 | 9,230 | 0.019 | 30 | 480 | 1,225 |
| 2.86 | 7,170 | 8,220 | 9,370 | 10,950 | 0.027 | 30 | 380 | 1,130 |
| 2.29 | 6,030 | 7,940 | 8,820 | 9,570 | 0.033 | 35 | 430 | 1,225 |
| 3.33 | 7,940 | 9,550 | 9,810 | 11,150 | 0.032 | 30 | 400 | 1,300 |
| 2.98 | 6,810 | 9,150 | 9,560 | 11,460 | 0.027 | 30 | 400 | 1,105 |
| 3.37 | 8,420 | 9,720 | 10,200 | 11,610 | 0.031 | 30 | 415 | 1,175 |
| 2.78 | 7,340 | 9,020 | 9,530 | 10,700 | 0.029 | 30 | 385 | 1,080 |
| 3.84 | 9,180 | 9,540 | 10,790 | 12,460 | 0.031 | 32 | 350 | 1,130 |
| 3.43 | 7,930 | 6,430 | 10,590 | 11,560 | 0.028 | 35 | 400 | 1,105 |
| 2.45 | 6,780 | 8,030 | 9,330 | 10,230 | 0.029 | 35 | 450 | 1,130 |
| 2.30 | 4,510 | 5,650 | 6,740 | 7,230 | 0.031 | 35 | 465 | 1,270 |
| 2.16 | 5,370 | 6,870 | 8,030 | 9,430 | 0.048 | 35 | 370 | 1,175 |
| 2.37 | 6,700 | 7,800 | 9,820 | 10,350 | 0.028 | 30 | 450 | 1,175 |
| 2.39 | 7,120 | 8,750 | 9,530 | 10,880 | 0.033 | 35 | 465 | 1,105 |
| 2.46 | 7,470 | 9,000 | 10,500 | 10,340 | 0.023 | 35 | 400 | 1,105 |
| 2.27 | 7,070 | 8,750 | 9,230 | 9,780 | 0.030 | 30 | 385 | 1,175 |
| 4.23 | 9,070 | 11,300 | 12,510 | 13,170 | 0.037 | 35 | 385 | 1,140 |
| 2.86 | 6,490 | 9,050 | 10,150 | 11,550 | 0.031 | 35 | 450 | 1,105 |
| 2.41 | 6,680 | 8,140 | 9,970 | 11,050 | 0.032 | 35 | 440 | 1,225 |
| 2.48 | 7,500 | 9,240 | 9,890 | 10,850 | 0.023 | 35 | 400 | 1,150 |
| 2.65 | 7,650 | 9,500 | 10,300 | 10,560 | 0.036 | 30 | 400 | 1,150 |
| 2.74 | 7,280 | 9,100 | 10,060 | 11,830 | 0.026 | 35 | 385 | 1,130 |
| 3.00 | 8,000 | 10,780 | 11,850 | 13,260 | 0.033 | 30 | 385 | 1,225 |
| 2.21 | 7,070 | 8,340 | 8,280 | 9,010 | 0.035 | 30 | 450 | 1,175 |
| 2.88 | 7,300 | 8,650 | 9,850 | 10,610 | 0.033 | 35 | 465 | 1,150 |
| 4.24 | 8,700 | 10,520 | 12,300 | 13,210 | 0.033 | 35 | 400 | 1,090 |
| 2.42 | 7,130 | 8,620 | 8,860 | 11,590 | 0.031 | 30 | 415 | 1,150 |
| 2.49 | 7,170 | 9,350 | 9,320 | 11,260 | 0.029 | 30 | 465 | 1,055 |
| 3.23 | 8,490 | 10,470 | 9,830 | 11,780 | 0.027 | 30 | 400 | 1,080 |
| 2.50 | 7,500 | 8,270 | 8,140 | 10,460 | 0.032 | 30 | 430 | 1,225 |
| 2.81 | 7,264 | 8,829 | 9,708 | 10,824 | 0.029 | 32 | 414 | 1,167 |
| 0.62 | 1,229 | 1,342 | 1,343 | 1,345 | | | | |
| 1.25 | 2,485 | 2,715 | 2,718 | 2,720 | | | | |
| 4.06 | 9,749 | 11,544 | 12,426 | 13,544 | | | | |
| 1.56 | 4,779 | 6,114 | 6,990 | 8,104 | | | | |
| 3.43 | 8,493 | 10,171 | 11,051 | 12,169 | | | | |
| 2.19 | 6,035 | 7,487 | 8,365 | 9,479 | | | | |

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Table 7. Results of Compression-Perpendicular-to-Grain Tests, Green Timber

| Timber No. | Maximum Stress (psi) | | | | Testing Speed (in./min) | | | |
|---|---|---|---|---|---|---|---|---|
| | Static Speed | Dynamic Speed 2 | Dynamic Speed 3 | Dynamic Speed 4 | Static Speed | Dynamic Speed 2 | Dynamic Speed 3 | Dynamic Speed 4 |
| 1 | 760 | 1,030 | 1,180 | 1,410 | 0.012 | 50 | 145 | 1,070 |
| 2 | 770 | 1,070 | 1,610 | 1,260 | 0.025 | 100 | 980 | 2,230 |
| 3 | 850 | 1,280 | 1,390 | 1,570 | 0.004 | 110 | 790 | 2,300 |
| 4 | 600 | 1,080 | 1,510 | 1,110 | 0.010 | 100 | 680 | 1,760 |
| 5 | 670 | 1,270 | 1,720 | 970 | 0.015 | 100 | 950 | 2,360 |
| 6 | 700 | 1,270 | 1,610 | 1,210 | 0.009 | 110 | 855 | 2,360 |
| 7 | 1,260 | 1,450 | 2,160 | 1,620 | 0.025 | 100 | 845 | 1,615 |
| 8 | 670 | 1,220 | 1,830 | 1,330 | 0.009 | 50 | 570 | 1,320 |
| 9 | 990 | 1,530 | 1,630 | 1,510 | 0.011 | 40 | 480 | 1,870 |
| 10 | 1,390 | 2,140 | 2,260 | 1,950 | 0.007 | 50 | 390 | 1,430 |
| 11 | 810 | 1,440 | 1,720 | 1,740 | 0.035 | 110 | 935 | 1,800 |
| 12 | 650 | 820 | 860 | 1,280 | 0.020 | 105 | 695 | 1,350 |
| 13 | 870 | 960 | 1,320 | 1,340 | 0.015 | 115 | 835 | 1,705 |
| 14 | 680 | 1,190 | 1,420 | 1,280 | 0.020 | 100 | 1,005 | 2,300 |
| 15 | 970 | 970 | 1,440 | 1,520 | 0.015 | 105 | 925 | 1,830 |
| 16 | 820 | 1,280 | 1,760 | — | 0.015 | 105 | 790 | 2,070 |
| 18 | 640 | 1,120 | 1,240 | 1,260 | 0.010 | 105 | 1,045 | 2,070 |
| 19 | 800 | 1,030 | 1,300 | 1,230 | 0.015 | 105 | 895 | 2,220 |
| 20 | 740 | 1,040 | 1,640 | 1,620 | 0.013 | 50 | 275 | 1,525 |
| 21 | 760 | 1,420 | 1,700 | 1,060 | 0.020 | 95 | 1,045 | 2,280 |
| 22 | 730 | 1,240 | 1,210 | 1,190 | 0.015 | 100 | 940 | 2,190 |
| 23 | 840 | 950 | 1,250 | 1,170 | 0.015 | 110 | 870 | 1,680 |
| 24 | 840 | 1,020 | 1,510 | 1,320 | 0.015 | 110 | 725 | 1,985 |
| 25 | 830 | — | — | 1,460 | 0.015 | 95 | 805 | 2,320 |
| 26 | 700 | 1,050 | 1,280 | 1,400 | 0.015 | 100 | 960 | 1,840 |
| 27 | 780 | 850 | 1,140 | 1,670 | 0.020 | 100 | 875 | 1,520 |
| 28 | 820 | 1,520 | 1,640 | 1,470 | 0.012 | 110 | 580 | 1,490 |
| 29 | 920 | 1,750 | 1,340 | 1,470 | 0.015 | 100 | 1,025 | 2,390 |
| 30 | 680 | 1,110 | 1,740 | 1,680 | 0.020 | 100 | 685 | 1,480 |
| 31 | 1,300 | 2,530 | 2,120 | 2,120 | 0.015 | 100 | 955 | 2,485 |
| 32 | 1,090 | 1,580 | 1,720 | 1,300 | 0.015 | 95 | 550 | 2,265 |
| 33 | 570 | 1,170 | 1,270 | 1,560 | 0.010 | 100 | 880 | 1,990 |
| 34 | 1,200 | 1,240 | 1,410 | 1,450 | 0.025 | 95 | 850 | 2,390 |
| 35 | 850 | 1,820 | 1,710 | 2,080 | 0.015 | 100 | 1,000 | 2,225 |
| 36 | 700 | 810 | 940 | 1,090 | 0.015 | 100 | 985 | 2,345 |
| 37 | 870 | 1,080 | 1,290 | 1,200 | 0.015 | 100 | 940 | 1,890 |
| 38 | 1,090 | 2,060 | 1,430 | 2,340 | 0.015 | 90 | 1,085 | 2,465 |
| 39 | 870 | 920 | 770 | 1,250 | 0.010 | 95 | 860 | 2,265 |
| 40 | 980 | 1,360 | 1,320 | 1,770 | 0.015 | 100 | 1,060 | 2,240 |
| 41 | 1,120 | 1,650 | 1,470 | 1,170 | 0.010 | 105 | 905 | 2,490 |
| 42 | 880 | 1,700 | 2,330 | 1,970 | 0.010 | 45 | 395 | 1,560 |
| Average | 855 | 1,269 | 1,467 | 1,424 | 0.015 | 94 | 806 | 1,975 |
| Standard deviation | 194 | 425 | 413 | 383 | | | | |
| 95% confidence interval | 392 | 860 | 835 | 775 | | | | |
| Upper 95% confidence limit | 1,247 | 2,129 | 2,302 | 2,199 | | | | |
| Lower 95% confidence limit | 463 | 409 | 632 | 649 | | | | |
| Plus 1 standard deviation | 1,049 | 1,694 | 1,880 | 1,807 | | | | |
| Minus 1 standard deviation | 661 | 844 | 1,054 | 1,041 | | | | |

Note: 95% confidence interval = standard deviation x 2.021.

Table 8. Results of Compression-Perpendicular-to-Grain Tests, Dry Timber

| Timber No. | Maximum Stress (psi) | | | | Testing Speed (in./min) | | | |
|---|---|---|---|---|---|---|---|---|
| | Static Speed | Dynamic Speed 2 | Dynamic Speed 3 | Dynamic Speed 4 | Static Speed | Dynamic Speed 2 | Dynamic Speed 3 | Dynamic Speed 4 |
| 1 | 1,060 | 940 | 1,060 | 1,470 | 0.017 | 105 | 930 | 2,710 |
| 2 | 1,610 | 1,130 | 890 | 1,260 | 0.022 | 95 | 930 | 2,065 |
| 3 | 1,390 | 960 | 1,050 | 1,630 | 0.027 | 92 | 960 | 2,520 |
| 4 | 1,650 | 1,640 | 1,640 | 1,940 | 0.036 | 105 | 830 | 2,675 |
| 5 | 1,350 | 1,200 | 860 | 1,070 | 0.024 | 94 | 840 | 2,930 |
| 6 | 1,380 | 890 | 1,460 | 1,390 | 0.024 | 85 | 830 | 2,500 |
| 7 | 1,460 | 1,610 | 1,620 | 1,670 | 0.017 | 105 | 840 | 2,415 |
| 8 | 1,110 | 1,020 | 1,460 | 1,250 | 0.019 | 87 | 805 | 2,730 |
| 9 | 1,710 | 810 | 1,170 | 2,320 | 0.019 | 85 | 815 | 2,860 |
| 10 | 1,950 | 1,980 | 2,090 | 1,560 | 0.024 | 96 | 750 | 2,690 |
| 11 | 1,150 | 1,660 | 1,840 | 1,070 | 0.022 | 75 | 745 | 3,030 |
| 12 | 1,300 | 1,270 | 910 | 1,240 | 0.024 | 95 | 835 | 2,270 |
| 13 | 1,170 | 1,050 | 1,120 | 1,820 | 0.022 | 95 | 900 | 2,600 |
| 14 | 1,010 | 1,350 | 1,150 | 1,530 | 0.034 | 110 | 920 | 2,085 |
| 15 | 1,880 | 1,500 | 1,400 | 1,700 | 0.017 | 90 | 915 | 2,725 |
| 16 | 1,140 | 1,000 | 1,030 | 1,580 | 0.029 | 95 | 915 | 2,270 |
| 18 | 980 | 640 | 1,410 | 950 | 0.014 | 100 | 785 | 2,960 |
| 19 | 1,290 | 1,070 | 1,150 | 1,810 | 0.027 | 90 | 890 | 2,740 |
| 20 | 1,220 | 630 | 840 | 1,250 | 0.029 | 90 | 815 | 2,810 |
| 21 | 1,150 | 710 | 750 | 1,480 | 0.029 | 90 | 900 | 2,650 |
| 22 | 1,380 | 690 | 1,210 | 1,030 | 0.017 | 105 | 840 | 2,870 |
| 23 | 1,190 | 920 | 940 | 1,370 | 0.022 | 90 | 830 | 2,740 |
| 24 | 1,230 | 930 | 1,170 | 1,830 | 0.024 | 95 | 830 | 2,510 |
| 25 | 1,290 | 940 | 1,110 | 2,220 | 0.024 | 95 | 905 | 3,200 |
| 26 | 1,190 | 820 | 1,410 | 1,150 | 0.014 | 95 | 830 | 2,540 |
| 27 | 1,190 | 1,800 | 1,570 | 2,250 | 0.022 | 90 | 875 | 2,450 |
| 28 | 1,020 | 800 | 1,050 | 1,040 | 0.012 | 90 | 860 | 2,670 |
| 29 | 1,280 | 2,060 | 1,230 | 1,320 | 0.024 | 80 | 875 | 2,590 |
| 30 | 1,270 | 1,570 | 1,370 | 1,190 | 0.031 | 85 | 890 | 2,550 |
| 31 | 2,000 | 1,790 | 1,560 | 1,780 | 0.027 | 90 | 820 | 2,710 |
| 32 | 1,480 | 1,590 | 1,270 | 2,250 | 0.033 | 90 | 910 | 2,565 |
| 33 | 1,990 | 1,990 | 1,470 | 2,400 | 0.022 | 85 | 895 | 2,740 |
| 34 | 1,350 | 1,760 | 1,500 | 2,090 | 0.029 | 85 | 880 | 2,365 |
| 35 | 2,020 | 2,040 | 2,460 | 1,650 | 0.017 | 85 | 815 | 2,750 |
| 36 | 900 | 780 | 870 | 1,010 | 0.017 | 100 | 920 | 2,995 |
| 37 | 1,030 | 690 | 1,670 | 1,240 | 0.031 | 90 | 873 | 2,150 |
| 38 | 2,100 | 1,110 | 1,500 | 1,450 | 0.019 | 80 | 815 | 2,600 |
| 39 | 950 | 1,020 | 1,000 | 1,220 | 0.022 | 90 | 810 | 2,530 |
| 40 | 1,490 | 1,440 | 1,870 | 1,220 | 0.034 | 85 | 875 | 2,840 |
| 41 | 1,420 | 1,490 | 1,000 | 1,960 | 0.017 | 85 | 850 | 2,990 |
| 42 | 1,580 | 1,700 | 960 | 2,420 | 0.029 | 85 | 825 | 2,480 |
| Average | 1,341 | 1,243 | 1,294 | 1,563 | 0.023 | 92 | 858 | 2,628 |
| Standard deviation | 430 | 436 | 365 | 423 | | | | |
| 95% confidence interval | 870 | 883 | 739 | 856 | | | | |
| Upper 95% confidence limit | 2,211 | 2,126 | 2,033 | 2,419 | | | | |
| Lower 95% confidence limit | 471 | 360 | 555 | 707 | | | | |
| Plus 1 standard deviation | 1,771 | 1,679 | 1,659 | 1,986 | | | | |
| Minus 1 standard deviation | 911 | 807 | 929 | 1,140 | | | | |

Note: 95% confidence interval = standard deviation x 2.021.

Table 9. Summary of Effects of Dynamic Loads on Green Specimens

| Test Designation | Static Speed | 1 in./min | % Diff. | 10 in./min | % Diff. | 100 in./min | % Diff. | 1,000 in./min | % Diff. | 1,500 in./min | D |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Shear** | | | | | | | | | | | |
| Average | | | | | | | | | | | |
| Maximum stress (psi) | 893 | 1,000 | +12 | 1,060 | +19 | 1,150 | +29 | 1,350 | +51 | – | |
| Minus 1 Standard Deviation | | | | | | | | | | | |
| Maximum stress (psi) | 789 | 900 | +14 | 960 | +22 | 1,040 | +32 | 1,210 | +53 | – | |
| Lower 95% Confidence Limit | | | | | | | | | | | |
| Maximum stress (psi) | 683 | 800 | +17 | 860 | +26 | 930 | +36 | 1,040 | +52 | – | |
| **Bending** | | | | | | | | | | | |
| Average | | | | | | | | | | | |
| Proportional limit (psi) | 3,276 | 3,630 | +11 | 3,990 | +22 | 4,450 | +36 | 5,350 | +63 | – | |
| Modulus of elasticity (psi x $10^6$) | 1.73 | 1.73 | 0 | 1.73 | 0 | 1.74 | + 1 | 1.77 | + 2 | – | |
| Modulus of rupture (psi) | 7,066 | 7,650 | + 8 | 8,320 | +18 | 9,180 | +30 | 9,990 | +41 | – | |
| Minus 1 Standard Deviation | | | | | | | | | | | |
| Proportional limit (psi) | 2,539 | 2,830 | +11 | 3,210 | +26 | 3,650 | +44 | 4,400 | +73 | – | |
| Modulus of elasticity (psi x $10^6$) | 1.36 | 1.35 | – 1 | 1.34 | – 2 | 1.34 | – 2 | 1.35 | – 1 | – | |
| Modulus of rupture (psi) | 5,992 | 6,500 | + 9 | 7,100 | +19 | 7,800 | +30 | 8,600 | +44 | – | |
| Lower 95% Confidence Limit | | | | | | | | | | | |
| Proportional limit (psi) | 1,786 | 2,120 | +19 | 2,460 | +38 | 2,860 | +60 | 3,480 | +95 | – | |
| Modulus of elasticity (psi x $10^6$) | 0.98 | 0.96 | – 2 | 0.94 | – 4 | 0.94 | – 4 | 0.93 | – 5 | – | |
| Modulus of rupture (psi) | 4,894 | 5,300 | + 8 | 5,810 | +19 | 6,420 | +31 | 7,210 | +47 | – | |
| **Compression Parallel** | | | | | | | | | | | |
| Average | | | | | | | | | | | |
| Modulus of elasticity (psi x $10^6$) | 1.92 | 1.95 | + 2 | 1.98 | + 3 | 2.02 | + 5 | 2.58 | +34 | 3.05 | |
| Maximum stress (psi) | 3,796 | 4,130 | + 9 | 4,480 | +18 | 4,920 | +30 | 5,780 | +52 | 6,100 | |
| Minus 1 Standard Deviation | | | | | | | | | | | |
| Modulus of elasticity (psi x $10^6$) | 1.49 | 1.55 | + 4 | 1.59 | + 7 | 1.63 | + 9 | 1.95 | +31 | 2.17 | |
| Maximum stress (psi) | 3,100 | 3,460 | +11 | 3,760 | +21 | 4,170 | +35 | 4,850 | +56 | 5,100 | |
| Lower 95% Confidence Limit | | | | | | | | | | | |
| Modulus of elasticity (psi x $10^6$) | 1.05 | 1.14 | + 9 | 1.19 | +13 | 1.25 | +19 | 1.32 | +26 | 1.34 | |
| Maximum stress (psi) | 2,388 | 2,700 | +13 | 3,000 | +26 | 3,360 | +41 | 3,940 | +65 | 4,160 | |
| **Compression Perpendicular** | | | | | | | | | | | |
| Average | | | | | | | | | | | |
| Maximum stress (psi) | 855 | 1,010 | +18 | 1,130 | +32 | 1,270 | +49 | 1,470 | +72 | – | |
| Minus 1 Standard Deviation | | | | | | | | | | | |
| Maximum stress (psi) | 661 | 720 | + 9 | 755 | +14 | 850 | +29 | 1,060 | +60 | – | |
| Lower 95% Confidence Limit | | | | | | | | | | | |
| Maximum stress (psi) | 463 | 420 | – 9 | 405 | –12 | 405 | –12 | 635 | +37 | – | |

Note: Percent difference is calculated from the value at static speed in all cases.

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Table 9. Summary of Effects of Dynamic Loads on Green Specimens

| | Static Speed | 1 in./min | % Diff | 10 in./min | % Diff. | 100 in./min | % Diff | 1,000 in./min | % Diff | 1,500 in./min | % Diff. | 2,000 in./min | % Diff. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 893 | 1,000 | +12 | 1,060 | +19 | 1,150 | +29 | 1,350 | +51 | – | – | 1,520 | +70 |
| on | | | | | | | | | | | | | |
| | 789 | 900 | +14 | 960 | +22 | 1,040 | +32 | 1,210 | +53 | – | – | 1,280 | +62 |
| imit | | | | | | | | | | | | | |
| | 683 | 800 | +17 | 860 | +26 | 930 | +36 | 1,040 | +52 | – | – | 1,050 | +54 |
| i) | 3,276 | 3,630 | +11 | 3,990 | +22 | 4,450 | +36 | 5,350 | +63 | – | – | 5,930 | +81 |
| (psi x $10^6$) | 1.73 | 1.73 | 0 | 1.73 | 0 | 1.74 | + 1 | 1.77 | + 2 | – | – | 1.60 | – 8 |
| si) | 7,066 | 7,650 | + 8 | 8,320 | +18 | 9,180 | +30 | 9,990 | +41 | – | – | 10,170 | +44 |
| on | | | | | | | | | | | | | |
| i) | 2,539 | 2,830 | +11 | 3,210 | +26 | 3,650 | +44 | 4,400 | +73 | – | – | 4,920 | +94 |
| (psi x $10^6$) | 1.36 | 1.35 | – 1 | 1.34 | – 2 | 1.34 | – 2 | 1.35 | – 1 | – | – | 1.14 | –16 |
| si) | 5,992 | 6,500 | + 9 | 7,100 | +19 | 7,800 | +30 | 8,600 | +44 | – | – | 8,870 | +48 |
| imit | | | | | | | | | | | | | |
| i) | 1,786 | 2,120 | +19 | 2,460 | +38 | 2,860 | +60 | 3,480 | +95 | – | – | 3,890 | +118 |
| (psi x $10^6$) | 0.98 | 0.96 | – 2 | 0.94 | – 4 | 0.94 | – 4 | 0.93 | – 5 | – | – | 0.66 | –33 |
| si) | 4,894 | 5,300 | + 8 | 5,810 | +19 | 6,420 | +31 | 7,210 | +47 | – | – | 7,530 | +54 |
| (psi x $10^6$) | 1.92 | 1.95 | + 2 | 1.98 | + 3 | 2.02 | + 5 | 2.58 | +34 | 3.05 | +59 | – | – |
| | 3,796 | 4,130 | + 9 | 4,480 | +18 | 4,920 | +30 | 5,780 | +52 | 6,100 | +61 | – | – |
| on | | | | | | | | | | | | | |
| (psi x $10^6$) | 1.49 | 1.55 | + 4 | 1.59 | + 7 | 1.63 | + 9 | 1.95 | +31 | 2.17 | +46 | – | – |
| | 3,100 | 3,460 | +11 | 3,760 | +21 | 4,170 | +35 | 4,850 | +56 | 5,100 | +64 | – | – |
| imit | | | | | | | | | | | | | |
| (psi x $10^6$) | 1.05 | 1.14 | + 9 | 1.19 | +13 | 1.25 | +19 | 1.32 | +26 | 1.34 | +28 | – | – |
| | 2,388 | 2,700 | +13 | 3,000 | +26 | 3,360 | +41 | 3,940 | +65 | 4,160 | +74 | – | – |
| | 855 | 1,010 | +18 | 1,130 | +32 | 1,270 | +49 | 1,470 | +72 | – | – | 1,445 | +69 |
| on | | | | | | | | | | | | | |
| | 661 | 720 | + 9 | 755 | +14 | 850 | +29 | 1,060 | +60 | – | – | 1,035 | +56 |
| imit | | | | | | | | | | | | | |
| | 463 | 420 | – 9 | 405 | –12 | 405 | –12 | 635 | +37 | – | – | 650 | +40 |

alculated from the value at static speed in all cases.

Table 10. Summary of Effects of Dynamic Loads on Dry Specimens

| Test Designation | Static Speed | 1 in./min | % Diff. | 10 in./min | % Diff. | 100 in./min | % Diff. | 1,000 in./min | % Diff. | 1,500 in./min | % Diff. | 2,000 in./min | % Diff. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Shear** | | | | | | | | | | | | | |
| Average | | | | | | | | | | | | | |
| Maximum stress (psi) | 1,380 | 1,520 | +10 | 1,610 | +17 | 1,710 | +24 | 1,920 | +39 | – | – | 2,340 | +70 |
| Minus 1 Standard Deviation | | | | | | | | | | | | | |
| Maximum stress (psi) | 1,196 | 1,290 | + 8 | 1,370 | +15 | 1,470 | +23 | 1,660 | +39 | – | – | 1,900 | +59 |
| Lower 95% Confidence Limit | | | | | | | | | | | | | |
| Maximum stress (psi) | 1,008 | 1,070 | + 6 | 1,120 | +11 | 1,210 | +20 | 1,410 | +40 | – | – | 1,450 | +44 |
| **Bending** | | | | | | | | | | | | | |
| Average | | | | | | | | | | | | | |
| Modulus of elasticity (psi x $10^6$) | 1.98 | 2.02 | + 2 | 2.06 | + 4 | 1.99 | + 1 | 1.23 | -38 | – | – | 1.33 | -33 |
| Modulus of rupture (psi) | 12,941 | 13,690 | + 6 | 14,400 | +11 | 13,880 | + 7 | 9,540 | -26 | – | – | 9,520 | -26 |
| Minus 1 Standard Deviation | | | | | | | | | | | | | |
| Modulus of elasticity (psi x $10^6$) | 1.62 | 1.64 | + 1 | 1.66 | + 2 | 1.59 | - 2 | 1.02 | -37 | – | – | 1.07 | -34 |
| Modulus of rupture (psi) | 11,182 | 11,730 | + 5 | 12,200 | + 9 | 11,790 | + 5 | 7,890 | -29 | – | – | 7,860 | -30 |
| Lower 95% Confidence Limit | | | | | | | | | | | | | |
| Modulus of elasticity (psi x $10^6$) | 1.25 | 1.26 | + 1 | 1.26 | + 1 | 1.19 | - 5 | 0.82 | -34 | – | – | 0.81 | -35 |
| Modulus of rupture (psi) | 9,386 | 9,620 | + 3 | 9,890 | + 5 | 9,280 | - 1 | 6,200 | -34 | – | – | 6,200 | -34 |
| **Compression Parallel** | | | | | | | | | | | | | |
| Average | | | | | | | | | | | | | |
| Modulus of elasticity (psi x $10^6$) | 1.97 | 2.06 | + 5 | 2.13 | + 8 | 2.23 | +13 | 2.72 | +38 | 3.02 | +53 | – | – |
| Maximum stress (psi) | 7,264 | 7,960 | +10 | 8,500 | +17 | 9,190 | +26 | 10,580 | +46 | 11,400 | +57 | – | – |
| Minus 1 Standard Deviation | | | | | | | | | | | | | |
| Modulus of elasticity (psi x $10^6$) | 1.41 | 1.49 | + 6 | 1.55 | +10 | 1.68 | +19 | 2.13 | +51 | 2.33 | +65 | – | – |
| Maximum stress (psi) | 6,035 | 6,620 | +10 | 7,130 | +18 | 7,800 | +29 | 9,200 | +53 | 10,000 | +66 | – | – |
| Lower 95% Confidence Limit | | | | | | | | | | | | | |
| Modulus of elasticity (psi x $10^6$) | 0.84 | 0.91 | + 8 | 0.96 | +14 | 1.14 | +36 | 1.55 | +85 | 1.58 | +88 | – | – |
| Maximum stress (psi) | 4,779 | 5,380 | +12 | 5,820 | +22 | 6,430 | +35 | 7,820 | +64 | 8,630 | +80 | – | – |
| **Compression Perpendicular** | | | | | | | | | | | | | |
| Average | | | | | | | | | | | | | |
| Maximum stress (psi) | 1,341 | 1,341 | 0 | 1,320 | - 2 | 1,240 | - 8 | 1,325 | - 1 | – | – | 1,490 | +11 |
| Minus 1 Standard Deviation | | | | | | | | | | | | | |
| Maximum stress (psi) | 911 | 890 | - 2 | 870 | - 4 | 805 | -12 | 955 | + 5 | – | – | 1,085 | +19 |
| Lower 95% Confidence Limit | | | | | | | | | | | | | |
| Maximum stress (psi) | 471 | 445 | - 5 | 430 | - 9 | 365 | -22 | 575 | +22 | – | – | 670 | +42 |

Note: Percent difference is calculated from the value at static speed in all cases.

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Table 11. Comparisons of Test Results on Green and Dry Specimens

| Test Designation | Static Speed | | 1 in./min | | 10 in./min | | 100 in./min | | 1,000 in./min | | 1,500 in./min | | 2,000 in./min | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Green | Dry | Green | Dry | Green | Dry | Green | Dry | Green | Dry | Green | Dry | Green | Dry |
| **Shear** | | | | | | | | | | | | | | |
| Average | | | | | | | | | | | | | | |
| Maximum stress (psi) | 893 | 1,380 | 1,000 | 1,520 | 1,060 | 1,610 | 1,150 | 1,710 | 1,350 | 1,920 | – | – | 1,520 | 2,340 |
| Minus 1 Standard Deviation | | | | | | | | | | | | | | |
| Maximum stress (psi) | 789 | 1,196 | 900 | 1,290 | 960 | 1,370 | 1,040 | 1,470 | 1,210 | 1,660 | – | – | 1,280 | 1,900 |
| Lower 95% Confidence Limit | | | | | | | | | | | | | | |
| Maximum stress (psi) | 683 | 1,008 | 800 | 1,070 | 860 | 1,120 | 930 | 1,210 | 1,040 | 1,410 | – | – | 1,050 | 1,450 |
| **Bending** | | | | | | | | | | | | | | |
| Average | | | | | | | | | | | | | | |
| Modulus of elasticity (psi x $10^6$) | 1.73 | 1.98 | 1.73 | 2.02 | 1.73 | 2.06 | 1.74 | 1.99 | 1.77 | 1.23 | – | – | 1.60 | 1.33 |
| Modulus of rupture (psi) | 7,066 | 12,941 | 7,650 | 13,690 | 8,320 | 14,400 | 9,180 | 13,880 | 9,990 | 9,540 | – | – | 10,170 | 9,520 |
| Minus 1 Standard Deviation | | | | | | | | | | | | | | |
| Modulus of elasticity (psi x $10^6$) | 1.36 | 1.62 | 1.35 | 1.64 | 1.34 | 1.66 | 1.34 | 1.59 | 1.35 | 1.02 | – | – | 1.14 | 1.07 |
| Modulus of rupture (psi) | 5,992 | 11,182 | 6,500 | 11,730 | 7,100 | 12,200 | 7,800 | 11,790 | 8,600 | 7,890 | – | – | 8,870 | 7,860 |
| Lower 95% Confidence Limit | | | | | | | | | | | | | | |
| Modulus of elasticity (psi x $10^6$) | 0.98 | 1.25 | 0.96 | 1.26 | 0.94 | 1.26 | 0.94 | 1.19 | 0.93 | 0.82 | – | – | 0.66 | 0.81 |
| Modulus of rupture (psi) | 4,894 | 9,386 | 5,300 | 9,620 | 5,810 | 9,890 | 6,420 | 9,280 | 7,210 | 6,200 | – | – | 7,530 | 6,200 |
| **Compression Parallel** | | | | | | | | | | | | | | |
| Average | | | | | | | | | | | | | | |
| Modulus of elasticity (psi x $10^6$) | 1.92 | 1.97 | 1.95 | 2.06 | 1.98 | 2.13 | 2.02 | 2.23 | 2.58 | 2.72 | 3.05 | 3.02 | – | – |
| Maximum stress (psi) | 3,796 | 7,264 | 4,130 | 7,960 | 4,480 | 8,500 | 4,920 | 9,190 | 5,780 | 10,580 | 6,100 | 11,400 | – | – |
| Minus 1 Standard Deviation | | | | | | | | | | | | | | |
| Modulus of elasticity (psi x $10^6$) | 1.49 | 1.41 | 1.55 | 1.49 | 1.59 | 1.55 | 1.63 | 1.68 | 1.95 | 2.13 | 2.17 | 2.33 | – | – |
| Maximum stress (psi) | 3,100 | 6,035 | 3,460 | 6,620 | 3,760 | 7,130 | 4,170 | 7,800 | 4,850 | 9,200 | 5,100 | 10,000 | – | – |
| Lower 95% Confidence Limit | | | | | | | | | | | | | | |
| Modulus of elasticity (psi x $10^6$) | 1.05 | 0.84 | 1.14 | 0.91 | 1.19 | 0.96 | 1.25 | 1.14 | 1.32 | 1.55 | 1.34 | 1.58 | – | – |
| Maximum stress (psi) | 2,388 | 4,779 | 2,700 | 5,380 | 3,000 | 5,820 | 3,360 | 6,430 | 3,940 | 7,820 | 4,160 | 8,630 | – | – |
| **Compression Perpendicular** | | | | | | | | | | | | | | |
| Average | | | | | | | | | | | | | | |
| Maximum stress (psi) | 855 | 1,341 | 1,010 | 1,341 | 1,130 | 1,320 | 1,270 | 1,240 | 1,470 | 1,325 | – | – | 1,445 | 1,490 |
| Minus 1 Standard Deviation | | | | | | | | | | | | | | |
| Maximum stress (psi) | 661 | 911 | 720 | 890 | 755 | 870 | 850 | 805 | 1,060 | 955 | – | – | 1,035 | 1,085 |
| Lower 95% Confidence Limit | | | | | | | | | | | | | | |
| Maximum stress (psi) | 463 | 471 | 420 | 445 | 405 | 430 | 405 | 365 | 635 | 575 | – | – | 650 | 670 |

Table 12. Beam Deflections at Modulus of Rupture, Green and Dry Specimens

(Deflections are in inches.)

| Timber No. | Static Speed | | Dynamic Speed 2 | | Dynamic Speed 3 | | Dynamic Speed 4 | |
|---|---|---|---|---|---|---|---|---|
| | Green | Dry | Green | Dry | Green | Dry | Green | Dry |
| 1 | 0.768 | 0.675 | 0.640 | 0.527 | 0.775 | 0.475 | 0.703 | 0.554 |
| 2 | 0.768 | 0.487 | 0.858 | 0.620 | 0.778 | 0.520 | 0.744 | 0.477 |
| 3 | 0.790 | 0.695 | 1.065 | 0.721 | 0.788 | 0.560 | 0.885 | 0.599 |
| 4 | 0.727 | 0.720 | 0.610 | 0.743 | 0.780 | 0.823 | 0.875 | 0.734 |
| 5 | 1.007 | 0.692 | 0.707 | 0.613 | 0.777 | 0.626 | 0.925 | 0.528 |
| 6 | 0.703 | 0.762 | 0.695 | 0.826 | 0.810 | 0.709 | 1.015 | 0.580 |
| 7 | 0.550 | 0.621 | 0.743 | 0.586 | 0.500 | 0.693 | 0.717 | 0.524 |
| 8 | 0.727 | 0.555 | 0.817 | 0.658 | 0.743 | 0.636 | 0.812 | 0.684 |
| 9 | 0.681 | 0.746 | 0.461 | 0.874 | 0.698 | 0.704 | 0.691 | 0.728 |
| 10 | 0.646 | 0.575 | 0.627 | 0.595 | 0.727 | 0.751 | 0.596 | 0.623 |
| 11 | 0.637 | 0.530 | 0.600 | 0.679 | 0.800 | 0.671 | 0.960 | 0.587 |
| 12 | 0.628 | 0.597 | 0.778 | 0.724 | 0.881 | 0.644 | 0.805 | 0.660 |
| 13 | 0.713 | 0.858 | 0.868 | 0.698 | 0.805 | 0.706 | 0.755 | 0.740 |
| 14 | 0.740 | 0.756 | 0.746 | 0.557 | 0.795 | 0.490 | 0.760 | 0.557 |
| 15 | 0.639 | 0.527 | 0.715 | 0.671 | 0.806 | 0.749 | 0.574 | 0.675 |
| 16 | 0.621 | 0.585 | 0.813 | 0.716 | 0.660 | 0.676 | 0.813 | 0.680 |
| 18 | – | – | 0.700 | 0.610 | 0.750 | 0.897 | 0.750 | 0.627 |
| 19 | 0.721 | 0.685 | 0.887 | 0.679 | 0.725 | 0.698 | 0.875 | 0.678 |
| 20 | 0.675 | 0.742 | 0.584 | 0.600 | 0.610 | 0.544 | 0.721 | 0.603 |
| 21 | 0.641 | 0.775 | 0.771 | 0.560 | 0.800 | 0.576 | 0.708 | 0.619 |
| 22 | 0.708 | 0.490 | 0.725 | 0.622 | 0.741 | 0.714 | 0.809 | 0.625 |
| 23 | 0.761 | 0.770 | 0.920 | 0.541 | 0.817 | 0.702 | 1.353 | 0.524 |
| 24 | 0.675 | 0.669 | 0.975 | 0.713 | 1.010 | 0.643 | 0.887 | 0.638 |
| 25 | 0.849 | 0.779 | 0.748 | 0.621 | 0.875 | 0.619 | 0.650 | 0.698 |
| 26 | 0.567 | 0.781 | 0.772 | 0.649 | 0.642 | 0.848 | 0.690 | 0.645 |
| 27 | 0.728 | 0.710 | 0.700 | 0.649 | 0.625 | 0.668 | 0.716 | 0.480 |
| 28 | 0.533 | 0.751 | 0.572 | 0.686 | 0.688 | 0.613 | 0.741 | 0.758 |
| 29 | 0.700 | 0.896 | 0.774 | 0.804 | 0.797 | 0.468 | 0.729 | 0.625 |
| 30 | 0.897 | 0.838 | 0.794 | 0.590 | 0.630 | 0.688 | – | – |
| 31 | – | – | – | – | – | – | – | – |
| 32 | 0.517 | 0.464 | 0.660 | 0.564 | 0.562 | 0.732 | 0.758 | 0.720 |
| 33 | 0.550 | 0.807 | 0.650 | 0.542 | 0.658 | 0.666 | 0.800 | 0.770 |
| 34 | 0.705 | 0.708 | 0.672 | 0.555 | 0.585 | 0.568 | 0.766 | 0.668 |
| 35 | 0.907 | 0.739 | 0.800 | 0.750 | 0.838 | 0.794 | 0.850 | 0.608 |
| 36 | 0.791 | 0.605 | 0.715 | 0.602 | 0.860 | 0.629 | 0.800 | 0.437 |
| 37 | 0.460 | 0.612 | 0.678 | 0.571 | 0.720 | 0.653 | 0.667 | 0.689 |
| 38 | 0.740 | 0.760 | 0.688 | 0.621 | 0.714 | 0.554 | 0.589 | 0.628 |
| 39 | 0.655 | 0.671 | 0.875 | 0.706 | 0.750 | 0.624 | 0.675 | 0.664 |
| 40 | 0.747 | 0.726 | 0.894 | 0.680 | 0.851 | 0.553 | 0.717 | 0.546 |
| 41 | 0.525 | 0.756 | 0.890 | 0.839 | 0.820 | 0.794 | 0.930 | 0.671 |
| 42 | 0.840 | 0.738 | 0.895 | 0.854 | 0.880 | 0.662 | 1.099 | 0.811 |
| Average | 0.698 | 0.688 | 0.752 | 0.662 | 0.752 | 0.658 | 0.792 | 0.632 |

## Appendix

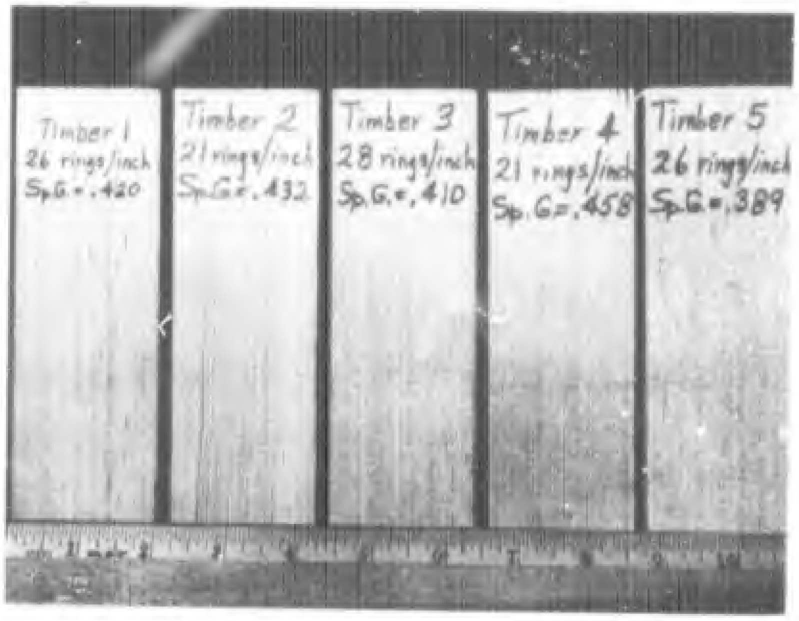
## PERTINENT FACTORS CONCERNING THE TIMBERS

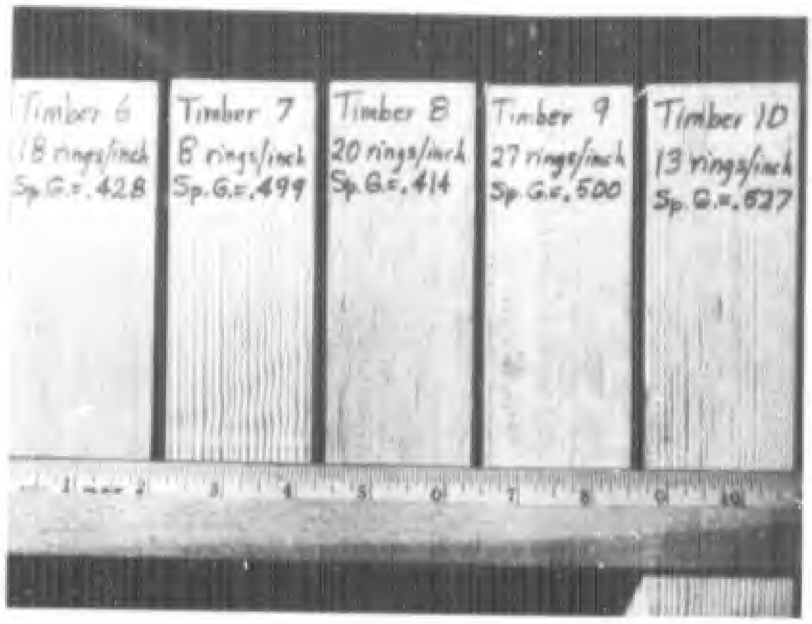
The lumber mills from which the timbers were selected are listed in Table 13, together with the number designations for the timbers furnished by each mill.

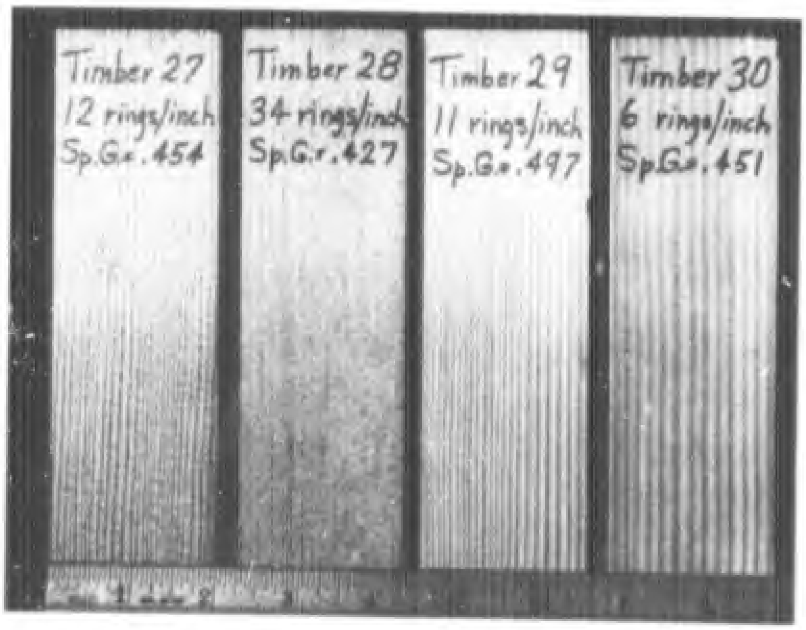
By intent, the timbers were selected to meet or exceed the specification for structural grade, as summarized in standard grading rules.[8] The timbers closely conformed to a grading equivalent to that of dense select structural, based on the number of growth rings per inch, a listing of which is presented, along with other supplementary data, in Table 14. Pictures of sticks typical of each timber are shown in Figure 20. The moisture contents of the green timbers were safely above the fiber saturation value of about 25% for Douglas fir. The overall average moisture content of the green timbers was about 46%. Moisture contents of dry timbers were quite consistent and averaged about 11%. The average specific gravity for each timber (Table 14) indicates, for the most part, rather dense material.

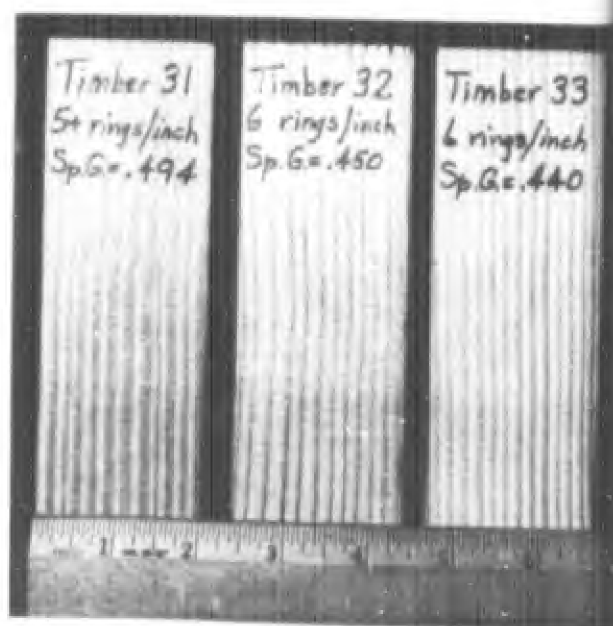
**Table 13. Lumber Mill Sources for Timbers**

| Lumber Mill | Timber No. |
|---|---|
| Rock Lumber Company<br>Sandy, Oregon | 1, 2, 3, 4, 5 |
| Willamette Valley Lumber Company<br>Dallas, Oregon | 6, 7, 8, 9, 10, 11, 12, 13, 14, 15 |
| Pope and Talbot Lumber Company<br>Oakridge, Oregon | 16, 18, 19, 20, 21, 22 |
| Spaulding Lumber Company<br>Grants Pass, Oregon | 23, 24, 25, 26, 27, 28, 37, 38 |
| W. O. W. Lumber Company<br>Eddyville, Oregon | 29, 30, 31, 32, 33, 34, 35, 36 |
| Santiam Lumber Company<br>Sweet Home, Oregon | 39, 40, 41, 42 |


Timber 1
26 rings/inch
Sp.G. = .420
Timber 2
21 rings/inch
Sp.G. = .432
Timber 3
28 rings/inch
Sp.G. = .410
Timber 4
21 rings/inch
Sp.G. = .458
Timber 5
26 rings/inch
Sp.G. = .389


Timber 6
18 rings/inch
Sp.G. = .428
Timber 7
8 rings/inch
Sp.G. = .499
Timber 8
20 rings/inch
Sp.G. = .414
Timber 9
27 rings/inch
Sp.G. = .500
Timber 10
13 rings/inch
Sp.G. = .527


Timber 27
12 rings/inch
Sp.G. = .454
Timber 28
34 rings/inch
Sp.G. = .427
Timber 29
11 rings/inch
Sp.G. = .497
Timber 30
6 rings/inch
Sp.G. = .451


Timber 31
5+ rings/inch
Sp.G. = .494
Timber 32
6 rings/inch
Sp.G. = .450
Timber 33
6 rings/inch
Sp.G. = .440

Figu

A

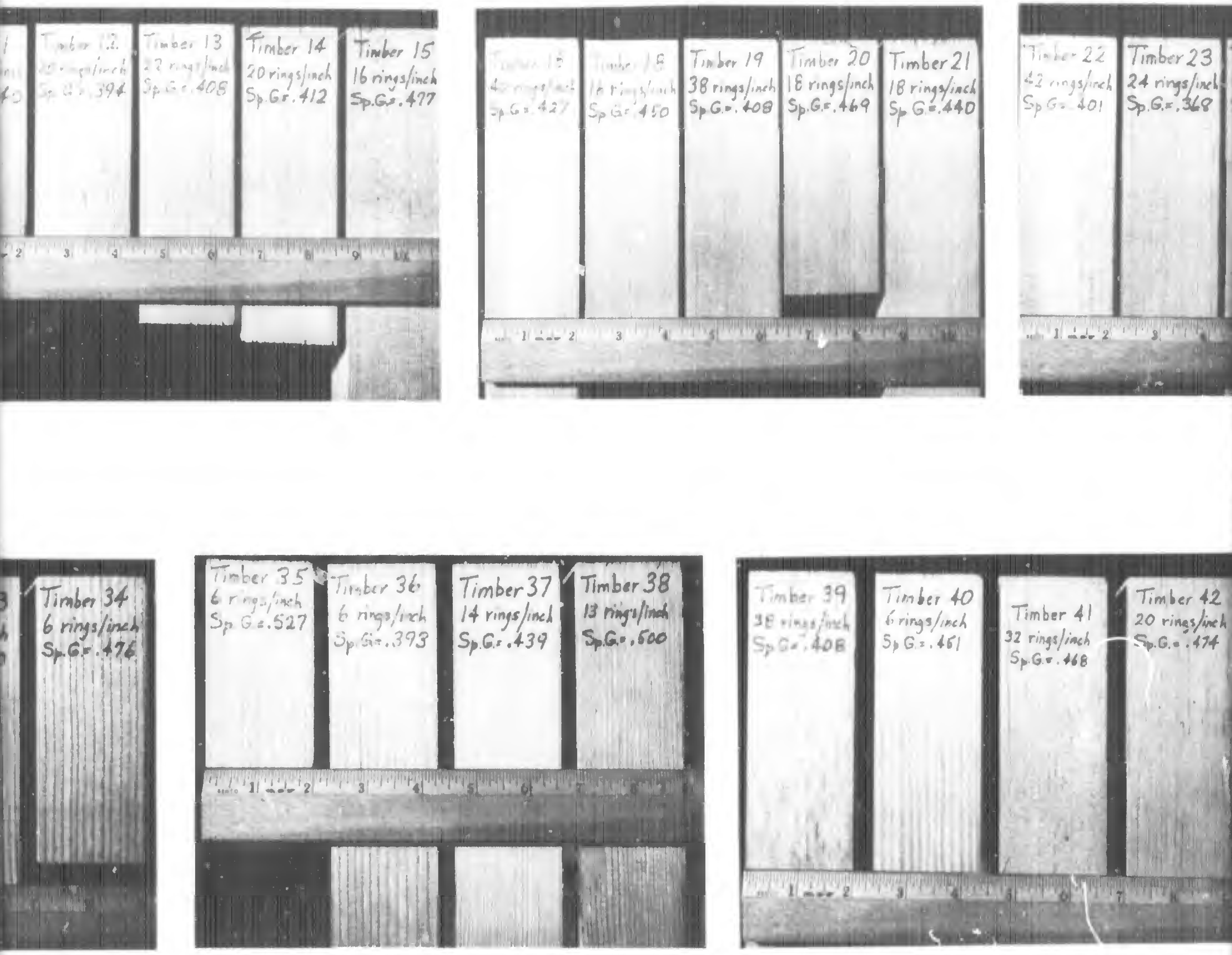
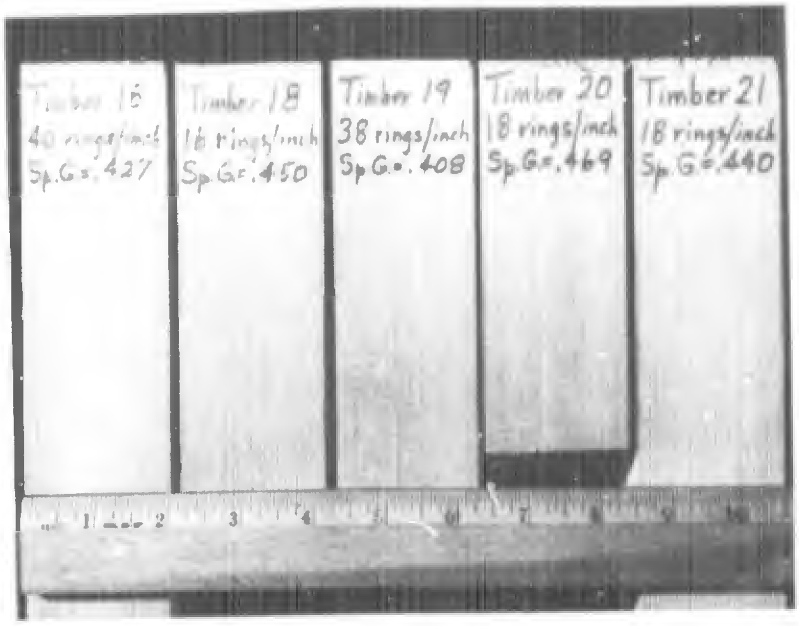
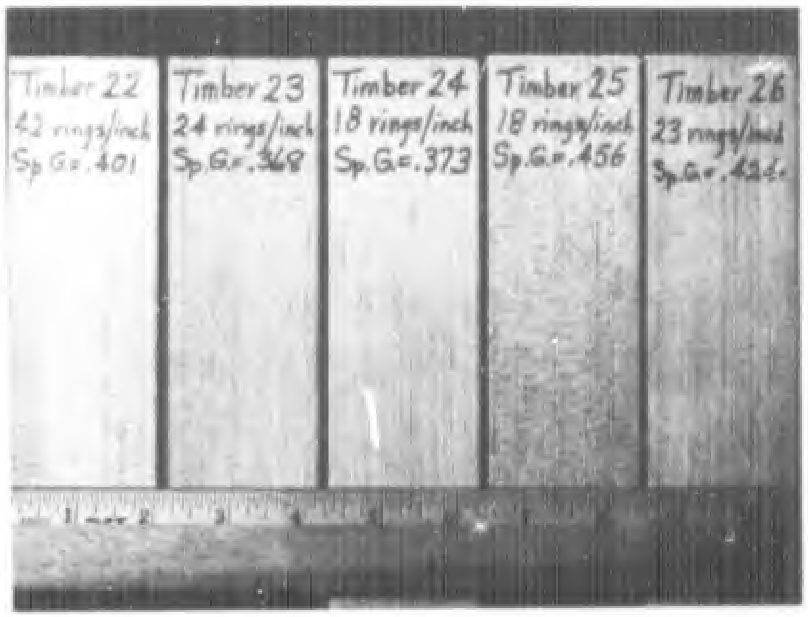


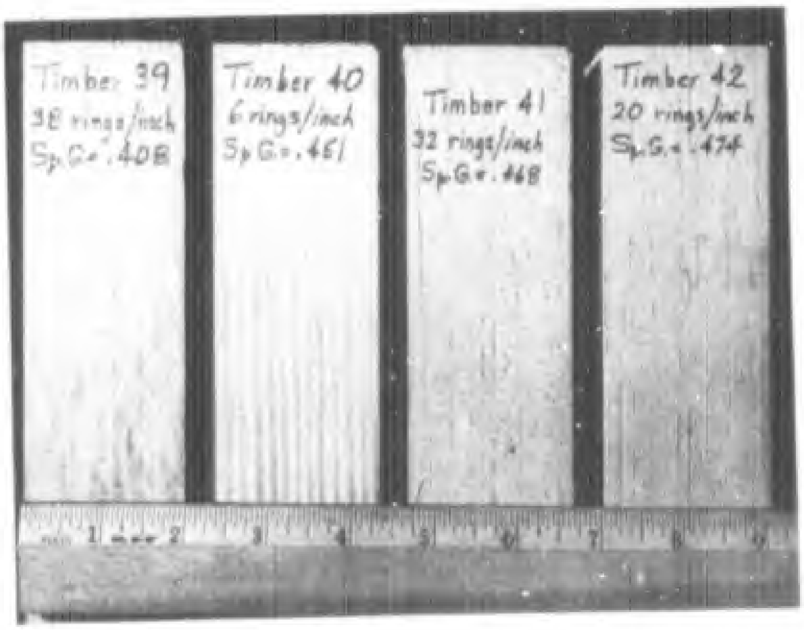

Figure 20. Sticks typical of each of the timbers.

B


40 rings/inch
Sp.G.=.427
Timber 18
16 rings/inch
Sp.G.=.450
Timber 19
38 rings/inch
Sp.G.=.408
Timber 20
18 rings/inch
Sp.G.=.469
Timber 21
18 rings/inch
Sp.G.=.440


Timber 22
42 rings/inch
Sp.G.=.401
Timber 23
24 rings/inch
Sp.G.=.368
Timber 24
18 rings/inch
Sp.G.=.373
Timber 25
18 rings/inch
Sp.G.=.456
Timber 26
23 rings/inch
Sp.G.=.424


Timber 37
14 rings/inch
Sp.G.=.439
Timber 38
13 rings/inch
Sp.G.=.500


Timber 39
38 rings/inch
Sp.G.=.408
Timber 40
6 rings/inch
Sp.G.=.461
Timber 41
32 rings/inch
Sp.G.=.468
Timber 42
20 rings/inch
Sp.G.=.474

B

C

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Table 14. Supplementary Data on Individual Timbers

| Timber No. | Average Moisture Content (%) | | Average Specific Gravity | Growth Rings Per Inch |
|---|---|---|---|---|
| | Green | Dry | | |
| 1 | 34 | 11 | 0.43 | 26 |
| 2 | 45 | 11 | 0.43 | 21 |
| 3 | 49 | 11 | 0.41 | 28 |
| 4 | 37 | 12 | 0.46 | 21 |
| 5 | 83 | 11 | 0.39 | 26 |
| 6 | 48 | 11 | 0.43 | 18 |
| 7 | 51 | 12 | 0.50 | 8 |
| 8 | 36 | 11 | 0.41 | 20 |
| 9 | 35 | 12 | 0.50 | 27 |
| 10 | 31 | 11 | 0.53 | 13 |
| 11 | 43 | 12 | 0.54 | 18 |
| 12 | 60 | 11 | 0.39 | 20 |
| 13 | 47 | 11 | 0.41 | 22 |
| 14 | 51 | 11 | 0.41 | 20 |
| 15 | 43 | 11 | 0.48 | 16 |
| 16 | 42 | 11 | 0.43 | 40 |
| 18 | 48 | 11 | 0.45 | 16 |
| 19 | 47 | 11 | 0.41 | 38 |
| 20 | 33 | 11 | 0.47 | 18 |
| 21 | 49 | 11 | 0.44 | 18 |
| 22 | 44 | 11 | 0.40 | 42 |
| 23 | 50 | 11 | 0.37 | 24 |
| 24 | 44 | 11 | 0.37 | 18 |
| 25 | 54 | 11 | 0.46 | 18 |
| 26 | 44 | 11 | 0.42 | 23 |
| 27 | 49 | 11 | 0.45 | 12 |
| 28 | 35 | 11 | 0.43 | 34 |
| 29 | 41 | 12 | 0.50 | 11 |
| 30 | 45 | 11 | 0.45 | 6 1/ |
| 31 | 51 | 11 | 0.49 | 6 1/ |
| 32 | 64 | 11 | 0.45 | 5 1/ |
| 33 | 58 | 11 | 0.44 | 6 1/ |
| 34 | 40 | 11 | 0.48 | 6 1/ |
| 35 | 42 | 12 | 0.53 | 6 1/ |
| 36 | 41 | 11 | 0.39 | 6 1/ |
| 37 | 44 | 11 | 0.44 | 14 |
| 38 | 42 | 11 | 0.50 | 13 |
| 39 | 48 | 10 | 0.41 | 38 |
| 40 | 54 | 11 | 0.45 | 6 1/ |
| 41 | 47 | 11 | 0.47 | 32 |
| 42 | 43 | 11 | 0.47 | 20 |

1/ Thick summerwood.

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13. ABSTRACT

About 300 static and 1,100 dynamic tests were made on small, clear specimens of Douglas fir (coast type). Green specimens and dry specimens were tested in shear parallel to the grain, bending, compression parallel to the grain, and compression perpendicular to the grain. Green specimens showed increases in dynamic strength values over static strength values, with the exception of modulus of elasticity in bending. Dry specimens showed increases in dynamic strengths over static strengths in shear, compression parallel to the grain, and compression perpendicular to the grain. In bending, the strength of dry specimens was drastically reduced at the higher rates of dynamic loading. In bending tests on green specimens, the modulus of rupture at speeds (or strain rates) corresponding to impact and blast loading was a maximum of 54% greater than the MOR at static speeds. On the basis of these results, it was concluded that conventional increased strength allowances for impact loading are excessive by as much as 46%.

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| Douglas fir timber | | | | | | |
| Green and dry | | | | | | |
| Structural grade | | | | | | |
| Dynamic tests | | | | | | |
| Shear parallel to grain | | | | | | |
| Bending | | | | | | |
| Compression parallel to grain | | | | | | |
| Compression perpendicular to grain | | | | | | |

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Y-F011-05-04-003
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25 October 1968

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Ocean W. Chandley

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**R 573**

Technical Report

# DYNAMIC PROPERTIES OF SMALL, CLEAR SPECIMENS OF STRUCTURAL-GRADE TIMBER

April 1968

NAVAL FACILITIES ENGINEERING COMMAND

NAVAL CIVIL ENGINEERING LABORATORY

Port Hueneme, California

**DYNAMIC PROPERTIES OF SMALL, CLEAR SPECIMENS OF STRUCTURAL-GRADE TIMBER**

Technical Report R-573

Y-F011-05-04-003

by

John R. Keeton

## ABSTRACT

About 300 static and 1,100 dynamic tests were made on small, clear specimens of Douglas fir (coast type). Green specimens and dry specimens were tested in shear parallel to the grain, bending, compression parallel to the grain, and compression perpendicular to the grain. Green specimens showed increases in dynamic strength values over static strength values, with the exception of modulus of elasticity in bending. Dry specimens showed increases in dynamic strengths over static strengths in shear, compression parallel to the grain, and compression perpendicular to the grain. In bending, the strength of dry specimens was drastically reduced at the higher rates of dynamic loading. In bending tests on green specimens, the modulus of rupture at speeds (or strain rates) corresponding to impact loading was a maximum of 102% greater than allowable working stress at static speeds, thus verifying the current overallowance. At speeds corresponding to blast loads, modulus of rupture was a maximum of 130% greater than allowable working stress at static speeds.

## INTRODUCTION

Considerable attention has been given in recent years to the resistance of structural materials to loads simulating those imposed by atomic blasts. Original experiments involved field tests of full-scale structures and structural elements subjected to loads imposed by actual atomic blasts. Subsequently, most research testing was moved to the laboratories, where testing and recording equipment has become more and more sophisticated and where specimen sizes have varied from full-scale structural elements to test coupons a few inches long.

Of all structural materials included in blast-resistance research, timber seems to have been most neglected except in the early field tests where wooden buildings were exposed to atomic blasts. In addition, great strides have been made in manufactured timber components such as glued-laminated beams and plywood. This study was undertaken to provide up-to-date information on the response of wood to dynamic (rapidly applied) loads approximating those experienced in atomic blasts.

Allowable unit stresses for wood originated with what are known as basic stresses, which, in turn, were obtained from tests of small, clear wood specimens. Accordingly, research in this study was limited to tests on small, clear specimens (2 x 2 inches) of Douglas fir (coast type), selected as typical of widely used structural timbers. The specimens were selected and prepared to conform with an equivalent grading of dense select structural. (See the Appendix.)

## PHYSICAL CHARACTERISTICS OF WOOD

The following discussion of the structure of wood is taken from References 1, 2, and 3. Wood is an organic material consisting principally of hollow tube like cells of cellulose cemented together by lignin and containing minor amounts of extractives. Most of the cells (or fibers) are oriented vertically in the growing tree. In most timbers the length of a cell is as much as 100 times its width, varying from about 0.04 to 0.33 inch in length and from 0.0004 to 0.0033 inch in diameter.

The strength of wood depends upon the thickness of its cell walls rather than upon the length of its cells. The thickness of the cell walls varies with the species and varies throughout a growing season. The cell walls are not as thick in the early part of the growing season (springwood) as they are in the later season (summerwood). In turn, the wood showing wider summerwood rings is a stronger wood, other things being equal.

The hollow portion of the cell, called the cell cavity, is usually full of water when the wood is green. The cell walls (the woody material) are porous and highly hygroscopic. The capillaries existing in the cell walls have significantly large surface areas and can accommodate relatively large amounts of water. The presence of this capillary water contributes to the flexibility of wood; however, green wood generally has lower strength than the more brittle dry wood.

As wood dries, the water in the cell cavities evaporates first; the depletion of this water has been found to have no effect upon the strength properties. The fiber saturation point is the moisture content at which the cavity water is removed but the cell capillaries remain saturated. For Douglas fir, the fiber saturation point is 25% to 30% moisture. As the water in the capillaries begins to evaporate, the woody material composing the cell starts to stiffen and gains in strength, principally in the direction of the length of the fibers (cells). The moisture content of the wood is defined as the weight of the water present divided by the oven-dry weight of the wood.

The average specific gravity of woody material is about 1.49, which means that if it were voidless, it would not float in water. Due to the porosity and general makeup of wood, however, the bulk specific gravity of structural timber ranges between 0.3 and 0.6. The specific gravity (or density), then, is a measure of the inherent strength of wood, because in general, the more woody material present per unit volume, the higher the strength.

As the moisture content falls below the fiber saturation point, surface tensile stresses set up in the pores of the cell walls cause the wood to shrink. Most shrinkage occurs transverse to the cells, that is, across the grain. It is the action of the shrinkage stresses which imparts the higher inherent strength to dry wood by tending to bind the cells tighter together in compression. As the wood cells become drier and stiffer, they also become more brittle, with the result that properly dried wood has higher strength than green wood but is not as flexible.

1 second would be at about dynamic speed 2. The values for modulus of rupture in bending of green specimens (Table 3) indicate the increase over the static strength at dynamic speed 2 was about 13% for the average, 28% for minus 1 standard deviation, and 29% for the lower 95% confidence limit. The allowable increase in design working stress of 100% is equivalent to an increase of about 24% when referred to the test data reported herein. Thus, it is seen that results in this study verify the use of 100% working stress overallowance for impact.

For a long-duration load of a blast or shock type, the flexural elements in structures undergo strain rates in the range of 0.1 to 1.0 inch per inch per second. These strain rates correspond to testing speeds between 392 and 3,920 inches per minute as reported herein. Earthquake velocities may vary between even wider limits than do blast velocities. It should be emphasized, however, that current timber design specifications define earthquake loads as those which have a duration of about 1 day. Such a definition certainly removes earthquake considerations from a dynamic study such as this.

The highest testing speed in this study approximates a load duration of about 0.026 second in bending. At such a short load duration, it is seen in Table 9 that the modulus of rupture at the top dynamic speed exceeds the static value by a maximum of 54%, representing an increase in allowable working stress of about 130%. The curve[9] from which the design allowances for duration of load are obtained indicates that for durations extrapolated to less than 1 second, allowances considerably higher than 100% might be permissible. Test results in this study confirm an allowable working stress increase of as much as 130% for speeds in the blast or shock loading zone covered in these tests. Dynamic analysis and determination of dynamic stresses which may act on a given structure will of course depend on the judgment of the individual designer.

Perhaps the most serious implications arising from this study lie in the results observed in the bending tests of dry specimens. While it may be true that a large solid sawn beam in place in a structure never completely dries, it will certainly dry to some extent inward from all exposed surfaces. If, in its semidry state, it is then subjected to an impact or shock load, the results could be disastrous because drying reduces dynamic bending strength. (See Figure 12 and Table 10.)

An unknown factor regarding the performance of wood under shock and impact loading is the amount of support provided to structural timber elements by fastenings such as nails, bolts, screws, and proprietary fasteners during such loading. A study of the behavior of these fasteners under dynamic loading would perhaps reveal the extent to which fastenings can be depended upon to absorb and transmit shock loadings.

The results of bending tests on dry specimens introduce another important consideration. In the production of glued-laminated beams, the individual laminations consist of predried wood planks or boards. These boards are glued together under high temperature and pressure and the resulting beams are subsequently utilized in structures in many ways. The performance of these dry members in bending when subjected to shock or impact loading may well depend solely upon the strength of the glue bond. These glue-bonded members should also be subjected to dynamic loading in the laboratory to clarify this highly important aspect of timber construction.

## FINDINGS

1. Compared with values found for static loading rates, small clear specimens of green Douglas fir, when loaded at testing speeds up to about 2,000 inches per minute (equivalent to a strain rate of about 0.5 inch per inch per minute), showed net increases in all strength values with the exception of modulus of elasticity in bending. The modulus of elasticity decreased above a speed of about 600 inches per minute (strain rate of about 0.15 inch per inch per minute).

2. Under similar conditions, small, clear specimens of dry timber showed increases in all strength values except in bending. Dramatic decreases in strength were observed in the latter.

3. The increases in dynamic bending strength of green specimens verified the current overallowances of 100% in working stress for impact loading and established a maximum overallowance of 130% in working stress for blast or shock loads.



## CONCLUSIONS

1. Present recommended overallowance for impact loads in bending is verified by test data. Working stresses in structures subjected to blast or shock loads could safely be increased as much as 130%.

2. As a timber beam dries in place in a structure, its dynamic strength properties approach those of dry timber and it may eventually exhibit less strength under blast or shock loading than when first installed in the structure.