FATIGUE RESISTANCE OF QUARTER-SCALE BRIDGE STRINGERS IN FLEXURE AND SHEAR[1]

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Digest

Research on the behavior under repeated loading of about 300 specimens (2 by 4 by 43 inches, loaded at third points of a 39-inch span) of southern pine and Douglas-fir included the variables of green, air-dry, and preservative-treated wood and straight grain and 1:12 slope of grain. With air-dry and treated wood, an additional variable was the use of artificial checks at midheight to simulate those produced from drying. An equal number of control specimens matched to the fatigue specimens were loaded to failure statically to provide information on the static strength of each fatigue specimen.

Fatigue specimens were loaded repeatedly at the rate of 500 cycles per minute at selected levels of stress until failure developed or the specimen withstood 10 million repetitions of stress. The minimum repeated stress for each cycle was 0.10 of the maximum.

The fatigue strength for 2 million cycles of stress was estimated for each of the species and the 10 combinations of condition, grain, and checking from curves of stress to number of cycles to failure (figs. 30, 31, 32, and 33). These values and those from the static control tests are summarized in table 41.

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[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

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Analyses of the research results indicate that, with the present method of deriving working stresses for timber (considerations for duration of load and margin of safety), fatigue resistance from bending stress is probably adequate for timbers when green, air-dry, or treated, except for those of treated southern pine. The fatigue strength values were slightly below 50 percent of the static strength for the treated southern pine.

The results from the artificially checked specimens, which fail in shear under repeated loading, suggest further consideration in the method of providing working stresses in shear because of the possibility of fatigue failures from repeated stresses. Such failures are particularly possible with southern pine, as estimated fatigue strength was as low as 30 percent of static strength.

Introduction

Approximately 1,800 miles of short-span and multiple short-span wood bridges and trestles are located on Class I railroads in the United States. Practice varies in different areas, but timber stringer bridges are used on both main and branch lines. Stringers were formerly replaced at fairly frequent intervals because of decay in timbers. The present universal practice of treating these timbers with preservatives has extended the life of bridge stringers. The lengthened service life of the timbers, however, has raised questions about the fatigue resistance of the stringers, since bridges are subjected to numerous repetitions of loading.

Fatigue in engineering materials is the phenomenon of failure due to repetitions of stress of a magnitude less than the static strength. Failure due to an accumulation of loadings of varying duration is different in character and is a separate consideration. In present design, a factor is applied in deriving working stresses for wood members that are subjected to long accumulations of loadings during the life of a structure. No such factor is applied for the effect of fatigue, nor is such a factor considered necessary, since the static strength of a member is not reduced by repetitions of stress until a failure starts. Unless the magnitude of repeated stresses exceeds the fatigue strength for the number of repetitions in service, there is no reduction of the margin of safety.

Members of the technical staff at the Association of American Railroads Research Center estimate that the number of repetitions of design load or near-design load will not exceed 2 million during the life of the structure. The important questions that led to the fatigue work reported herein are the following:

(1) If stringers in service for 30 or 40 years were free of decay, should they be replaced because of possible fatigue failures in the future, or was their fatigue resistance sufficient to permit their continued use?

(2) If the fatigue strength of timber was low, as compared to the stresses in service, what allowances should be suggested in design to overcome the possibility of fatigue in service?

(3) How do fatigue failures develop? What inspection procedures should be integrated with regular inspections to forestall possible critical failures that may interrupt service?

This information was not available for wood stressed in bending or for relatively short beams with a ratio of bending moment to shear force that causes critical shear stresses. Further, because of the checking that sometimes occurs in drying, timbers of the size used in many bridges may fail in service as the result of shear. Therefore, engineers at the Forest Products Laboratory and the subcommittee on repeated loading of Committee 7, Wood Bridges and Trestles, American Railway Engineering Association developed a program of testing quarter-scale specimens. It embodied these variables: Moisture content (green and air-dry wood), straight grain and 1:12 slope of grain, specimens free of checks and with a V-notch to simulate a drying check, two species (southern pine and Douglas-fir), and the effect on strength of preservative treatment for protection against decay.

Green, air-dry, and treated specimens were selected to encompass the range of moisture content and conditions encountered in service. Although the majority of timbers actually installed are treated, the dry untreated specimens were included so that any effects of treatment on fatigue behavior could be isolated. The variable of 1:12 slope of grain was included because that is the maximum slope allowed in structural timbers used in bridge stringers. The artificial checks were included because abrupt changes in cross section introduce stress concentrations, which become more critical under repeated loads than under static loads. One-half the width of the timber was selected for the total depth of checks, because in cross sectioning severely checked timbers of the size used in bridge stringers, the total depth of checks was approximately one-half the total width of the timbers.

The research evaluation program was supported jointly by the Association of American Railroads and the Forest Products Laboratory. This is the final report on the research study.[3] It presents the results of the static-control and fatigue study for these kinds of specimens:

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[3] Progress report on tests of green and air-dry southern pine was published under the title, "Fatigue Resistance of Quarter-Scale Bridge Stringers of Green and Dry Southern Pine," in AREA Bulletin 538, September-October 1957.

1. Green, unchecked, southern pine with straight grain
2. Green, unchecked, southern pine with 1:12 slope of grain
3. Air-dry, unchecked, southern pine with straight grain
4. Air-dry, unchecked, southern pine with 1:12 slope of grain
5. Treated, unchecked, southern pine with straight grain
6. Treated, unchecked, southern pine with 1:12 slope of grain
7. Air-dry, artificially checked, southern pine with straight grain
8. Air -dry, artificially checked southern pine with 1:12 slope of grain
9. Treated, artificially checked southern pine with straight grain
10. Treated, artificially checked, southern pine with 1:12 slope of grain
11. Green, unchecked Douglas -fir with straight grain
12. Green, unchecked Douglas-fir with 1:12 slope of grain
13. Air-dry, unchecked Douglas -fir with straight grain
14. Air-dry, unchecked Douglas-fir with 1:12 slope of grain
15. Treated, unchecked Douglas-fir with straight grain
16. Treated, unchecked Douglas fir with 1:12 slope of grain
17. Air-dry, artificially, checked Douglas-fir with straight grain
18. Air-dry, artificially checked Douglas-fir with 1:12 slope of grain
19. Treated, artificially checked Douglas -fir with straight grain
20. Treated, artificially checked Douglas-fir with 1:12 slope of grain

Preparation of Specimens

All specimens were fabricated in pairs; one of each pair was used for a static control test and the other for a fatigue test. Each pair of specimens was longitudinally matched as exactly as possible for such large-sized specimens.

Material was either from loblolly pine logs from eastern Texas or Coast-type Douglas-fir logs from Oregon.

Specimens were sawn from log flitches as shown in figure 1. Each specimen was identified and numbered as to log and position in the log, in order to make comparisons of the results from different types of specimens. Radial matching, though less desirable than longitudinal or tangential matching because different growth rings are represented, was used to observe the effects of the variables of moisture content, slope of grain, preservative treatment, and the artificial checks on static and fatigue strength.

A common size for a stringer is 8 by 16 inches by 13 feet, so for this study individual specimens were scaled down to 2 by 4 by 39 inches. The actual length of specimens was 43 inches, which provided for a 2-inch extension of each end beyond the supports when the specimens were tested. Green specimens were sawed to final dimension and maintained green until tested.

Specimens to be tested in the air-dry condition and those to be treated before test were cut to a rough size of approximately 3 by 5 by 48 inches while green. Both kinds were carefully kiln dried to approximately 12 percent moisture content before being cut to final size. The specimens are shown in figure 2. The artificial checks were cut with a spindle router and finished with a special hand tool that made the point of the V-notch sharp to simulate the edge of a check as closely as possible.

A numbering system for the specimens was used to identify each specimen as to log origin, species, moisture content or treatment, as a control or fatigue specimen, whether checked or unchecked, and as to location in the log. During specimen preparation, pairs were matched as to orientation of the annual rings, in order that pairs would be loaded on matching faces in both the control and fatigue tests. In the identification system used, the first symbol is the log number; the second is a letter, either P for southern pine or F for Douglas-fir; the third is either D for air-dry, G for green, or T for preservative-treated material; the fourth is either C, designating control specimens, or F, fatigue specimens; and the fifth symbol is either CH for checked specimens or U for unchecked ones.

Treatment and Conditioning

Material for the specimens was separated into three groups, depending on whether it was to be used green, air dry, or after preservative treatment.

Green Specimens

The moisture content of the green specimens was maintained by placing individual fatigue specimens in plastic cocoons in a solution of water and a mild fungicide to prevent mold or other deterioration during storage. A specimen encased in a plastic cocoon and positioned in the fatigue testing machine is shown in figure 3. The static-control specimens were close piled and covered with wetted cloths for the short period between fabrication and test.

Air-Dry Specimens

The equilibrium moisture content of air-dry wood is about 12 percent. The material was dried, conditioned, stored, and tested at 75° F. and 64 percent relative humidity.

Treated Specimens

Since any deleterious effect on the strength of wood due to treatment may result from the presence of the preservative itself or from the conditions of heat and pressure required to force the preservative into the wood, the quarter-scale specimens were treated under the same conditions as though they were full-sized timbers, except that the wood was at about 12 percent moisture content at the start of the treatment. Retentions, therefore, were greater than would be normal for that size material.

The treating industry and the railroads were surveyed, and the actual treatments selected were chosen as typical of practice at the time specimens were treated. For the southern pine specimens, treatment involved the following steps:

1. Steaming for 1 hour to reach 259° F.

2. Continue steaming for an additional 3 hours

3. Vacuum of 24 to 28 inches for 2 hours

4. Initial air pressure of 70 pounds per square inch for 30 minutes

5. Coal-tar creosote at 175 pounds per square inch of pressure at 200° F. for 3 hours

6. Final vacuum of 24 to 28 inches at 200° F. for 1 hour

The Douglas-fir was incised before treatment at one-fourth the spacing and about one-fourth the depth used on full-sized timbers, as shown in figure 2. The steps in treatment were as follows:

1. Boiled in coal-tar creosote under a vacuum of 24 inches at 190° F. for 8 hours

2. Initial air pressure of 30 pounds per square inch for 30 minutes

3. Creosote at 200° F. and 100 pounds per square inch of pressure for 12 hours

4. Final vacuum of 24 inches at 200° F. for 1 hour

After treatment, specimens were stored in a covered shed for a minimum of 6 weeks; excess creosote was then wiped off the specimen surfaces and they were conditioned to constant weight at 75° F. and 64 percent relative humidity.

Methods of Test

Specimens were loaded in bending at the third points while simply supported over a 39-inch span. The procedure for the control tests conformed to the requirements of American Society for Testing and Materials designation D 198-27.[4] The specimens were supported and loaded on the 2-inch face, as shown in figure 4. To conform to the requirement of D 198-27, the specimens were loaded at a uniform rate of head travel of 0.10 inch per minute.

Maximum loads were obtained and ultimate stresses were calculated with the formula appropriate for the type of failure. 'The values of modulus of rupture 'for failures in bending were computed with the conventional $\frac{Mc}{I}$ formula, which became

$$R = \frac{39\ P}{bh^2}$$

[4]American Society for Testing and Materials method, "Static Tests of Timbers in Structural Sizes."

where R is the modulus of rupture or extreme fiber stress in pounds per square inch, P is the maximum test machine load in pounds, b is the width of the specimen in inches, and h is the height of the specimen in inches.

The values of unit shear stress for specimens that failed in shear were calculated on the basis of the gross cross section, even though the artificial checks reduced the effective area in shear by a factor of one-half. This conformed to design practice where no reduction is made in width for checking that may occur in service. The formula for calculating unit shear stress is:

$$S_{sg} = \frac{0.75\ P}{bh}$$

where S_{sg} is the shear stress on the gross cross section in pounds per square inch, and P is the maximum test machine load in pounds.

The unit shear stresses based on the net cross section were approximately double those calculated on the basis of the gross section.

Fatigue tests were made in axial loading fatigue machines adapted for bending, as shown in figure 5. Two specimens were tested simultaneously. The amplitude of the load was measured by measuring the deflection of the cantilever loading arm, which was calibrated and found to be directly proportional to amount of the loading. Reset counters for each side of the machine counted the repetitions applied to each specimen.

In making each fatigue test, the following steps were followed:

1. With the cam set at zero and the static loading screw in a lowered position, the specimen was placed in position; a bridge with a 0.0001-micrometer dial, for measuring deflection of the center of the cantilever loading arm with respect to its ends, was placed in position and a zero reading taken.

2. The static loading screw was raised until the cantilever loading arm was deflected by the amount corresponding to that required for the desired mean load.

3. The cam was adjusted and slowly rotated by hand until the minimum and maximum deflections of the cantilever loading arm were the desired amounts.

4. The machine was started and, after a few hundred cycles the machine was stopped and the loading was adjusted.

5. The machine was restarted, and the electronic shutoff mechanism was adjusted so that a slight change in load (as indicated by hand pressure on the cantilever loading arm) shut off the power to the driving motor.

6. Loading was checked periodically until the test was completed.

In practice, it was found that a logarithmic schedule of monitoring loads worked well unless a progressive failure was developing. Loads were checked at about 1,000, 10,000, and 100,000 cycles, and daily thereafter until failure started. When any failure developed, the electronic mechanism stopped the machine, and it was necessary to adjust the load. With this procedure, indications are that loadings were within 5 percent of those desired at all times during test.

Because of dynamic effects (loading during the actual running of the machine was greater than when turning it over slowly by hand), it was necessary to correct the alternating loads. This correction was found to be proportional to the amplitude of the alternating load at any speed of machine operation. At 500 cycles per minute, it amounted to 3 percent for one fatigue machine used in the program and 2 percent for the other.

Specimens were loaded repeatedly to a previously computed percentage of the strength of the matched control. Loads were repeated at the rate of 500 cycles per minute. The green specimens were tested while in the plastic cocoons, as shown in figure 3, to maintain the moisture content. The moisture content of the air-dry, and treated specimens was maintained because all fatigue tests were made in a room conditioned and maintained at 75° F. and 64 percent relative humidity. The tests were continued until the specimen either failed or had withstood 10 million repetitions of stress. The specimen was considered to have failed when a major tension failure or shear failure developed, or when it could no longer sustain the maximum repeated load because of severe compression failures. The end point of the test was selected as 10 million cycles, to provide a margin beyond the 2 million cycles estimated for the life of a bridge stringer. The ratio of minimum repeated stress to maximum repeated stress (stress ratio) was 0.10 for all tests.

After test, a moisture content coupon 1 inch long was cut from each untreated specimen near the point of failure. This was weighed, ovendried, weighed again, and the moisture content calculated. The moisture content is expressed as a percentage of the weight of the ovendry wood. The specific gravity of each specimen was also determined on the basis of the weight and volume of the wood when ovendry. Determination of moisture content of treated specimens by conventional ovendrying techniques is neither accurate nor suitable. For accurate determinations of treated specimens, it is necessary

to use extraction methods to remove the treating chemical, but electric resistance moisture meters were used to give reasonable approximations. Further, because both the air-dry and treated specimens were conditioned at the same atmospheric condition before and during test, results are comparable between the two kinds of specimens.

Presentation and Discussion of Test Results

The data from the research program are presented in tables 1 through 40 for the individual variables. Results of the static control tests are presented in odd-numbered tables and results of the fatigue tests in even-numbered tables. The following tabulation lists the various tables presenting the results of the tests:

Identification	Table No. Static control tests	Table No. Fatigue tests
Unchecked Southern Pine		
Green, straight grain	1	2
Green, 1:12 slope of grain	3	4
Air dry, straight grain	5	6
Air dry, 1:12 slope of grain	7	8
Treated, straight grain	9	10
Treated, 1:12 slope of grain	11	12
Artificially Checked Southern Pine		
Air dry, straight grain	13	14
Air dry, 1:12 slope of grain	15	16
Treated, straight grain	17	18
Treated, 1:12 slope of grain	19	20
Unchecked Douglas -fir		
Green, straight grain	21	22
Green, 1:12 slope of grain	23	24
Air dry, straight grain	25	26
Air dry, 1:12 slope of grain	27	28
Treated, straight grain	29	30
Treated, 1:12 slope of grain	31	32

Identification	Table No. Static control tests	Fatigue tests
Artificially Checked Douglas -fir		
Air dry, straight grain	33	34
Air dry, 1:12 slope of grain	35	36
Treated, straight grain	37	38
Treated, 1:12 slope of grain	39	40

The results of the fatigue tests are presented graphically in this report with the values of maximum repeated stress plotted as ordinates and the corresponding number of cycles to failure plotted logarithmically as the abscissas as is commonly done for tests of this kind. Because of the variation in strength properties with specific gravity, values of maximum repeated stress are plotted both as percentages of the static strength of the matched control and in pounds per square inch.

These plots of data and estimates of the fatigue strength for 2 million cycles of stress (maximum stress that can be repeated 2 million times before failure) are presented and discussed in the following sections.

Green Southern Pine Specimens with Straight and 1:12 Slope of Grain

The results of the fatigue tests of the green, unchecked southern pine with straight grain are plotted in figure 6, with values of maximum repeated stress in percentages of the static bending strength as ordinates in the top part and in pounds per square inch in the bottom. The results for the similar material with 1:12 slope of grain are plotted in figure 7.

The plotted data exemplify the difficulty in obtaining a spread of values for fatigue life (cycles to failure) in green material when it is stressed in bending. It was apparent during the tests that unless repeated stresses were sufficiently large to produce compression wrinkles in the fiber, specimens did not fail in 10 million cycles of stress. Compression failures that developed when stresses were sufficiently high became apparent early and deepened as the test progressed. Tension failures developed only part of the time, even in the specimens with the 1:12 slope of cross grain. In other specimens (tables 2 and 4), either the severe, progressive compression was followed by shear, or compression became so severe that the specimens could no longer sustain the maximum repeated loads. Consequently, about one-half of the specimens at various loading levels sustained 10 million cycles without failure.

Examination of figure 6 (top) discloses that failures in the straight-grained material did not develop if the maximum repeated stresses were less than about 50 percent of the static strength. This level is indicated by the horizontal line on the figure. The average static strength of the control specimens for the straight-grained material was 7,450 pounds per square inch, so the indicated level of stress below which failures would not be expected in 2 million cycles in green, straight-grained southern pine of the quality in this study is about 3,700 pounds per square inch. This is shown by the horizontal line in the bottom part of figure 6.

The corresponding stress for the green material with 1:12 slope of grain was about 55 percent of the static strength. This difference is logical, since modulus of rupture is influenced more by slope of grain than is compressive strength. The effect of slope of grain on static strength of wood is discussed in the Wood Handbook.[5] Data in table 15 of that handbook indicate that the static modulus of rupture for wood with a 1:12 slope of grain is about 84 percent of the strength of straight-grained material. The data in the Wood Handbook also indicate that in compression parallel to grain, the static strength for wood with a 1:12 slope of grain is about 99.5 percent that of straight-grained wood. The control strength for fatigue tests on green wood is based on modulus of rupture but the critical stress, as far as fatigue is concerned, is compression; therefore, it is reasonable to expect that fatigue strength values for the specimens with 1:12 slope of grain will be higher percentages of static strength values than those for straight-grained specimens.

The absolute, or pound-per-square-inch values, of fatigue strength are essentially the same for the green material with 1:12 slope of grain as for the straight-grained material. Figures 6 and 7 (bottom) indicate that the fatigue strength value for 2 million cycles of stress is almost the same, about 3,900 (55 percent of 7,020) pounds per square inch, for material with the 1:12 slope of grain as for the specimens with straight grain. The average static strength of the controls with 1:12 slope of grain was 7,020 pounds per square inch (table 3) and that of the straight-grained controls was 7,450 pounds per square inch (table 1). The static strength of the slope-of-grain specimens in this test was about 94 percent that of the straight-grained ones. This reduction is less than those indicated in table 15 of the Wood Handbook, which are based on tests of dry rather than green wood.

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[5] Forest Products Laboratory, Wood Handbook, U. S. Department of Agriculture Handbook No. 72, p. 95-97. 1955.

Air-Dry, Unchecked Southern Pine Specimens with Straight Grain or 1:12 Slope of Grain

The results of the fatigue tests of the air-dry, unchecked southern pine with straight grain are plotted in figure 8, with values of maximum repeated stress in percentages of control bending strength in the top part and in pounds per square inch for the bottom. Results for the fatigue tests of the material with 1:12 slope of grain are similarly plotted in figure 9.

The typical fatigue failure in the straight-grained material was compression, followed by either simple or splintering tension (table 6). The fatigue specimens with 1:12 slope of grain failed in cross-grain tension (table 8); there was no visible evidence of compression. Both types of failure were similar in appearance to failures from the static tests.

The plotted results in figures 8 and 9 are more typical of values usually obtained from fatigue tests than are the results obtained with the green material; that is, the lower the repeated stress, the greater the number of cycles to failure. Sloping lines, showing the approximate relation of stress to number of cycles (S-N curve) to failure, are drawn for each set of data. These indicate that the fatigue strength for straight-grained material for 2 million cycles of stress is about 60 percent of the static strength, or about 8,000 pounds per square inch (fig. 8) for material of the same average quality as that used in these tests. For the material with 1:12 slope of grain, the corresponding fatigue strength is estimated to be about 50 percent of the static strength, or about 5,200 pounds per square inch (fig. 9) for material of the quality and density included in this study.

Treated, Unchecked Southern Pine Specimens with' Straight Grain or 1:12 Slope of Grain

The results of the fatigue tests of the treated, unchecked southern pine with straight grain are plotted in figure 10 in the same way as were the green and air-dry tests in figures 6 to 9. Examination of figure 10 and tables 9 and 10 indicates that when fatigue life (cycles to failure) was more than about 1 million cycles, failures in fatigue were in horizontal shear and not in bending, which was the type of failure in all but one of the static controls.

This difference in manner of failure is shown in figure 11 (top pair of specimens) where the static control was a flexural failure and the fatigue specimen failed in horizontal shear. It also makes analyses of fatigue strength on the basis of bending stress less valid than if static and fatigue

failures were similar, because only in beams with equivalent loading (third point) and span-to-depth ratio is the relation between bending and shear stress the same. The indicated fatigue strength for 2 million cycles for the straight-grained material is about 45 percent of the static bending strength, or about 5,400 pounds per square inch.

Because failures in the region of 2 million cycles were in horizontal shear, the maximum repeated shear stresses were calculated and plotted against the cycles to failure in figure 12. The fatigue strength at 2 million cycles of stress, in terms of the shear stress, is estimated from that figure to be about 425 pounds per square inch. Because failures in the static control tests of the straight-grained treated material were mainly in bending, and because the fatigue failures were in horizontal shear when cycles of stress to failure exceeded 1 million cycles, shear was more critical in fatigue than in bending, while the opposite was true in the static tests.

This difference was not apparent when slope of grain in the specimens was 1:12, as shown in figure 11 (bottom pair) and recorded in tables 11 and 12. The normal failure was in cross-grained tension, with little or no compression in both the static and fatigue tests. Consequently, both plottings of the data from the fatigue tests of the sloping grain material in figure 13 are on the same basis as for the other green and air-dry material, with values of maximum repeated stress expressed as percentages of the static control strength and in pounds per square inch of bending stress. From this figure, fatigue strength at 2 million cycles of stress is estimated to be about 45 percent of the static strength or about 4,100 pounds per square inch for material of similar quality to that used for the tests.

Air -Dry, Artificially Checked Southern Pine Specimens with Straight Grain or 1:12 Slope of Grain

Results from the fatigue tests of the air-dry, artificially checked southern pine specimens are plotted in figures 14 and 15. Values from tests of straight-grained material are included in figure 14 and those from the 1:12 slope of grain are in figure 15.

The artificial checks were V-notches at midheight (neutral axis), fabricated to simulate as closely as possible the checks that occur in the drying of large timbers. At one end of each specimen, the artificial checks extended from the end of the beam to a point midway between the support and the load point. This was done to simulate a drying check that terminated in the shear area. At the other end of the beam, the checks were continuous from the load point to the end to simulate a check that was continuous for the full

length of the area in shear. The straight-grained control specimens and the four controls with 1:12 slope of grain failed in shear along the continuous or long check, indicating that under static loading a continuous check was more severe than a check that terminated within the zone stressed in shear. The fatigue failures were also along the long check (tables 14 and 16), showing that under repeated stress the results were the same.

In the straight-grained material, all of the static and fatigue failures occurred in shear. In the static tests of specimens with 1:12 slope of grain (table 15), four specimens failed in shear, eight failed in cross-grained tension, and four failed in a combination of cross-grained tension and shear so nearly simultaneously that it was impossible to tell which occurred first. In fatigue tests of the slope of grain specimens, however, all failures were in shear (table 16). Thus, it is indicated that shear is a more critical factor under repeated stress than is the presence of cross grain of a severity of 1:12 or less.

Values of shear stress were calculated on the basis of the gross cross section rather than the net cross section. This means that the actual shear stresses were approximately twice the values presented in tables 13, 14, 15, and 16, so the practice corresponds to that used in design of large timbers. Thus, no reduction need be made in applying the values to design practice.

The fatigue strength of the straight-grained, artificially checked southern pine for 2 million cycles of stress is about 45 percent of the static strength (fig. 14). The average static shear strength, calculated on the basis of gross cross section, was 885 pounds per square inch; so on this basis, the fatigue strength for 2 million cycles is estimated at about 390 pounds per square inch (fig. 14) for specimens of the same average quality as those included in these tests.

Because most of the static control tests of the specimens with 1:12 slope of grain failed in bending (table 15) and all of the fatigue specimens failed in shear (table 16), it was more difficult to make the same kind of an analysis for these specimens as was possible with those with straight grain. The ultimate shear strength of the specimens that failed in bending was estimated on the basis of specific gravity and used for computing the values of maximum repeated stresses in percentages of control (table 16) plotted in figure 15 (top). On this basis, the indicated fatigue strength at 2 million cycles for the artificially checked material with 1:12 slope of grain is about 40 percent of the static shear strength, or an average of about 320 pounds per square inch computed on the gross section (fig. 15, bottom).

Treated, Artificially Checked Southern Pine with Straight Grain or 1:12 Slope of Grain

Results from the fatigue tests of the treated, artificially checked southern pine specimens are plotted in figures 16 and 17 in a manner similar to those for the air-dry specimens in figures 14 and 15. Values from the tests of straight-grained material are included in figure 16 and those from the material with 1:12 slope of grain in figure 17. Specimens were fabricated exactly as for the air-dry specimens, except that they were given the coal-tar-creosote preservative treatment after fabrication.

In the treated, straight-grained controls, all specimens but one failed in shear (table 17). Shear failures were along the long checks, as were those for the untreated specimens in most instances. One specimen failed along the short check and one failed simultaneously along both checks. All failures in fatigue in the straight-grained material were in shear originating along the long check. In the static control specimens with sloping grain, failures were similar to those for the control tests of untreated material. Some failed in bending, some failed in shear, and some failed in a combination of bending and shear, In the fatigue tests, however, failures were in shear, supporting the conclusion made on the basis of the air-dry tests that shear is a more critical factor under repeated loading than the presence of cross grain of a severity of 1:12 or less.

The fatigue strength for 2 million cycles of the treated, straight-grained, artificially checked southern pine is about 40 percent of the static strength (fig. 16). The average static shear strength, calculated on the basis of gross cross section, was 690 pounds per square inch; on this basis, the fatigue strength for 2 million cycles is estimated at about 260 pounds per square inch.

For artificially checked specimens with sloping grain, the fatigue strength for 2 million cycles is estimated to be about 30 percent of the static strength (fig. 17), or about 210 pounds per square inch for material of quality equivalent to that used in this research.

Green Douglas -fir Specimens with Straight and 1:12 Slope of Grain

The results of the fatigue tests of the green, unchecked Douglas-fir are plotted in figures 18 (straight-grained tests) and 19 (1:12 slope of grain tests).

The experience in the fatigue testing of the green Douglas-fir was the same as that for the green southern pine--unless the stresses repeated were sufficiently large to produce wrinkling of the extreme fibers on the compression face, no failure developed during 10 million cycles. When failures did develop during the repeated loading, the initial failure was in compression, which became progressively more severe as the cycles of stress increased until either a shear or tension failure occurred.

Examination of the data in table 22 and figure 18 (top) for the green, straight-grained, unchecked Douglas-fir discloses that if the repeated stresses were less than 60 percent of the static strength, failures did not occur during the 10 million cycles. A horizontal line was located at 55 percent of the static strength as an estimate of the level of repeated stress where no failure would likely occur in 2 million cycles (fatigue strength). The average static bending strength for the material included in this study was 6,760 pounds per square inch; so the stress corresponding to 55 percent of the strength is about 3,700 pounds per square inch. This is shown as a horizontal line in figure 18 (bottom).

The specimens with the 1:12 slope of grain behaved similarly (table 24 and fig. 19, top) to those with straight grain. The level of stress below which failures would not occur appeared to be about 60 percent of the static strength. This is shown by the horizontal lines in figure 19 at 60 percent of the static control strength (upper part) and at 3,600 pounds per square inch (lower part). These values are, therefore the estimates of the fatigue strength for 2 million cycles of stress for green Douglas-fir with 1:12 slope of grain.

The apparently higher percentage value for fatigue resistance of Douglas-fir with 1:12 slope of grain than that of straight-grained Douglas-fir can be explained in the same way as for the similar difference in southern pine, although it should be stated also in this instance that the estimate of stress below which failures would not occur might be 2 or 3 percent higher for the straight-grained material than the 55 percent shown. With the kind of failures experienced with fatigue tests of the green material, estimates closer than 5 percent do not seem warranted.

Air -Dry, Unchecked Douglas -Fir Specimens with Straight and 1:12 Slope of Grain

The results of the fatigue tests of the air-dry, straight-grained Douglas-fir plotted in figure 20 indicate behavior under repeated stress very similar to that for the corresponding specimens of southern pine. As the magnitude of the repeated stress decreased, the number of cycles to failure increased. The location of the S-N curve was estimated, and on this basis, the fatigue

strength for 2 million cycles is indicated to be about 60 percent of the static strength (fig. 20, top), or about 6,300 pounds per square inch for material of the same quality as the average included in this study.

The corresponding results for the air-dry Douglas-fir with 1:12 slope of grain plotted in figure 21 indicate that the fatigue strength for 2 million cycles for that material may be about 55 percent of the static modulus of rupture, or about 4,200 pounds per square inch for Douglas -fir of the average quality used in this study.

Failures for normal specimens with straight grain were in compression, followed by tension, both statically (control tests) and from fatigue. In a few instances, the initial compression was followed by shear, as shown in figure 22, bottom. The remainder of the figure shows typical static failures (upper one of each pair) and severe compression followed by tension (next to top) in fatigue of the air-dry, straight-grained specimens.

Failures in the air-dry specimens with 1:12 slope of grain were typically in cross -grain tension, with no evidence of any compression.

Treated, Unchecked Douglas-fir Specimens with Straight Grain or 1:12 Slope of Grain

In the fatigue tests of the treated, straight-grained, unchecked Douglas -fir, bending failures occurred only when maximum stresses repeated were large and the fatigue life, therefore, was short (relatively a few cycles before failure). When the stress repeated was such that the specimen withstood a large number of cycles before failure, the specimens failed in horizontal shear after initial compression, or in horizontal shear with no evidence of compression. This experience is the same as for the tests of treated, straight-grained, unchecked southern pine, where static failures were predominantly due to bending stresses, and fatigue failures in the zone of 2 million cycles were in shear. The same practice was followed in presenting the data, which in addition to the plots of data where ordinates are expressed in terms of bending stress (fig. 23), an additional plot (fig. 24) is provided with the values of the maximum repeated shear stress as ordinates and the logarithm of the number of cycles to failure as abscissas.

On the basis of bending stress, the estimated fatigue strength for 2 million cycles of stress is about 50 percent of the static modulus of rupture (fig. 23, top), or for material of the average quality included in this study, it is about 5,400 pounds per square inch. On the basis of shear stress, the fatigue strength for 2 million cycles is indicated to be about 400 pounds per square inch for material of the quality equivalent to that used in the study.

The treated, unchecked Douglas-fir with a 1:12 slope of grain predominantly failed in cross-grain tension in both the static control and the fatigue tests, as was the experience in tests of the treated, similar southern pine specimens. The values from the fatigue tests plotted in figure 25 indicate that the fatigue strength for 2 million cycles was about 55 percent of the static strength, or about 3,900 pounds per square inch on an average basis.

Air-Dry, Artificially Checked Douglas-Fir Specimens with Straight Grain or 1:12 Slope of Grain

The results from the fatigue tests of the air-dry, artificially checked Douglas-fir specimens with straight grain and 1:12 slope of grain are plotted in figure 26 and figure 27.

Tables 33 and 34 show that the normal failures in both the static and fatigue specimens were in horizontal shear along the long check, as was the predominant experience with the corresponding specimens of southern pine, indicating that in Douglas-fir, also, the continuous check was more severe than a check that terminated within the zone stressed in shear. The fatigue strength for 2 million cycles for the straight-grained Douglas-fir is estimated to be about 45 percent of the static strength (fig. 26, top), or about 310 pounds per square inch for material of the same average quality that is included in this study.

Table 35 for the static control tests of specimens with a 1:12 slope of grain indicates that the predominant static failure was in horizontal shear, although some specimens failed in bending or a combination of bending and horizontal shear. In the fatigue tests (table 36), however, all normal failures were in horizontal shear, as was the experience with the air-dry tests of southern pine, which supports the observation that shear is a more critical factor under repeated stress than is the presence of cross grain of a severity of 1:12 or less. This is substantiated also by the fatigue strength of both southern pine and Douglas-fir. In the unchecked specimens, where fatigue failures were in bending, the values are indicated between 50 and 60 percent of the static strength, while for the artificially checked specimens, which failed in shear, the corresponding fatigue strength values were indicated to be lower percentages of the static shear strength.

The results of the fatigue tests of the artificially checked specimens with sloping grain plotted in figure 27 indicate that the fatigue strength for 2 million cycles was also about 45 percent of the static shear strength (top curve), or about 280 pounds per square inch (bottom curve) for material of the quality included in this study.

The values for fatigue strength at 2 million cycles, of 310 pounds per square. inch for the straight-grained wood and 280 pounds per square inch for that with the 1:12 slope of grain, are based on calculations using the total width of the specimen without any reduction in width for the artificial checks. Actual widths of the area in shear were one-half the width, so true values would be about twice those presented. This corresponds to the common practice in design where no reduction in width is made for checks that develop in service.

Treated, Artificially Checked Douglas -fir with Straight Grain or 1:12 Slope of Grain

All of the treated straight-grained, artificially checked specimens, except two tested statically as controls, and all of those loaded repeatedly until fatigue failures developed, failed in horizontal shear along the long check (tables 37 and 38). Similar specimens with a 1:12 slope of grain usually failed in the same manner, but there were more--two in fatigue and several in static tests--where bending was predominant (tables 39 and 40).

The plotted results for the fatigue tests of straight-grained, artificially checked specimens of Douglas-fir, presented in figure 28, indicate a fatigue strength for 2 million cycles of approximately 50 percent of the control strength, or about 270 pounds per square inch for treated wood of the quality used in the study. When the slope of grain was 1:12 instead of straight, the fatigue strength for the treated, artificially checked wood was indicated from figure 29 to be about 45 percent of the static strength or about 240 pounds per square inch in shear, calculated on the gross width of the section with no reduction in width for the artificial checks that reduced the width by one-half.

As discussed before, in presenting results of this research, where shear was critical in the artificially checked specimens, the practice was adopted of making calculations on gross rather than actual width, so that values would correspond more closely with actual design practices.

Comparisons of Static and Fatigue Strengths of Green, Dry, and Treated Specimens

The data on static strength and fatigue behavior presented and discussed in previous sections are summarized in table 41. This condition is also true of the values for the estimated fatigue strength at 2 million cycles in pounds per square inch in column 8, where failures were due to bending forces, and in column 11, where failures were in shear. Values presented are useful

for comparisons within a species, but should not be used for direct comparisons between species unless specific gravity differences are also recognized.

The estimated S-N curves (stress-number of cycles to failure) are combined for the unchecked southern pine in figures 30 and 31 (top) and for the unchecked Douglas -fir (bottom). In figure 30, the maximum repeated stresses (ordinates) are in percentages of static strength, and in figure 31, they are on a pounds-per-square-inch basis. Figures 32 and 33 present similar S-N curves for the artificially checked specimens.

The conditions of treatment for the southern pine and Douglas-fir apparently had some effect in reducing static strength also. Static bending strength of the treated southern pine was about 9 percent lower for the straight-grained specimens and about 15 percent for those with a 1:12 slope of grain (column 6, table 41). Shear values were about 22 percent less (column 9). The reductions in static strength due to treatment of the Douglas-fir were not so large. Bending strength values were reduced about 5 percent and those for shear about 22 percent on the average. The number of tests is too small to definitely establish the amounts of these reductions, but they do suggest further study of the effect of treatment on strength.

Green Southern Pine and Douglas-fir

No material difference was observed in the behavior of the green southern pine and Douglas-fir specimens under fatigue loading. Because of the phenomenon of progressive compression when failures developed, any estimation of fatigue strength was difficult. The differences of about 5 percent of fatigue strength shown in table 41 cannot be considered significant. Failures were substantially the same.

Air-Dry and Treated, Unchecked Southern Pine and Douglas -fir

Examination of the curves of figure 30 and the values for the unchecked specimens in table 41 for the southern pine ‘reveals that the fatigue strength for the treated, straight-grained material was lower on a percent-of-control basis than that for untreated southern pine or treated material with 1:12 slope of grain. In the Douglas -fir, there was a difference in the fatigue strength at 2 million cycles on a percentage basis also, but it was not so large as for the southern pine. Values for the straight-grained, untreated southern pine and Douglas-fir were estimated at 60 percent; for the treated,

straight-grained southern pine, it was estimated to be about 45 percent, and for the 'equivalent Douglas-fir it was estimated at about 50 percent of the static strength.

The lower fatigue strength of both species for the straight-grained, treated material are substantiated by the fact that actual failures were in shear in fatigue and in bending statically, indicating that something occurred during the treating process that reduced the shear resistance in fatigue as compared to static loading.

There were no substantial differences in the locations of the S-N curves of the unchecked specimens with 1:12 slope of grain for either species. Fatigue strength estimations for 2 million cycles of stress ranged from 45 to 55 percent of the static strength, indicating that fatigue behavior would be similar whether the material was treated or not, provided adjustments were made in design stress for any effects of treatment on static strength.

There was an apparent reduction in static strength for both the straight-grained and sloping-grained unchecked southern pine (column 6, table 41) when treated, and it is possibly explained by the severity of steaming exposure for the southern pine during treatment. Similar differences have been observed in studies of the strengths of treated poles.[6]

These differences account for the lower position of the curve in figure 31 (top) for treated southern pine with a 1:12 slope of grain as compared to its untreated equivalent, and for the much lower position of the curve for treated, straight-grained material than that indicated by the differences in fatigue strength on a percentage basis. There was no such difference for the Douglas-fir, as is shown by figure 31 (bottom), but the conditions of treatment were milder and probably the effect of treatment was not so great.

Because of the fatigue failures in shear in the treated, straight-grained specimens of both species, fatigue strength at 2 million cycles was calculated on the basis of shear stress on the measured width and presented in column 11 of table 41. While these values are presented on a pound-per-square-inch basis, values should only be considered as relative to material of equivalent specific gravity to that included in the study. Again, the density of the Douglas-fir used was less than that for the southern pine, and lower values are expected for that reason. That both values, 425 and 400 pounds per square inch for the southern pine and Douglas-fir, respectively, were substantially greater than design stresses in shear indicates a comfortable margin in service between actual stresses in shear and those which would produce fatigue failures in service.

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[6] Wood, L. W., et. al. Strength and Related Properties of Wood Poles, ASTM Wood Pole Research Program, Final Report, Sept. 1960.

The reason for fatigue failures in shear in the straight-grained Douglas-fir and southern pine, when stresses were low enough so that a large number of cycles were sustained before failure, is largely one of conjecture. Minor checking was observed after treatment, and it is reasonable to assume that if some checking was visible, other invisible strains and damage created internal stresses that reduced the fatigue resistance in shear. These same internal stresses were not so critical in the slope-of-grain specimens, because principal failures were in cross-grain tension.

Air -Dry and Treated, Artificially Checked Southern Pine and Douglas -fir

Examination of the values for static shear strength (column 9, table 41) of the artificially checked specimens with the notches, which reduce the width in shear by one-half to simulate drying checks, shows that in each instance the average shear strength values of the treated specimens were materially lower than the corresponding values for untreated material, The static strength of the treated southern pine specimens was apparently reduced about 22 percent by the treatment, and the Douglas-fir from 15 to 19 percent. This difference between species is probably reasonable because of different treatment conditions.

The values for fatigue strength at 2 million cycles based on a percentage of static strength (column 10, table 41, and figure 33) indicate that there was no material difference in the fatigue behavior of Douglas-fir in shear, whether the material was treated or not. Because values of fatigue strength were about the same percentages of static strength for these two variables, it is reasonable to conclude that, if any necessary reductions in the static strength for treatment are made, no additional reduction is necessary for considerations of repeated loading.

In the southern pine, fatigue strength apparently was definitely lower for the treated material than for the untreated material for wood with both straight grain and 1:12 slope of grain; this suggests that the fatigue resistance of the treated wood was proportionately lower than that for the untreated wood.

Values of fatigue strength on the pound-per-square-inch basis (column 11, table 41 and the curves of figure 33) show the cumulative effects of reduced static strength and lower percentage fatigue resistance for the southern pine and the much closer grouping of values for the Douglas-fir.

Analysis of Results in Terms of Design Practice

No data are available by which the results of small tests, such as those of the quarter-scale bridge stringers herein reported, can be directly applied to full-sized timbers used in structures, with full confidence of their applicability. Some difficulty always exists in transferring results from a study of small tests to large full-sized members. A research program on full-sized members with the variables controlled as they were in this study, however, is impractical if not impossible, because of the difficulty in obtaining large members matched to each other so that pairs of specimens could be tested, one statically and one in fatigue.

The data obtained from such a study as this are valuable, however, in appraising the possibilities of fatigue failures in service. In any structural part that undergoes a large number of repetitions of stress, such as is possible in a railroad bridge stringer, the important consideration is: Are the stresses which are repeated in service below those that will cause either failure of that part of the structure or excessive maintenance from fatigue produced by repetitions of stress?

In arriving at working stresses for normal loading of timber structures, factors for (1) variability, (2) duration of load, (3) a combination of other intangibles, and (4) the strength ratio based on the maximum defect permitted in a certain stress grade are applied to the strength of clear wood. A working stress derived in this way gives a near minimum factor of safety of 1-1/4 to 1-1/2, with an average more nearly equal to 2 to 2-1/2.[7] If the factor for duration of stress of 5/8 is combined with the near minimum factor of safety of 1-1/4, the combined factor is 0.50.[8] This value can then be compared directly to the various values for fatigue strength for 2 million cycles on a percentage basis in columns 7 and 10 of table 41.

Of the unchecked specimens, green, dry, or treated of either species, only the treated southern pine did not have a fatigue strength of 50 percent or greater, indicating that except for treated, unchecked southern pine, the reductions made in arriving at working stresses were probably adequate from the standpoint of members withstanding the repeated loads expected in service.

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[7] Wood, L. W., Safety Factor in Design of Timber Structures, American Society of Chemical Engineers, Proceedings Vol. 84, ST 7, 1958.

[8] Lewis, Wayne C., Design Considerations for Fatigue in Timber Structures, American Society of Chemical Engineers, Proceedings Vol. 86, ST 5, 1960.

The artificially checked tests indicate a greater possibility for fatigue failures to develop in service. The fatigue strength values of the artificially checked southern pine with straight and sloping grain were found to be substantially less than 50 percent of the static strength, while those for the Douglas-fir were generally slightly less than 50 percent. Those results indicate that possible revision of working stresses in shear may be desirable to provide a margin against possible fatigue failure in service for bridge stringers.

The previous analyses do not take into account any reduction in static strength for treatment, such as was indicated for all of the southern pine and for the artificially checked Douglas -fir. If there is such an effect of treatment, it should be established and the necessary reductions in static working stress made. Some of the reduction in static shear strength due to treatment may have been the results of further checking along the line of the artificial check. The original assumption for this study was that checking in service in big timbers could reduce the cross section by as much as one-half. If the total cross section damage from both drying and treatment is no more than that amount, the above consideration for reductions in static shear strength due to treatment is conservative.

Examination of the values for fatigue strength in pounds per square inch for the different kinds of material and specimens discloses a comfortable margin between the values of fatigue strength and working stresses used usually in design. These are, however, average values for average material and are not representative of the minimum quality possible in a structure.

The fatigue strength of an assembly or material is influenced by the difference between the maximum and minimum loads for each cycle (repeated stress amplitude). The greater this amplitude, the lower is the fatigue strength for any specific number of cycles. The amplitude of the repeated stress is usually indicated by the stress ratio, the ratio of minimum to maximum repeated stress. Stress ratio for this research was 0.10, which in effect implied that the dead load was equal to one-tenth of the “live plus the dead load," a reasonable assumption for short-span structures with timber stringers. If the actual amplitude of the repeated stress in service was a smaller percentage of the maximum (stress ratio more than 0.10), fatigue strength obtained would be a higher percentage of the static strength than reported here.

Summary and Conclusions

Definite conclusions based on approximately 15 evaluations of each variable are difficult for a property, such as fatigue, where there is an inherent

scatter of values from test, added to the difficulty produced by the variability of wood itself. The interrelations of the different variables, however, support each other, and it is believed that the following conclusions are warranted:

1. Fatigue Resistance, Green Unchecked Specimens

Green, unchecked southern pine and Douglas-fir, whether straight-grained or with a 1:12 slope of grain, did not fail in fatigue in 10 million cycles if maximum repeated stresses were not high enough to produce wrinkling of the compression face. When failures did develop, compression failures became apparent early in test and became progressively worse, with final failure in horizontal shear originating at the bottom of the compression failure or in tension. The levels of stress below which no failures developed in 2 million cycles were about 50 percent of the flexural strength for straight-grained southern pine, 55 percent for southern pine with 1:12 slope of grain and straight-grained Douglas-fir, and 60 percent of the static strength of the Douglas-fir with 1:12 slope of grain.

2. Fatigue Resistance, Air-Dry, Unchecked Specimens

Southern pine and Douglas-fir that were air-dry, unchecked, and with straight grain or 1:12 slope of grain developed fatigue failures as was expected for fatigue tests--the lower the level of the maximum repeated stress, the greater the number of cycles to failure. Fatigue failures in the straight-grained material were usually in compression followed by tension. Those for the material with 1:12 slope of grain were usually in cross-grain tension with no evidence of compression. Fatigue strength values for 2 million cycles of stress were estimated to be the following percentages of the static strength in flexure:

Southern pine with straight grain, 60 percent

Southern pine with 1:12 slope of grain, 50 percent

Douglas-fir with straight grain, 60 percent

Douglas-fir with 1:12 slope of grain, 55 percent

3. Fatigue Resistance, Treated, Unchecked Specimens

Treated, unchecked, straight-grained southern pine and Douglas-fir developed horizontal shear failures in fatigue when the number of cycles of stress before failure was about 1 million or more. As a consequence, fatigue strength values were lower percentages of the static flexural strength for the treated specimens (the static control specimens failed in bending) than for the untreated specimens--45 percent for southern pine and 50 percent for Douglas-fir.

The treated specimens of both species with 1:12 slope of grain failed in fatigue in cross-grain tension, with indicated fatigue strength for 2 million cycles of 45 percent of the static flexural strength for southern pine and 55 percent of the static flexural strength for Douglas-fir.

4. Fatigue Resistance, Air-Dry, Artificially Checked Specimens

Air-dry, artificially checked specimens with straight grain or 1:12 slope of grain failed in fatigue in horizontal shear along the V-notches, cut parallel to the axis of the beam to simulate a drying check at midheight, that reduced the total width by one -half. Failures were predominantly along the checks that extended from load point to support, rather than along the shorter check that originated halfway between the load point and support, indicating the continuous check was more severe than the other one. Fatigue strength for 2 million cycles was estimated at 45 percent of the static shear strength for the straight-grained southern pine, 40 percent of the static shear strength for the southern pine with 1:12 slope of grain, and 45 percent of the static shear strength for Douglas-fir with straight or sloping grain.

5. Fatigue Resistance, Treated, Artificially Checked Specimens

The treated, artificially checked specimens with straight or sloping grain of both species developed fatigue failures under repeated loading in the same manner as did the air-dry specimens. The percentages of matched shear strength estimated to represent fatigue strength at 2 million cycles were:

Southern pine with straight grain, 40 percent

Southern pine with sloping grain, 30 percent

Douglas-fir with straight grain, 50 percent

Douglas-fir with sloping grain, 45 percent

6. Species Effect, Green Material

Comparisons of the fatigue strength of the green, unchecked southern pine and Douglas-fir indicate no significant differences in fatigue behavior between species.

7. Species Effect, Straight-Grain Unchecked Treated vs. Air-Dry

Comparisons between the results of the tests for air-dry and the treated unchecked specimens indicate that the fatigue strength at 2 million cycles for the treated, straight-grained southern pine was substantially lower, based on a percentage of static strength, than that for the untreated, equivalent air-dry material. There was a similar, but not so large, difference between treated and untreated straight-grained Douglas-fir. This lower fatigue resistance for treated, straight-grained material suggests that the conditions of treatment reduce the resistance to fatigue in addition to any reduction in static strength.

8. Treatment Effect, 1:12 Slope of Grain, Unchecked

The fatigue tests of unchecked specimens with 1:12 slope of grain showed slight or no difference between treated and untreated material. Fatigue strength values were not substantially different when comparisons were based on percentages of static strength. There were differences between the static strength of the treated and air-dry southern pine with sloping grain that made the fatigue strength lower for the treated material when compared on a basis of pounds per square inch.

9. Treatment Effect, Artificially Checked

There was no material difference in the fatigue behavior of Douglas-fir in shear (artificially checked specimens), whether the material was treated or not. Values for fatigue strength were about the same percentages of the static strength for both straight- and sloping-grained specimens, regardless of whether or not they were treated. In southern pine the fatigue strength values were a lower percentage of the static strength when specimens were treated than when they were not, which suggests that the conditions of treatment reduced the fatigue resistance of the southern pine somewhat over the reduction in static strength.

10. Effect of Treatment on Static Strength in Bending and Shear

The conditioning and treatment for the southern pine and Douglas-fir apparently had some effect in reducing static strength. Static bending strength of the treated southern pine was 9 to 15 percent less than that of corresponding untreated material. Shear strength (artificially checked specimens) was about 22 percent less. Bending strength of the Douglas-fir was not reduced so much--about 5 percent--and shear strength was reduced about 17 percent on the average. These reductions were not considered in previous conclusions because all comparisons were based on percentages of static strength.

11. Fatigue Resistance in Terms of Present Design

The results of the fatigue test research program indicate that with present methods of deriving working stresses for timber, the fatigue strength for 2 million repetitions of stress in flexure is probably adequate for all unchecked material, except treated southern pine, providing proper reductions are made in deriving working stresses for reductions in static strength due to treatment, and slope of grain does not exceed 1:12. The flexural fatigue resistance of the treated southern pine was less than the factor of 0.50 obtained by combining the factors for the near minimum factor of safety and the factor for duration of stress.

All of the estimated fatigue strength values for shear in the artificially checked specimens of southern pine were less than 50 percent of the static strength and the corresponding values for Douglas-fir were 50 percent, or slightly less, of the static strength, suggesting that some reduction in shear design stresses should be considered where fatigue may be important.

12. Limitation of Results on a Pound-Per-Square-Inch Basis

Analyses of the results of fatigue strength for 2 million cycles of stress in pounds per square inch are only indicative of average values for material of the same density as included in this study and cannot be used to determine the margin of fatigue resistance for material of the lowest quality permitted in either species.

Table 1.--Summary of results of static control tests of green, straight-grained, unchecked, quarter-scale, southern pine bridge stringers[1]

Specimen No.	Moisture content	Specific gravity[2]	Modulus of rupture	Type of failure
	Percent		P.s.i.	
2-P-G-C-U-8	30.3	0.54	7,760	Heavy compression followed by splintering tension
3-P-G-C-U-9	88.1	.52	7,670	Do.
3-P-G-C-U-10	147.7	.46	6,020	Do.
5-P-G-C-U-6	116.2	.54	6,910	Do.
7-P-G-C-U-9	118.7	.54	7,600	Do.
9-P-G-C-U-8	34.4	.56	7,720	Do.
10-P-G-C-U-7	35.9	.58	8,270	Do.
11-P-G-C-U-7	92.9	.56	8,080	Do.
12-P-G-C-U-6	115.8	.55	7,350	Heavy progressive compression
13-P-G-C-U-7	101.4	.57	7,180	Heavy compression followed by splintering tension
14-P-G-C-U-10	46.8	.60	8,540	Do.
14-P-G-C-U-11	118.1	.54	6,740	Do.
15-P-G-C-U-6	147.3	.47	6,160	Heavy progressive compression
15-P-G-C-U-11	32.0	.55	6,920	Heavy compression followed by splintering tension
16-P-G-C-U-12	33.7	.59	8,800	Heavy compression followed by tension and shear
Av.....	84.0	.54	7,450	

[1] Specimens 2 by 4 by 43 inches tested in bending by loading at third points of 39-inch span.

[2] Based on volume and weight when ovendry.

Table 2.--Summary of results of fatigue tests of green, straight-grained, unchecked, quarter-scale, southern pine bridge stringer[1]

Specimen No.	Moisture content	Specific gravity[2]	Control strength[3]	Maximum repeated stress[4]		Cycles to failure	Type of failure
	Percent		P.s.i.	Percent of control	P.s.i.		
2-P-G-F-U-13	28.0	0.54	7,760	60	4,660	6,238,300	Progressive compression followed by shear
3-P-G-F-U-14	99.2	.52	7,670	59.6	4,570	67,600	Heavy progressive compression followed by slight tension
3-P-G-F-U-15	157.0	.47	6,020	60	3,610	158,700	Do.
5-P-G-F-U-11	123.1	.52	6,910	50	3,460	297,200	Do.
7-P-F-G-U-14	79.4	.57	7,600	50	3,800	10,684,000	No failure
9-P-G-F-U-13	21.6	.57	7,720	50	3,860	14,689,700	Do.
10-P-G-F-U-12	26.5	.58	8,270	50	4,140	11,702,800	Do.
11-P-G-F-U-12	130.2	.54	8,080	50	4,040	238,600	Heavy progressive compression followed by slight tension
12-P-G-F-U-11	82.2	.52	7,350	50	3,680	11,109,700	Heavy progressive compression, no tension (incomplete failure)
13-P-G-F-U-12	83.6	.60	7,180	40	2,870	10,837,900	No failure
14-P-G-F-U-15	56.8	.....	8,540	40	3,420	10,968,700	Do.
14-P-G-F-U-16	120.3	.56	6,740	55	3,700	839,600	Heavy progressive compression, no tension
15-P-G-F-U-11	135.2	.49	6,160	55	3,390	11,077,500	Heavy progressive compression followed by slight tension (incomplete failure)
15-P-G-F-U-16	29.8	.55	6,920	40	2,770	10,191,300	No failure
16-P-G-F-U-17	31.9	.58	8,800	40	3,520	10,968,700	Do.
Av.....	79.0	.54	7,450	.....	.....	.....	

[1] Specimens 2 by 4 by 43 inches loaded at third points of 39-inch span at 500 cycles per minute.

[2] Based on volume and weight when ovendry.

[3] Static strength of matched specimen.

[4] Fiber stress in bending, minimum repeated stress 0.10 of maximum.

Table 3.--Summary of results of static control tests of green, unchecked, quarter-scale, southern pine bridge stringers[1] with 1:12 slope of grain

Specimen No.	Moisture content	Specific gravity[2]	Modulus of rupture	Type of failure
	Percent		P.s.i.	
2-P-G-C-U-3	32.5	0.51	6,440	Cross-grained tension
3-P-G-C-U-5	30.2	.52	6,420	Compression followed by cross-grained tension
4-P-G-C-U-1	131.0	.50	5,750	Do.
5-P-G-C-U-1	64.7	.56	6,860	Do.
6-P-G-C-U-2	32.7	.58	7,280	Heavy compression followed by splintering tension
8-P-G-C-U-4	39.1	.64	8,810	Compression followed by cross-grained tension
9-P-G-C-U-5	35.1	.51	6,590	Do.
10-P-G-C-U-2	33.5	.55	7,260	Compression followed by shear
11-P-G-C-U-4	117.1	.60	7,510	Compression followed by cross-grained tension
12-P-G-C-U-5	93.9	.62	7,480	Do.
13-P-G-C-U-1	106.9	.59	7,240	Heavy compression followed by splintering tension
14-P-G-C-U-2	35.5	.58	7,930	Compression followed by cross-grained tension
15-P-G-C-U-5	125.7	.55	6,610	Heavy compression followed by splintering tension
16-P-G-C-U-1	125.5	.51	6,100	Compression followed by cross-grained tension
17-P-G-C-U-1	79.0	.62	7,000	Do.
18-P-G-C-U-2	32.8	.54	7,480	Do.
20-P-G-C-U-1	99.8	.55	6,550	Do.
Av.....	71.5	.56	7,020	

[1]Specimens 2 by 4 by 43 inches tested in bending by loading at the third points of 39-inch span.

[2]Based on volume and weight when ovendry.

Table 4.--Summary of results of fatigue tests of green, unchecked, quarter-scale, southern pine bridge stringers[1] with 1:12 slope of grain

Specimen No.	Moisture content	Specific gravity[2]	Control strength[3]	Maximum repeated stress[4]		Cycles to failure	Type of failure
	Percent		P.s.i.	Percent of control	P.s.i.		
2-P-G-F-U-8	31.3	0.54	6,440	60	3,860	3,888,100	Heavy progressive compression followed by shear
3-P-G-F-U-10	62.2	.56	6,420	60	3,850	10,783,200	No failure
4-P-G-F-U-6	110.5	.49	5,750	50	2,880	11,686,600	Do.
5-P-G-F-U-6	53.2	.55	6,860	50	3,430	10,285,600	Do.
6-P-G-F-U-7	27.1	.59	7,280	40	2,910	10,182,800	Do.
8-P-G-F-U-9	38.1	.63	8,810	40	3,520	10,244,800	Do.
9-P-G-F-U-10	65.7	.57	6,590	60	3,950	92,600	Heavy progressive compression followed by cross-grained tension
10-P-G-F-U-7	31.9	.55	7,260	60	4,360	4,704,400	Heavy progressive compression followed by shear
11-P-G-F-U-9	57.1	.59	7,510	50	3,760	10,748,400	No failure
12-P-G-F-U-10	103.7	.63	7,480	50	3,740	10,346,300	Do.
13-P-G-F-U-6	104.0	.61	7,240	40	2,900	10,765,000	Do.
14-P-G-F-U-7	33.5	.61	7,930	40	3,170	11,697,400	Do.
15-P-G-F-U-10	133.5	.54	6,610	65	4,300	96,400	Heavy progressive compression
16-P-G-F-U-6	140.2	.55	6,100	65	3,960	103,500	Do.
17-P-G-F-U-6	93.0	.58	7,000	65	4,550	27,200	Heavy progressive compression followed by cross-grained tension
18-P-G-F-U-7	34.7	.54	7,480	60	4,480	107,400	Do.
20-P-G-F-U-6	148.6	.51	6,550	60	3,930	177,800	Do.
Av.....	74.6	.57	7,020	.....	.....	.....	

[1] Specimens 2 by 4 by 43 inches loaded at third points of 39-inch span at 500 cycles per minute.

[2] Based on volume and weight when ovendry.

[3] Static strength of matched specimen.

[4] Fiber stress in bending, minimum repeated stress 0.10 of maximum.

Table 5.--Summary of results of static control tests of air-dry, straight-grained, unchecked, quarter-scale, southern pine bridge stringers[1]

Specimen No.	Moisture content	Specific gravity[2]	Modulus of rupture	Type of failure
	Percent		P.s.i.	
2-P-D-C-U-7	10.8	0.54	13,440	Compression followed by tension
3-P-D-C-U-8	11.1	.56	13,580	.....do.....
4-P-D-C-U-7	11.2	.56	13,370	.....do.....
5-P-D-C-U-10	11.0	.54	11,590	.....do.....
6-P-D-C-U-9	10.9	.54	10,910	.....do.....
7-P-D-C-U-8	10.9	.57	15,680	.....do.....
8-P-D-C-U-7	12.0	.59	15,540	.....do.....
9-P-D-C-U-7	11.2	.54	14,370	.....do.....
10-P-D-C-U-6	10.9	.54	10,180	.....do.....
12-P-D-C-U-10	11.2	.58	14,270	.....do.....
13-P-D-C-U-6	11.1	.58	14,140	.....do.....
14-P-D-C-U-9	11.6	.59	16,400	.....do.....
15-P-D-C-U-10	11.2	.50	10,940	.....do.....
16-P-D-C-U-11	11.0	.56	15,100	.....do.....
Av.....	11.2	.56	13,540	

[1]Specimens 2 by 4 by 43 inches tested in bending by loading at the third points of a 39-inch span.

[2]Based on volume and weight when ovendry.

Table 6.--Summary of results of fatigue tests of air-dry, straight-grained, unchecked, quarter-scale, southern pine bridge stringers[1]

Specimen No.	Moisture content	Specific gravity[2]	Control strength[3]	Maximum repeated stress[4]		Cycles to failure	Type of failure	Remarks
	Percent		P.s.i.	Percent of control	P.s.i.			
2-P-D-F-U-12	10.3	0.54	13,440	65	8,740	3,983,300	Compression followed by tension	
3-P-D-F-U-13	10.5	.55	13,580	65	8,830	927,600	.....do.....	
4-P-D-F-U-12	10.5	.54	13,370	60	8,020	10,265,300	No failure	
5-P-D-F-U-15	11.1	.50	11,590	60	6,950	183,100	Cross-grained tension failure--not typical	
6-P-D-F-U-14	10.6	.54	10,910	50	5,450	10,198,200	No failure	
7-P-D-F-U-13	9.9	.60	15,680	50	7,840	10,141,400	.....do.....	
8-P-D-F-U-12	10.3	.62	15,540	50	7,770	10,011,300	.....do.....	
9-P-D-F-U-12	9.9	.56	14,370	50	7,180	480,000	Shear	Conditioning off cull test
10-P-D-F-U-11	9.9	.52	10,180	60	6,110	10,453,200	No failure	
12-P-D-F-U-15	10.1	.56	14,270	55	7,840	10,450,400	Partial failure	
13-P-D-F-U-11	9.9	.60	14,140	55	7,780	6,266,500	Compression followed by tension	
14-P-D-F-U-14	12.0	.63	16,400	60	9,840	51,500	.....do.....	
15-P-D-F-U-15	10.6	.50	10,940	70	7,660	3,400,600	.....do.....	
16-P-D-F-U-16	10.5	.54	15,100	70	10,570	3,000	.....do.....	
Av.....	10.4	.56	13,540	.....	.....	.....		

[1]Specimens 2 by 4 by 43 inches loaded at third points of a 39-inch span at 500 cycles per minute.

[2]Based on volume and weight when ovendry.

[3]Static strength of matched specimen.

[4]Fiber stress in bending, minimum repeated stress 0.10 of maximum.

Table 7.--Summary of results of static control tests of air-dry, unchecked, quarter-scale, southern pine bridge stringers[1] with 1:12 slope of grain

Specimen No.	Moisture content	Specific gravity[2]	Modulus of rupture	Type of failure
	Percent		P.s.i.	
1-P-D-C-U-1	10.8	0.52	8,280	Cross-grained tension
2-P-D-C-U-2	11.0	.54	10,420	Do.
4-P-D-C-U-5	10.5	.56	9,000	Do.
6-P-D-C-U-1	10.7	.57	10,060	Do.
9-P-D-C-U-1	11.2	.55	10,640	Do.
10-P-D-C-U-1	10.7	.52	11,530	Do.
12-P-D-C-U-4	11.1	.60	12,770	Do.
13-P-D-C-U-5	10.7	.58	8,120	Do.
14-P-D-C-U-1	11.3	.60	11,770	Do.
15-P-D-C-U-4	11.2	.56	10,700	Do.
16-P-D-C-U-5	10.8	.51	10,550	Slight compression followed by cross-grained tension
17-P-D-C-U-5	11.1	.65	10,360	Cross-grained tension
18-P-D-C-U-5	10.6	.50	7,490	Do.
19-P-D-C-U-4	10.5	.56	10,350	Do.
20-P-D-C-U-4	10.9	.61	[3]7,720	Combination cross grain tension and vertical shear not typical
Av.....	10.9	.56	10,150	

[1]Specimens 2 by 4 by 43 inches tested in bending by loading at the third points of a 39-inch span.

[2]Based on volume and weight when ovendry.

[3]Not included in average.

Table 8.--Summary of results of fatigue tests of air-dry, unchecked, quarter-scale, southern pine bridge stringers[1] with 1:12 slope of grain

Specimen No.	Moisture content	Specific gravity[2]	Control strength[3]	Maximum repeated stress[4]		Cycles to failure	Type of failure
	Percent		P.s.i.	Percent of control	P.s.i.		
1-P-D-F-U-6	10.3	0.48	8,280	60	4,970	10,063,500	Tension splinter, incomplete failure
2-P-D-F-U-7	10.9	.54	10,420	60	6,260	962,200	Cross-grained tension
4-P-D-F-U-10	10.6	.49	9,000	55	4,950	367,000	Cross-grained tension influenced by small knot
6-P-D-F-U-6	10.8	.61	10,060	55	5,530	567,000	Cross-grained tension
9-P-D-F-U-6	10.7	.51	10,640	50	5,320	1,226,200	Do.
10-P-D-F-U-6	10.5	.51	11,530	50	5,760	4,147,000	Do.
12-P-D-F-U-9	10.5	.66	12,770	45	5,740	10,000,200	No failure
13-P-D-F-U-10	10.4	.60	8,120	45	3,660	10,240,400	Do.
14-P-D-F-U-6	11.1	.54	11,770	70	8,240	2,500	Cross-grained tension
15-P-D-F-U-9	11.4	.62	10,700	70	7,490	93,600	Do.
16-P-D-F-U-10	10.7	.57	10,550	60	6,330	213,200	Do.
17-P-D-F-U-10	10.2	.62	10,360	50	5,180	10,213,400	No failure
18-P-D-F-U-10	10.4	.....	7,490	65	4,870	10,233,200	Do.
19-P-D-F-U-9	10.8	.58	10,350	65	6,730	262,700	Cross-grained tension
20-P-D-F-U-9	11.0	.63	[5]12,000	45	5,400	5,481,400	Do.
Av.....	10.7	.57	10,150	.....	.....	.....	

[1]Specimens 2 by 4 by 43 inches loaded at third points of a 39-inch span at 500 cycles per minute.

[2]Based on volume and weight when ovendry.

[3]Static strength of matched specimen.

[4]Fiber stress in bending, minimum repeated stress 0.10 of maximum.

[5]Estimated on basis of specific gravity because matched control was not typical. Not included in average.

Table 9.--Summary of results of static control tests of treated, straight grain, unchecked, quarter-scale, southern pine bridge stringers[1]

Specimen No.	Moisture content[2]	Specific gravity[3]	Modulus of rupture	Type of failure
	Percent		P.s.i.	
2-P-T-C-U-9	[4]12.3	[4]0.50	[5]10,170	Horizontal shear at bark inclusion and splintering tension
3-P-T-C-U-6	11.8	.51	10,710	Compression and simple tension
3-P-T-C-U-10	11.6	.52	10,540	Severe compression, splintering tension and shear
4-P-T-C-U-9	11.5	.49	12,000	Compression and simple tension
5-P-T-C-U-7	[4]11.4	[4].54	[4]11,660	Cross-grain tension; combined slope 1:10
6-P-T-C-U-6	[4]12.0	[4].61	[4]11,590	Cross-grain tension; slope wide face 1:10
8-P-T-C-U-9	10.8	.58	11,810	Severe compression and splintering tension
9-P-T-C-U-9	11.7	.56	12,370	Do.
10-P-T-C-U-8	12.0	.58	12,950	Slight compression and simple tension
12-P-T-C-U-7	11.0	.62	15,150	Slight compression and horizontal shear
13-P-T-C-U-8	10.2	.59	13,030	Simple tension
14-P-T-C-U-6	[4]11.5	[4].60	[4]13,720	Horizontal shear
15-P-T-C-U-7	12.2	.53	11,420	Severe compression and splintering tension
16-P-T-C-U-13	[4]13.5	[4].59	[4]12,930	Cross-grain tension and horizontal shear local slope 1:10
17-P-T-C-U-12	11.5	.57	13,720	Splintering tension
Av.....	11.4	.56	12,370	

[1]Specimens 2 by 4 by 43 inches tested in bending by loading at the third points of a 39-inch span.

[2]Determined by resistance-type moisture meter.

[3]From adjacent untreated specimen (based on volume and weight when ovendry)

[4]Value not included in average.

[5]Control value not used; not included in average.

Table 10.--Summary of results of fatigue tests of treated, straight-grained, unchecked, quarter-scale southern pine bridge stringers[1]

Specimen No.	Moisture content[2]	Specific gravity[3]	Control strength[4]	Maximum repeated bending stress[5]		Maximum repeated shear stress	Cycles to failure	Types of failure
	Percent		P.s.i.	Percent of control	P.s.i.	P.s.i.		
2-P-T-F-U-14	10.8	0.50	[6]10,750	57	6,100	475	2,336,300	Horizontal shear
3-P-T-F-U-11	12.0	.51	10,710	55	5,890	460	2,589,300	Do.
3-P-T-F-U-15	11.0	.52	10,540	50	5,270	410	3,314,600	Do.
4-P-T-F-U-14	11.8	.48	12,000	60	7,200	560	388,400	Severe compression followed by slight splintering tension
5-P-T-F-U-12	11.0	.56	[7]11,660	55	6,420	500	828,300	Cross-grain tension; combined slope 1:10
6-P-T-F-U-11	12.0	.62	[7]11,590	50	5,800	450	1,931,200	Cross-grain tension; slope wide face 1:8
8-P-T-F-U-14	11.5	.58	11,810	70	8,270	645	7,800	Horizontal shear
9-P-T-F-U-14	11.0	.58	12,370	45	5,560	430	1,361,600	Do.
10-P-T-F-U-13	11.5	.56	12,950	45	5,820	455	1,631,700	Do.
12-P-T-F-U-12	11.5	.57	15,150	60	9,090	710	9,100	Severe compression followed by splintering tension
13-P-T-F-U-13	11.5	.62	13,030	65	8,470	660	39,000	Severe compression followed by simple tension
14-P-T-F-U-11	11.5	.60	[7]13,720	40	5,490	430	1,878,700	Horizontal shear
15-P-T-F-U-12	11.5	.52	11,420	40	4,570	355	3,598,100	Do.
16-P-T-F-U-18	11.5	.58	[7]12,930	35	4,530	350	2,888,500	Do.
17-P-T-F-U-17	11.0	.57	13,720	35	4,800	370	10,514,000	No failure
Av.....	11.4	.56	12,370					

[1] Specimens 2 by 4 by 43 inches loaded at third points of a 39-inch span at 500 cycles per minute.
[2] Determined by resistance-type moisture meter.
[3] From adjacent untreated specimen (based on volume and weight when ovendry).
[4] Static strength of matched specimen.
[5] Fiber stress in bending, minimum repeated stress 0.10 of maximum.
[6] Estimated on basis of specific gravity, not included in average.
[7] Not included in average.

Table 11.--Summary of results of static control tests of treated, unchecked quarter-scale, southern pine bridge stringers[1] with 1:12 slope of grain

Specimen No.	Moisture content[2]	Specific gravity[3]	Modulus of rupture	Type of failure
	Percent		P.s.i.	
3-P-T-C-U-1	11.5	0.57	7,160	Cross-grain tension
4-P-T-C-U-2	11.0	.53	9,210	Do.
6-P-T-C-U-3	[4]12.2	[4].58	[5]7,820	Cross-grain tension at local slope near knot; cull
8-P-T-C-U-5	11.5	.64	9,920	Cross-grain tension
9-P-T-C-U-2	11.0	.55	8,140	Do.
11-P-T-C-U-5	11.5	.60	7,220	Do.
12-P-T-C-U-1	12.0	.60	8,160	Do.
13-P-T-C-U-2	11.5	.59	9,350	Do.
15-P-T-C-U-1	12.0	.52	8,830	Do.
16-P-T-C-U-3	[4]12.0	[4].57	[5]5,800	Shear from check and cross-grain tension; cull
18-P-T-C-U-3	10.8	.54	9,520	Cross-grain tension
19-P-T-C-U-1	11.0	.59	9,220	Cross-grain and brittle tension
20-P-T-C-U-2	10.2	.57	7,400	Cross-grain tension
20-P-T-C-U-3	[4]11.0	[4].59	[5]5,880	Cross-grain tension at local slope of grain of 1:4; cull
21-P-T-C-U-1	12.0	.....	9,490	Cross-grain tension
Av.....	11.3	.57	8,640	

[1]Specimens 2 by 4 by 43 inches tested in bending by loading at the third points of a 39-inch span.

[2]Determined by resistance-type moisture meter.

[3]From adjacent untreated specimen (based on volume and weight when ovendry).

[4]Value not included in average.

[5]Control value not used; not included in average.

Table 12.--Summary of results of fatigue tests of treated, unchecked, quarter-scale, southern pine bridge stringers[1] with 1:12 slope of grain

Specimen No.	Moisture content[2]	Specific gravity[3]	Control strength[4]	Maximum repeated stress[5]		Cycles to failure	Type of failure
	Percent		P.s.i.	Percent of control	P.s.i.		
3-P-T-F-U-6	10.8	0.52	7,160	55	3,940	1,331,800	Cross-grain tension
4-P-T-F-U-7	11.0	.50	9,210	50	4,600	632,400	Do.
6-P-T-F-U-8	11.5	.59	[6]9,200	51	4,690	109,200	Do.
8-P-T-F-U-10	11.5	.63	9,920	55	5,460	130,400	Do.
9-P-T-F-U-7	12.0	.51	8,140	50	4,070	5,265,400	Cross-grain tension with slight compression
11-P-T-F-U-10	12.1	.59	7,220	70	5,050	219,900	Cross-grain tension
12-P-T-F-U-6	11.0	.63	8,160	45	3,670	4,648,400	Cross-grain tension with shear
13-P-T-F-U-7	11.0	.61	9,350	45	4,210	3,445,600	Cross grain tension
15-P-T-F-U-6	11.0	.55	8,830	60	5,300	479,000	Do.
16-P-T-F-U-8	11.0	.60	[6]9,400	43	4,060	10,936,000	No failure
18-P-T-F-U-8	11.5	.54	9,520	40	3,810	10,656,000	Do.
19-P-T-F-U-6	10.5	.58	9,220	40	3,690	10,586,000	Do.
20-P-T-F-U-7	10.5	.55	7,400	70	5,180	241,000	Cross grain tension
20-P-T-F-U-8	10.5	.59	[6]9,200	45	4,120	11,539,000	No failure
21-P-T-F-U-6	11.5	.....	9,490	50	4,740	5,447,100	Cross grain tension
Av.....	11.2	.57	8,640				

[1] Specimens 2 by 4 by 43 inches loaded at third points of a 39-inch span et 500 cycles per minute.

[2] Obtained by resistance-type moisture meter.

[3] From adjacent untreated specimen (based on volume end weight when ovendry).

[4] Static strength of matched specimen.

[5] Fiber stress in bending, minimum repeated stress 0.10 of maximum

[6] Estimated on basis of specific gravity; not included in average.

Table 13.--Summary of results of static control tests of air-dry, straight-grained, artificially checked, quarter-scale, southern pine bridge stringers[1]

Specimen No.	Moisture content	Specific gravity[2]	Shear strength (gross section)[3]	Type of failure
	Percent		P.s.i.	
2-P-D-C-CH-10	10.8	0.47	785	Shear along long check
3-P-D-C-CH-6	11.2	.54	825	Do.
3-P-D-C-CH-7	11.1	.51	830	Do.
4-P-D-C-CH-10	11.1	.49	740	Do.
6-P-D-C-CH-7	11.6	.61	990	Do.
7-P-D-C-CH-6	11.2	.53	930	Do.
8-P-D-C-CH-10	11.6	.56	905	Do.
10-P-D-C-CH-9	11.3	.57	915	Do.
11-P-D-C-CH-9	10.6	.54	800	Do.
12-P-D-C-CH-8	11.5	.70	1,015	Do.
13-P-D-C-CH-9	10.8	.61	975	Do.
14-P-D-C-CH-7	10.5	.60	965	Do.
15-P-D-C-CH-8	11.0	.59	885	Do.
16-P-D-C-CH-10	10.1	.51	800	Do.
17-P-D-C-CH-10	10.5	.57	890	Do.
Av.....	11.0	.56	885	

[1]Specimens 2 by 4 by 43 inches with artificial checks et mid-height, reducing width by one-half, were tested in bending by loading at third points of 39-inch span.

[2]Based on volume and weight when ovendry.

[3]Sheer strength on actual net cross section approximately 2 times value shown.

Table 14.--Summary of results of fatigue tests of air-dry, straight-grained, artificially checked, quarter-scale, southern pine bridge stringers[1]

Specimen No.	Moisture content	Specific gravity[2]	Control strength shear[3]	Maximum repeated stress[3,4]		Cycles to failure	Type of failure
	Percent		P.s.i. on gross section	Percent of control	P.s.i. on gross section		
2-P-D-F-CH-15	10.6	0.46	785	60	470	31,900	Shear along long check
3-P-D-F-CH-11	11.2	.52	825	60	495	34,100	Do.
3-P-D-F-CH-12	11.1	.51	830	50	415	650,800	Do.
4-P-D-F-CH-15	10.4	.48	740	50	370	1,012,400	Do.
6-P-D-F-CH-12	11.3	.62	990	65	645	25,900	Do.
7-P-D-F-CH-11	11.2	.56	930	65	605	9,300	Do.
8-P-D-F-CH-15	11.3	.60	905	55	500	134,700	Do.
10-P-D-F-CH-14	11.2	.55	915	55	500	233,400	Do.
11-P-D-F-CH-14	10.3	.52	800	45	360	11,366,000	No failure
12-P-D-F-CH-13	11.6	.62	1,015	45	455	611,400	Shear along long check
13-P-D-F-CH-14	11.0	.65	975	40	390	6,583,600	Do.
14-P-D-F-CH-12	10.9	.61	965	40	385	3,152,600	Do.
15-P-D-F-CH-13	11.3	.54	885	45	400	1,182,600	Do.
16-P-D-F-CH-15	10.4	.55	800	40	320	3,581,000	Do.
17-P-D-F-CH-15	10.5	.57	890	35	310	10,850,500	No failure
Av.....	11.0	.56	885	.....	.....	.....	

[1] Specimens 2 by 4 by 43 inches with artificial checks at midheight, reducing width by 0.5, loaded at third points of 39-inch span at 500 cycles per minute.

[2] Based on volume and weight when ovendry.

[3] Shear stress calculated on gross cross section; stress on actual net section was approximately 2 times values shown.

[4] Minimum repeated stress 0.10 of maximum.

Table 15.--Summary of results of static control tests of air-dry, artificially checked, quarter-scale, southern pine bridge stringers[1] with 1:12 slope of grain

Specimen No.	Moisture content	Specific gravity[2]	Modulus of rupture	Shear strength (gross section)[3]	Type of failure
	Percent		P.s.i.	P.s.i.	
2-P-D-C-CH-5	11.6	0.59	8,940	690	Cross-grained tension and shear
3-P-D-C-CH-2	10.6	.57	7,430	.....	Cross-grained tension
4-P-D-C-CH-3	10.5	.56	10,190	.....	Do.
6-P-D-C-CH-4	10.9	.67	.....	970	Shear along long check
7-P-D-C-CH-5	10.8	.54	6,900	.....	Cross-grained tension
8-P-D-C-CH-1	10.8	.59	10,480	810	Cross-grained tension and shear
10-P-D-C-CH-4	10.7	.58	9,730	.....	Cross-grained tension
11-P-D-C-CH-1	10.6	.54	7,060	.....	Do.
12-P-D-C-CH-2	10.8	.60	7,970	.....	Do.
14-P-D-C-CH-4	11.1	.57	.....	835	Shear along long check
15-P-D-C-CH-2	11.0	.52	10,930	845	Cross-grained tension and shear
16-P-D-C-CH-4	11.2	.60	.....	780	Shear along long check
17-P-D-C-CH-4	11.6	.67	12,430	.....	Cross-grained tension
18-P-D-C-CH-4	10.4	.54	.....	765	Shear along long check
19-P-D-C-CH-3	10.5	.59	10,040	775	Cross-grained tension and shear
21-P-D-C-CH-4	11.1	.63	9,860	.....	Cross-grained tension
Av.....	10.9	.58	.....	.....	

[1] Specimens 2 by 4 by 43 inches with artificial checks at midheight, reducing width by one-half, were tested in bending by loading at third points of 39-inch span.

[2] Based on volume and weight when ovendry.

[3] Shear strength on actual net section approximately 2 times value shown.

Table 16.--Summary of results of fatigue tests of air-dry, artificially checked, quarter scale, southern pine bridge stringers[1] with 1:12 slope of grain

Specimen No.	Moisture content	Specific gravity[2]	Control strength: Bending	Control strength: Shear[3]	Maximum repeated stress[4]: Ratio of control	Maximum repeated stress[4]: Shear[3]	Cycles to failure	Type of failure
	Percent		P.s.i.	P.s.i.	Percent	P.s.i.		
2-P-D-F-CH-10	11.4	0.56	8,940	[5]790	52	415	222,800	Shear along long check
3-P-D-F-CH-7	10.6	.52	7,430	[5]720	48	345	686,000	Do.
4-P-D-F-CH-8	10.5	.52	10,190	[5]720	55	395	129,700	Do.
6-P-D-F-CH-9	11.8	.72	.....	970	50	485	245,500	Do.
7-P-D-F-CH-10	10.6	.55	6,900	[5]770	28	215	10,525,000	No failure
8-P-D-F-CH-6	10.4	.59	.....	810	40	325	2,724,400	Shear along long check
10-P-D-F-CH-9	11.2	.58	9,730	[5]810	46	375	711,200	Do.
11-P-D-F-CH-6	10.7	.55	7,060	[5]770	36	275	9,037,700	Do.
12-P-D-F-CH-7	11.2	.63	7,970	[5]890	31	275	10,934,700	No failure
14-P-D-F-CH-9	11.9	.65	.....	835	45	375	774,200	Shear along long check
15-P-D-F-CH-7	11.5	.55	10,930	845	70	590	15,700	Do.
16-P-D-F-CH-9	11.4	.62	.....	780	70	545	54,800	Do.
17-P-D-F-CH-9	14.1	.78	12,430	[6]---	40	385	2,995,400	Do.
18-P-D-F-CH-9	10.6	.53	.....	765	40	305	4,670,100	Do.
19-P-D-F-CH-8	10.9	.67	10,040	[5]940	37	350	871,000	Do.
21-P-D-F-CH-9	11.0	.66	9,860	[5]920	41	380	1,158,200	Do.
Av.....	11.2	.60	.....	[5]840	.....	.....	.....	

[1] Specimens 2 by 4 by 43 inches with artificial checks at midheight, reducing width by 0.5, loaded at third points of 39-inch span at 500 cycles per minute.

[2] Based on volume and weight when ovendry.

[3] Shear stress calculated on gross cross section; stress on actual net section was approximately 2 times values shown.

[4] Minimum repeated stress 0.10 of maximum.

[5] Estimated on basis of specific gravity.

[6] Because of high specific gravity, shear strength was not estimated.

Table 17.--Summary of results of static control tests of treated, straight-grained, artificially checked, quarter-scale, southern pine bridge stringers[1]

Specimen No.	Moisture content[2]	Specific gravity[3]	Modulus of rupture	Shear strength (gross section)[4]	Type of failure
	Percent		P.s.i.	P.s.i.	
2-P-T-C-CH-6	11.2	0.56	.....	635	Shear along long check
3-P-T-C-CH-7	11.2	.54	.....	755	Do.
3-P-T-C-CH-8	11.8	.52	.....	765	Do.
4-P-T-C-CH-6	11.0	.56	.....	495	Do.
5-P-T-C-CH-9	11.4	.54	.....	770	Do.
6-P-T-C-CH-8	[5]11.2	[5].58	9,790	.....	Brittle tension
7-P-T-C-CH-7	12.0	.55	.....	695	Shear along long check
8-P-T-C-CH-6	11.8	.59	.....	600	Do.
9-P-T-C-CH-6	12.3	.54	.....	605	Do.
10-P-T-C-CH-10	11.2	.57	.....	640	Do.
11-P-T-C-CH-10	11.5	.54	.....	645	Do.
12-P-T-C-CH-9	11.5	.64	.....	740	Do.
13-P-T-C-CH-10	12.1	.61	.....	630	Shear along short check
14-P-T-C-CH-8	11.4	.60	.....	670	Shear along long check
15-P-T-C-CH-9	11.5	.54	.....	705	Do.
16-P-T-C-CH-14	11.4	.59	.....	810	Shear along both checks
17-P-T-C-CH-11	11.0	.57	10,800	840	Shear and simple tension
Av.....	11.5	.57	.....	690	

[1] Specimens 2 by 4 by 43 inches with artificial checks at midheight, reducing width by one-half were tested by loading at third points of 39-inch span.

[2] Determined by resistance-type moisture meter.

[3] From adjacent untreated specimen; based on volume and weight when ovendry.

[4] Shear strength on actual net cross section approximately 2 times value shown.

[5] Not included in average.

Table 18.--Summary of results of fatigue tests of treated, straight-grained, artificially checked, quarter-scale, southern pine bridge stringers[1]

Specimen No.	Moisture content[2]	Specific gravity[3]	Control strength		Maximum repeated stress[5]			Cycles to failure	Type of failure
			Bending	Shear[4]	Ratio	Bending	Shear[4]		
	Percent		P.s.i.	P.s.i.	Percent of control	P.s.i.	P.s.i.		
2-P-T-F-CH-11	12.0	0.54	.....	635	55	.....	350	254,900	Shear along long check
3-P-T-F-CH-12	10.5	.52	.....	755	50	.....	375	136,800	Do.
3-P-T-F-CH-13	11.0	.52	.....	765	40	.....	305	2,006,300	Do.
4-P-T-F-CH-11	12.0	.54	.....	495	30	.....	150	10,558,000	No failure
5-P-T-F-CH-14	11.0	.50	.....	770	55	.....	425	626,500	Shear along long check
6-P-T-F-CH-13	11.0	.58	9,790	[6]710	54	4,900	380	1,311,600	Do.
7-P-T-F-CH-12	11.5	.58	.....	695	40	.....	280	4,533,100	Do.
8-P-T-F-CH-11	11.5	.62	.....	600	30	.....	180	11,303,000	No failure
9-P-T-F-CH-11	11.5	.56	.....	605	35	.....	210	3,535,200	Shear along long check
10-P-T-F-CH-15	11.5	.55	.....	640	35	.....	225	2,712,100	Do.
11-P-T-F-CH-15	12.2	.52	.....	645	60	.....	385	111,300	Do.
12-P-T-F-CH-14	12.0	.59	.....	740	60	.....	445	110,600	Shear along short check
13-P-T-F-CH-15	12.0	.65	.....	630	70	.....	440	15,300	Shear along long check
14-P-T-F-CH-13	11.5	.62	.....	670	70	.....	470	17,600	Do.
15-P-T-F-CH-14	11.5	.52	.....	705	45	.....	320	454,300	Do.
16-P-T-F-CH-19	11.0	.59	.....	810	45	.....	365	90,500	Do.
17-P-T-F-CH-16	11.5	.57	.....	840	45	.....	380	413,700	Do.
Av.....	11.5	.56		690					

[1]Specimens 2 by 4 by 43 inches with artificial checks at midheight reducing width by one-half, loaded at third points of 39-inch span at 500 cycles per minute-

[2]Determined by resistance-type moisture meter.

[3]From adjacent untreated specimen; based on volume and weight when ovendry.

[4]Shear stress calculated on gross cross section; stress or actual net section was approximately 2 times value shown.

[5]Minimum repeated stress 0.10 of maximum.

[6]Estimated on basis of specific gravity.

Table 19.--Summary of results of static control tests of treated, artificially checked, quarter scale, southern pine bridge stringers[1] with 1:12 slope of grain

Specimen No.	Moisture content[2]	Specific gravity[3]	Modulus of rupture	Shear strength (gross section)[4]	Type of failure
	Percent		P.s.i.	P.s.i.	
2-P-T-C-CH-1	11.0	0.54	.....	570	Shear along long check
3-P-T-C-CH-3	[5]11.0	[5].57	[6]4,140	[6]320	Cross-grain tension and shear along short check
5-P-T-C-CH-5	[5]11.0	[5].55	9,440	.....	Cross-grain tension
6-P-T-C-CH-5	12.0	.67	8,710	675	Cross-grain tension and shear along short check
7-P-T-C-CH-1	11.0	.56	.....	610	Shear along long check
8-P-T-C-CH-2	11.5	.59	8,520	.....	Mainly cross-grain tension with possible shear
10-P-T-C-CH-5	11.5	.58	8,400	655	Cross-grain tension and shear along long check
11-P-T-C-CH-2	11.9	.54	8,230	.....	Cross-grain tension
13-P-T-C-CH-4	11.4	.58	.....	750	Shear along long check
14-P-T-C-CH-5	11.8	.57	.....	660	Do.
16-P-T-C-CH-2	11.0	.51	8,960	695	Cross-grain tension and shear along long check
17-P-T-C-CH-2	11.5	.62	9,280	.....	Cross-grain tension
18-P-T-C-CH-1	11.0	.54	.....	595	Shear along long check
19-P-T-C-CH-2	11.8	.59	8,640	670	Shear along long check predominate, with cross-grain tension
21-P-T-C-CH-2	[5]10.5	[5].63	[6]6,980	.....	Simple and cross-grain tension not typical
Av.....	11.8	.57	8,770	655	

[1] Specimens 2 by 4 by 43 inches with artificial checks at midheight, reducing width by one-half were tested in bending by loading at third points of 39-inch span.

[2] Determined by resistance-type moisture meter.

[3] From adjacent untreated specimen; based on volume and weight when ovendry.

[4] Shear strength on actual net section approximately 2 times value shown.

[5] Not included in average.

[6] Not used as control or included in average.

Table 20.--Summary of results of fatigue tests of treated, artificially checked, quarter-scale, southern pine bridge stringers[1] with 1:12 slope of grain

Specimen No.	Moisture content	Specific gravity[2]	Control strength		Maximum repeated stress[4]			Cycles to failure	Type of failure
			Bending	Shear[3]	Ratio	Bending	Shear[3]		
	Percent		P.s.i.	P.s.i.	Percent of control	P.s.i.	P.s.i.		
2-P-T-F-CH-6	11.5	0.54	.....	570	55	.....	315	53,100	Shear along long check
3-P-T-F-CH-8	11.5	.52	4,140	[5]560	29	.....	160	13,155,000	No failure
5-P-T-F-CH-10	11.5	.55	9,440	[6]735	40	.....	295	2,541,900	Shear along short check
6-P-T-F-CH-10	10.5	.72	8,710	675	30	.....	205	10,535,000	No failure
7-P-T-F-CH-6	12.0	.56	.....	610	55	.....	335	116,300	Shear along long check
8-P-T-F-CH-7	11.5	.59	8,520	[5]720	47	.....	335	181,000	Do.
10-P-T-F-CH-10	12.0	.58	8,400	655	40	.....	260	197,700	Do.
11-P-T-F-CH-7	11.5	.55	8,230	[6]640	30	.....	195	6,634,000	Do.
13-P-T-F-CH-9	11.0	.60	.....	750	35	.....	265	2,450,000	Do.
14-P-T-F-CH-10	11.0	.65	.....	660	35	.....	230	849,500	Do.
16-P-T-F-CH-7	10.5	.55	8,960	695	60	5,380	420	31,900	Shear along long check and cross-grain tension
17-P-T-F-CH-7	10.6	.62	9,280	[5]790	27	.....	215	12,972,000	No failure
18-P-T-F-CH-6	11.5	.54	.....	595	25	.....	150	12,216,000	Do.
19-P-T-F-CH-7	11.5	.67	.....	670	25	.....	170	10,410,000	Do.
21-P-T-F-CH-7	10.5	.66	6,980	[7]800	41	.....	325	1,660,200	Shear along long check
Av.....	11.2	.59		655					

[1] Specimens 2 by 4 by 43 inches with artificial checks at midheight reducing width by one-half, loaded at third points of 39-inch span at 500 cycles per minute.

[2] From adjacent untreated specimens; based on volume and weight when ovendry.

[3] Shear on actual net section approximately 2 times value shown.

[4] Minimum repeated stress 0.10 of maximum.

[5] Estimated on basis of specific gravity.

[6] Stress in control when bending failure occurred.

[7] Estimated but because of high gravity, value in doubt.

Table 21.--Summary of results of static control tests of green, straight-grained, unchecked quarter-scale Douglas-fir bridge stringers[1]

Specimen No.	Moisture content	Specific gravity[2]	Modulus of rupture	Type of failure
	Percent		P.s.i.	
1-F-G-C-U-7	32.2	0.52	7,320	Heavy compression followed by splintering tension
2-F-G-C-U-8A	31.9	[3].48	7,100	Do.
3-F-G-C-U-10	32.4	.56	7,740	Compression followed by shear
4-F-G-C-U-8A	[4]32.6	[4].49	[5]5,890	Heavy compression followed by simple tension at small knot
5-F-G-C-U-11	66.4	.50	6,520	Heavy compression followed by splintering tension
7-F-G-C-U-17	31.9	.51	6,840	Do.
7-F-G-C-U-22	107.8	.41	5,920	Do.
8-F-G-C-U-17	52.2	.46	6,340	Do.
9-F-G-C-U-27	34.3	.42	5,820	Do.
10-F-G-C-U-21	32.8	.48	6,040	Do.
10-F-G-C-U-26	33.5	.49	6,700	Do.
11-F-G-C-U-19	32.6	.61	8,400	Do.
12-F-G-C-U-17	32.0	.58	7,360	Heavy compression followed by cross-grain tension
13-F-G-C-U-21	[4]36.7	[4].44	[5]5,160	Compression followed by simple tension at small knot
14-F-G-C-U-16	33.7	.41	5,800	Heavy compression followed by splintering tension
16-F-G-C-U-16	[4]33.1	[4].49	[5]5,680	Diagonal grain outside load blocks
Av.....	42.6	.49	6,760	

[1] Specimens 2 by 4 by 43 inches tested in bending by loading at third points of 39-inch span.

[2] Based on volume and weight when ovendry.

[3] From specimen 2-F-D-F-U-7A.

[4] Not included in average.

[5] Control value not used, not included in average.

Table 22.--Summary of results of fatigue tests of green, straight-grained, unchecked, quarter-scale, Douglas-fir bridge stringers[1]

Specimen No.	Moisture content	Specific gravity[2]	Control strength[3]	Maximum repeated stress[4]		Cycles to failure	Type of failure
	Percent		P.s.i.	Percent of control	P.s.i.		
1-F-G-F-U-12	26.2	0.52	7,320	60	4,390	10,300,000	No failure
2-F-G-F-U-13A	37.0	.....	7,100	70	4,970	9,800	Heavy compression followed by splintering tension
3-F-G-F-U-15	23.6	.57	7,740	60	4,640	10,240,000	Incomplete failure; some compression
4-F-G-F-U-13A	32.6	.48	[5]6,700	62	4,120	1,709,600	Heavy compression followed by shear and tension
5-F-G-F-U-16	83.5	.49	6,520	70	4,560	4,400	Heavy compression followed by tension from small knot
7-F-G-F-U-25	31.7	.52	6,840	65	4,450	2,588,900	Heavy compression followed by horizontal shear
7-F-G-F-U-30	110.6	.40	5,920	65	3,860	23,300	Heavy compression followed by tension
8-F-G-F-U-25	43.2	.47	6,340	70	4,440	15,600	Do.
9-F-G-F-U-36	39.2	.43	5,820	60	3,490	35,500	Do.
10-F-G-F-U-30	37.2	.47	6,040	60	3,620	10,444,000	Incomplete failure; some compression
10-F-G-F-U-35	39.0	.48	6,700	65	4,350	5,063,900	Heavy compression followed by horizontal shear
11-F-G-F-U-26	34.5	.63	8,400	65	5,460	76,300	Heavy compression followed by tension 1:9 slope of grain
12-F-G-F-U-25	36.4	.58	7,360	60	4,420	2,871,900	Heavy compression followed by tension 1:10 slope of grain
13-F-G-F-U-29	44.8	.43	[5]5,950	52	3,100	10,292,000	Incomplete failure; some compression
14-F-G-F-U-24	32.3	.40	5,800	55	3,190	10,350,000	No failure
16-F-G-F-U-23	59.2	.43	[5]5,950	48	2,840	10,375,000	Do.
Av.....	44.4	.49	6,760				

[1] Specimens 2 by 4 by 43 inches loaded at third points of 39-inch span at 500 cycles per minute.

[2] Based on volume and weight when ovendry.

[3] Static strength of matched specimen.

[4] Fiber stress in bending, minimum repeated stress 0.10 of maximum.

[5] Estimated for value of specific gravity; see note on control test; not included in average.

Table 23.--Summary of results of static control tests of green, unchecked, quarter-scale, Douglas-fir bridge stringers[1] with 1:12 slope of grain

Specimen No.	Moisture content	Specific gravity[2]	Modulus of rupture	Type of failure
	Percent		P.s.i.	
2-F-G-C-U-1	30.8	0.55	6,840	Heavy compression followed by cross-grain tension
3-F-G-C-U-2A	32.9	.54	5,520	Do.
3-F-G-C-U-5	31.7	.56	7,030	Do.
4-F-G-C-U-4	[3]24.1	[3].51	[3]5,400	Compression at small knot followed by cross-grain tension
5-F-G-C-U-3	[3]32.9	[3].51	[3]5,720	Compression followed by tension at knot
7-F-G-C-U-1	29.0	.45	6,280	Heavy compression followed by splintering tension
7-F-G-C-U-6	30.8	.53	6,040	Heavy compression followed by cross-grain tension
9-F-G-C-U-2	32.3	.50	5,630	Do.
9-F-G-C-U-7	32.2	.48	5,230	Do.
10-F-G-C-U-1	32.1	.51	7,160	Do.
12-F-G-C-U-3	[3]30.9	[3].59	[3]4,670	Cross-grain tension along pitch-filled ring
13-F-G-C-U-1	31.3	.49	6,680	Heavy compression followed by cross-grain tension
13-F-G-C-U-6	34.4	.45	3,300	Cross-grain tension
15-F-G-C-U-6	33.0	.50	6,230	Heavy compression followed by cross-grain tension
Av.....	31.9	.51	5,990	

[1] Specimens 2 by 4 by 43 inches tested in bending by loading at third points at 39-inch span.

[2] Based on volume and weight when ovendry.

[3] Control value not used, not included in average.

Table 24.--Summary of results of fatigue tests of green, unchecked, quarter-scale, Douglas-fir bridge stringers[1] with 1:12 slope of grain

Specimen No.	Moisture content	Specific gravity[2]	Control strength[3]	Maximum repeated stress[4]		Cycles to failure	Type of failure
	Percent		P.s.i.	Percent of control	P.s.i.		
2-F-G-F-U-6	27.4	0.53	6,840	60	4,100	10,133,000	No failure
3-F-G-F-U-7A	27.9	.52	5,520	60	3,310	10,153,000	Do.
3-F-G-F-U-10	35.5	.55	7,030	70	4,920	189,800	Heavy compression followed by shear
4-F-G-F-U-9	32.5	.50	[5]6,200	61	3,780	2,153,100	Compression followed by cross-grain tension and shear
5-F-G-F-U-8	47.2	.48	[5]5,930	63	3,720	34,200	Heavy compression followed by cross-grain tension
7-F-G-F-U-8	35.2	.48	6,280	70	4,390	7,300	Heavy compression followed by splintering tension
7-F-G-F-U-13	33.1	.49	6,040	65	3,920	10,971,000	Incomplete failure; some compression
9-F-G-F-U-11	40.0	.47	5,630	65	3,660	11,148,000	Do.
9-F-G-F-U-16	34.7	.45	5,230	60	3,140	10,975,000	No failure
10-F-G-F-U-10	39.7	.48	7,160	55	3,940	[6]184,800	Heavy compression followed by cross-grain failure
12-F-G-F-U-10	32.7	.62	[5]7,600	34	2,570	11,330,400	No failure
13-F-G-F-U-9	34.1	.49	6,680	55	3,680	11,189,000	Do.
13-F-G-F-U-14	40.6	.41	3,300	55	1,820	10,135,000	Do.
15-F-G-F-U-13	34.0	.50	6,230	60	3,740	10,098,000	Do.
Av.....	35.3	.50	5,990				

[1] Specimens 2 by 4 by 43 inches loaded at third points of 39-inch span at 500 cycles per minute.

[2] Based on volume and weight when ovendry.

[3] Static strength of matched specimen.

[4] Fiber stress in bending, minimum repeated stress 0.10 of maximum.

[5] Estimated for value of specific gravity; see note on control test.

[6] Local slope of grain (1:4) at failure; not representative.

Table 25.--Summary of results of static control tests of air-dry, straight-grained, unchecked, quarter-scale, Douglas-fir bridge stringers[1]

Specimen No.	Moisture content	Specific gravity[2]	Modulus of rupture	Type of failure
	Percent		P.s.i.	
1-F-D-C-U-6	12.6	0.48	10,920	Compression followed by simple tension
2-F-D-C-U-10	13.2	.56	12,540	Compression followed by splintering tension
3-F-D-C-U-11	13.1	.56	12,230	Do.
7-F-D-C-U-16	13.1	.47	11,340	Do.
7-F-D-C-U-21	13.1	.46	11,200	Do.
8-F-D-C-U-18	13.2	.48	11,250	Do.
10-F-D-C-U-27	13.3	.41	8,580	Compression followed by simple tension
12-F-D-C-U-18	14.3	.60	12,600	Compression followed by splintering tension
13-F-D-C-U-17	13.6	.40	8,180	Compression followed by simple tension
13-F-D-C-U-22	13.5	.46	10,590	Compression followed by splintering tension
14-F-D-C-U-17	[3]13.6	[3].44	[3,4]7,410	Compression followed by splintering tension at knot outside of load
14-F-D-C-U-22	13.4	.37	7,860	Compression followed by simple tension
16-F-D-C-U-17	[3]13.5	[3].51	[3]9,170	Cross-grain tension 1:9 slope
Av.....	13.3	.48	10,660	

[1]Specimens 2 by 4 by 43 inches tested in bending by loading at the third points of a 39-inch span.

[2]Based on volume and weight when ovendry.

[3]Not included in average.

[4]Value not used as control value for fatigue test; knot in specimen adversely affected strength.

Table 26.--Summary of results of fatigue tests of air-dry, straight-grained, unchecked, quarter-scale, Douglas-fir bridge stringer[1]

Specimen No.	Moisture content	Specific gravity[2]	Control strength[3]	Maximum repeated stress[4]		Cycles to failure	Type of failure
	Percent		P.s.i.	Percent of control	P.s.i.		
1-F-D-F-U-11	12.6	0.48	10,920	70	7,650	672,600	Severe compression followed by shear and tension
2-F-D-F-U-15	13.1	.56	12,540	70	8,780	147,500	Severe compression followed by shear
3-F-D-F-U-16	12.6	.55	12,230	60	7,340	10,267,000	Incomplete failure, some compression
7-F-D-F-U-24	13.5	.46	11,340	70	7,940	314,300	Severe compression followed by shear and tension
7-F-D-F-U-29	13.0	.46	11,200	60	6,720	2,992,000	Severe compression followed by simple tension
8-F-D-F-U-26	13.3	.51	11,250	75	8,430	54,000	Severe compression followed by splintering tension
10-F-D-F-U-36	13.0	.40	8,580	50	4,290	9,817,800	Cross-grain tension
12-F-D-F-U-26	13.6	.59	12,600	50	6,300	2,438,200	Horizontal shear
13-F-D-F-U-25	13.3	.39	8,180	50	4,090	11,618,000	No failure
13-F-D-F-U-30	12.6	.47	10,590	50	5,290	12,577,000	Do.
14-F-D-F-U-25	12.7	.43	[5,6]9,400	39	3,705	11,289,000	Do.
14-F-D-F-U-30	13.5	.38	7,860	75	5,890	24,100	Severe compression followed by simple tension
16-F-D-F-U-24	13.0	.47	[6]9,170	50	4,580	4,616,100	Cross-grain tension 1:9 slope
Av.....	13.1	.47	10,660				

[1] Specimens 2 by 4 by 43 inches loaded at third points of a 39-inch span at 500 cycles per minute.

[2] Based on volume and weight when ovendry.

[3] Static strength of matched specimen.

[4] Fiber stress in bending, minimum repeated stress 0.10 of maximum.

[5] Estimated for value of specific gravity; see note on control test.

[6] Not included in average.

Table 27.--Summary of results of static control tests of air-dry, unchecked quarter-scale, Douglas-fir bridge stringers[1] with 1:12 slope of grain

Specimen No.	Moisture content	Specific gravity[2]	Modulus of rupture	Type of failure
	Percent		P.s.i.	
2-F-D-C-U-5	11.6	0.52	9,170	Cross-grain tension
2-F-D-C-U-2A	10.4	.47	5,150	Do.
5-F-D-C-U-2	11.1	.47	6,280	Do.
7-F-D-C-U-2	12.8	.46	[3]8,720	Do.
7-F-D-C-U-7	12.6	.43	8,360	Do.
9-F-D-C-U-8	12.4	.43	7,980	Do.
10-F-D-C-U-2	13.4	.47	6,600	Do.
11-F-D-C-U-[6]	13.6	.59	[4]10,130	Do.
12-F-D-C-U-4	13.5	.61	7,960	Do.
13-F-D-C-U-7	13.1	.44	[5]7,250	Do.
15-F-D-C-U-2	12.7	.52	9,540	Do.
15-F-D-C-U-7	12.5	.44	[6]8,580	Do.
16-F-D-C-U-5	[4]13.0	[4].48	[7]4,900	Tension at knot near lower face
Av.....	12.5	.49	7,980	

[1] Specimens 2 by 4 by 43 inches tested in bending by loading at the third points of a 39-inch span.

[2] Bed on volume and weight when ovendry.

[3] Actual slope on tension face 1:16.

[4] Combined slope of grain 1:6.5.

[5] Actual slope on tension face 1:9.

[6] Combined slope of grain 1:9.

[7] Not included in average.

Table 28.--Summary of results of fatigue tests of air-dry, unchecked, quarter-scale, Douglas-fir, bridge stringers[1] with 1:12 slope of grain

Specimen No.	Moisture content	Specific gravity[2]	Control strength[3]	Maximum repeated stress[4]		Cycles to failure	Type of failure
	Percent		P.s.i.	Percent of control	P.s.i.		
2-F-D-F-U-10	11.6	0.53	9,170	60	5,500	7,238,000	Cross-grain tension
2-F-D-F-U-7A	11.1	.48	5,150	70	3,600	7,500	Cross-grain tension at small knot
5-F-D-F-U-7	10.8	.51	6,280	60	3,770	10,191,000	Incomplete failure, slight compression and tension splinters
7-F-D-F-U-9	13.2	.48	8,720	70	6,100	379,800	Cross-grain tension
7-F-D-F-U-14	12.2	.44	8,360	60	5,020	10,123,000	No failure
9-F-D-F-U-17	12.4	.44	7,980	50	3,990	10,142,000	Do.
10-F-D-F-U-11	12.9	.51	6,600	70	4,620	5,965,200	Cross-grain tension
11-F-D-F-U-13	13.5	.64	10,130	50	5,060	6,011,900	Cross-grain tension[5]
12-F-D-F-U-11	13.4	.58	7,960	50	3,980	3,042,000	Horizontal shear influenced by drying check
13-F-D-F-U-15	12.9	.45	7,250	50	3,620	11,617,000	No failure
15-F-D-F-U-9	13.2	.53	9,540	60	5,720	6,400	Vertical shear along weak ring
15-F-D-F-U-14	12.8	.50	8,580	60	5,150	46,800	Cross-grain tension and vertical shear along weak ring[6]
16-F-D-F-U-12	12.8	.51	[7]9,000	46	4,150	10,266,000	Incomplete failure; slight tension splinter
Av.....	12.5	.51	7,980				

[1] Specimens 2 by 4 by 43 inches tested in bending by loading at third points of a 39-inch span.

[2] Based on volume and weight when ovendry.

[3] Static strength of matched specimen.

[4] Fiber stress in bending, minimum repeated stress 0.10 of maximum.

[5] Combined slope of grain at failure 1:7.5.

[6] Combined slope of grain at failure 1:6.5.

[7] Estimated for specific gravity; see note on control; not included in average.

Table 29.--Summary of results of static control tests of treated, straight-grained, unchecked, quarter-scale, Douglas-fir bridge stringers[1]

Specimen No.	Specific gravity[2]	Modulus of rupture	Type of failure
		P.s.i.	
1-F-T-C-U-8	0.52	9,140	Simple tension
2-F-T-C-U-7	.48	9,700	Do.
3-F-T-C-U-6	.56	12,100	Compression, splintering tension and shear
4-F-T-C-U-11	[3].49	[4]9,090	Compression and splintering tension influenced by distorted grain
5-F-T-C-U-6	.50	10,940	Splintering slight cross-grain tension
5-F-T-C-U-7	[3].50	[4]7,960	Horizontal shear in check
7-F-T-C-U-15	.47	11,430	Compression, tension and shear
7-F-T-C-U-20	.47	12,960	Compression followed by shear
8-F-T-C-U-24	.47	12,580	Do.
9-F-T-C-U-19	[3].48	[4]8,390	Splintering tension at local slope of grain
12-F-T-C-U-19	.60	9,540	Compression, splintering tension and shear
13-F-T-C-U-18	.45	10,700	Compression followed by shear
13-F-T-C-U-23	.43	10,400	Compression, splintering tension and shear
15-F-T-C-U-15	[3].52	[4]8,050	Cross-grain tension (1:9 slope)
15-F-T-C-U-20	.47	9,650	Splintering tension
Av.....	.49	10,830	

[1] Specimens 2 by 4 by 43 inches tested in bending by loading at the third points of a 39-inch span.

[2] Based on volume and weight when ovendry; because specimens were treated, values are from adjacent untreated specimens.

[3] Not included in average.

[4] Not included in average or used for control.

Table 30.--Summary of results of fatigue tests of treated, straight-grained, unchecked, quarter-scale, Douglas-fir bridge stringers[1]

Specimen No.	Specific gravity[2]	Control strength[3]	Maximum repeated stress[4]			Cycles to failure	Type of failure
			Ratio	Bending	Shear		
		P.s.i.	Percent of control	P.s.i.	P.s.i.		
1-F-T-F-U-13	0.52	9,140	45	4,110	315	10,354,000	No failure
2-F-T-F-U-12	.49	9,700	50	4,850	370	11,485,000	Do.
3-F-T-F-U-11	.55	12,100	60	7,260	560	54,300	Compression followed by horizontal shear
4-F-T-F-U-16	.49	[5]10,830	59	6,360	490	3,820,300	Do.
5-F-T-F-U-11	.50	[6]10,940	40	4,380	335	11,485,000	No failure
5-F-T-F-U-12	.50	[6]10,940	70	7,660	590	69,600	Compression followed by splintering tension
7-F-T-F-U-23	.44	11,430	70	8,000	610	32,500	Compression followed by simple tension
7-F-T-F-U-28	.47	12,960	60	7,780	595	35,200	Compression influenced by knot and splintering tension
8-F-T-F-U-32	.47	12,580	50	6,290	485	2,525,700	Compression followed by horizontal shear
9-F-T-F-U-28	.51	[5]11,400	51	5,870	450	1,312,000	Horizontal shear
12-F-T-F-U-27	.60	9,540	60	5,720	440	97,700	Do.
13-F-T-F-U-26	.47	10,700	45	4,820	370	11,925,000	No failure
13-F-T-F-U-31	.43	10,400	40	4,160	320	11,925,000	Do.
15-F-T-F-U-22	.52	[5]11,600	28	3,220	245	10,009,000	Do.
15-F-T-F-U-27	.45	9,650	45	4,340	335	12,353,000	Do.
Av.....	.49	10,830					

[1] Specimens 2 by 4 by 43 inches loaded at third points of a 39-inch span at 500 cycles per minute.

[2] Based on volume and weight when ovendry; because specimens were treated, values are from adjacent untreated specimens.

[3] Static strength of matched specimen (modulus of rupture).

[4] Fiber stress in bending, minimum repeated stress 0.10 of maximum.

[5] Estimated on basis of specific gravity.

[6] Estimated from adjacent static specimen.

Table 31.--Summary of results of static control tests of treated, unchecked, air-dry quarter-scale, Douglas-fir bridge stringers[1] with 1:12 slope of grain

Specimen No.	Specific gravity[2]	Modulus of rupture	Type of failure
		P.s.i.	
1-F-T-C-U-3	[3]0.49	[4]6,180	Cross-grain and splintering tension; distorted grain at failure
2-F-T-C-U-2	[3].55	[4]6,980	Brash tension; not typical
5-F-T-C-U-1	[3].47	[4]4,660	Horizontal shear; probably check
5-F-T-C-U-4	.53	7,200	Simple tension
8-F-T-C-U-1	.48	7,120	Cross-grain tension
9-F-T-C-U-9	.43	8,170	Compression and cross-grain tension
10-F-T-C-U-3	.47	8,440	Splintering cross-grain tension
10-F-T-C-U-8	.35	6,480	Cross-grain tension and vertical shear
11-F-T-C-U-7	.59	7,070	Cross-grain tension, combined slope 1:6
12-F-T-C-U-5	.60	8,100	Cross-grain tension and vertical shear along weak ring
13-F-T-C-U-3	[3].49	[4]5,950	Cross-grain at small knot
13-F-T-C-U-8	.44	5,230	Cross-grain tension
16-F-T-C-U-1	.51	6,700	Cross-grain tension; combined slope 1:8
16-F-T-C-U-6	.43	7,170	Cross-grain tension
Av.....	.48	7,170	

[1]Specimens 2 by 4 by 43 inches tested in bending by loading at the third points of a 39-inch span. Material conditioned and tested at 75° F. and 64 percent relative humidity.

[2]Based on volume and weight when ovendry; because specimens were treated, values are from adjacent untreated specimens.

[3]Not included in average.

[4]Not included in average or used for control.:

Table 32.--Summary of results of fatigue tests of treated, unchecked quarter-scale. Douglas-fir bridge stringers[1] with 1:12 slope of grain

Specimen No.	Specific gravity[2]	Control strength[3]	Maximum repeated stress[4]		Cycles to failure	Type of failure
		P.s.i.	Percent of control	P.s.i.		
1-F-T-F-U-8	0.49	[5]7,400	58	4,320	2,182,600	Cross-grain tension
2-F-T-F-U-7	.53	[5]8,200	51	4,200	11,418,000	No failure
5-F-T-F-U-6	.51	[6]7,200	50	3,600	11,033,000	Slight tension splinter
5-F-T-F-U-9	.52	7,200	40	2,880	143,500	Horizontal shear at check
8-F-T-F-U-9	.49	7,120	70	4,980	30,300	Cross-grain tension
9-F-T-F-U-18	.44	8,170	60	4,900	422,400	Do.
10-F-T-F-U-12	.51	8,440	50	4,220	3,070,000	Cross-grain tension around knot
10-F-T-F-U-17	.37	6,480	70	4,540	51,300	Cross-grain tension
11-F-T-F-U-14	.64	7,070	60	4,240	10,724,000	No failure
12-F-T-F-U-12	.60	8,100	50	4,050	10,378,000	Do.
13-F-T-F-U-11	.49	[5]7,400	44	3,270	10,117,000	Do.
13-F-T-F-U-16	.45	5,230	60	3,140	9,860,200	Cross-grain tension
16-F-T-F-U-8	.53	6,700	45	3,020	11,908,000	No failure
16-F-T-F-U-13	.46	7,170	50	3,580	11,089,000	Do.
Av.....	.50	7,170				

[1]Specimen 2 by 4 by 43 inches loaded at the third points of a 39-inch span at 500 cycles per minute.

[2]Based on volume and weight when ovendry; because specimens were treated, values are from adjacent untreated specimens.

[3]Static strength of matched specimen.

[4]Fiber stress in bending, minimum repeated stress 0.10 of maximum.

[5]Estimated on basis of specific gravity.

[6]Estimated from adjacent static specimen.

Table 33.--Summary of results of static control tests of air-dry, straight-grained, artificially checked, quarter-scale, Douglas-fir bridge stringers[1]

Specimen No.	Moisture content	Specific gravity[2]	Modulus of rupture	Shear strength (gross section)[3]	Type of failure
	Percent		P.s.i.	P.s.i.	
2-F-D-C-CH-8	11.9	0.48	.....	655	Shear along long check
4-F-D-C-CH-6	13.2	.50	.....	720	Compression followed by shear along long check
10-F-D-C-CH-19	12.9	.40	.....	570	Shear along long check
11-F-D-C-CH-17	13.7	.60	.....	665	Do.
12-F-D-C-CH-15	[4]14.6	[4].58	8,400	.....	Cross-grain tension 1:5 slope
12-F-D-C-CH-20	13.8	.61	.....	935	Compression and vertical shear at check not typical because of slope of grain
13-F-D-C-CH-19	13.1	.45	.....	545	Shear along long check
13-F-D-C-CH-24	11.6	.43	.....	550	Do.
14-F-D-C-CH-19	[4]13.4	[4].42	.....	[5]480	Shear along long check affected by knot
15-F-D-C-CH-16	13.3	.52	.....	690	Shear along long check
15-F-D-C-CH-21	12.8	.47	9,270	710	Compression followed by shear and tension along 1:8 slope of grain across artificial check
16-F-D-C-CH-19	12.8	.50	.....	550	Shear along long check
Av.....	12.9	.50		660	

[1]Specimens 2 by 4 by 43 inches with artificial checks at midheight reducing width by one-half, were tested in bending by loading at third points of 39-inch span.

[2]Based on volume and weight when ovendry.

[3]Shear strength on actual net cross section approximately 2 times value shown.

[4]Not included in average.

[5]Not used as control or included in average.

Table 34.--Summary of results of fatigue tests of air-dry, straight-grained, artificially checked, quarter-scale, Douglas-fir bridge stringers[1]

Specimen No.	Moisture content	Specific gravity[2]	Control strength		Maximum repeated stress[4]		Cycles to failure	Type of failure
			Bending	Shear[3]	Ratio	Shear[3]		
	Percent		P.s.i.	P.s.i.	Percent of control	P.s.i.		
2-F-D-F-CH-13	12.3	0.49	.....	655	70	460	18,700	Shear along long check
4-F-D-F-CH-11	13.2	.50	.....	720	60	430	110,200	Do.
10-F-D-F-CH-28	13.1	.39	.....	570	50	285	486,100	Do.
11-F-D-F-CH-24	13.7	.60	.....	665	50	330	1,061,200	Do.
12-F-D-F-CH-23	14.4	.56	8,400	[5]790	58	455	441,100	Shear along long check failure not typical because of grain slope
12-F-D-F-CH-28	14.2	.61	.....	935	60	560	6,500	Vertical shear along weak ring
13-F-D-F-CH-27	13.1	.47	.....	545	60	325	285,200	Shear along long check
13-F-D-F-CH-32	13.4	.43	.....	550	70	385	57,400	Do.
14-F-D-F-CH-27	13.0	.43	.....	[5]540	44	240	10,115,000	No failure
15-F-D-F-CH-23	12.6	.52	.....	690	40	275	10,115,000	Do.
15-F-D-F-CH-28	12.8	.45	.....	710	40	285	3,337,100	Diagonal shear across check
16-F-D-F-CH-26	13.0	.51	.....	550	45	250	3,008,300	Shear along long check
Av.....	13.2	.50		660				

[1] Specimens 2 by 4 by 43 inches with artificial checks at midheight, reducing width by one-half, loaded at third points of 39-inch span at 500 cycles per minute.

[2] Based on volume and weight when ovendry.

[3] Shear stress calculated on gross cross section; stress on actual net section was approximately 2 times values shown.

[4] Minimum repeated stress 0.10 of maximum.

[5] Estimated on basis of specific gravity; not included in average.

Table 35.--Summary of results of static control tests of air-dry, artificially checked, quarter-scale, Douglas-fir bridge stringers[1] with 1:12 slope of grain

Specimen No.	Moisture content	Specific gravity[2]	Modulus of rupture	Shear strength (gross section)[3]	Type of failure
	Percent		P.s.i.	P.s.i.	
1-F-D-C-CH-4	11.3	[4]0.49	.....	530	Shear along long check
3-F-D-C-CH-2	11.7	.53	.....	645	Do.
4-F-D-C-CH-1	11.4	.53	.....	575	Do.
5-F-D-C-CH-5	12.1	.56	.....	710	Do.
8-F-D-C-CH-2	12.3	.48	.....	590	Compression under load and shear along long check
8-F-D-C-CH-7	12.9	.48	.....	685	Do.
10-F-D-C-CH-9	11.9	.35	5,920	455	Combined cross-grain tension and shear along long check
11-F-D-C-CH-2	[5]13.0	[5].61	[6]9,220	.....	Cross-grain tension; combined slope of grain 1:7
11-F-D-C-CH-3	12.9	.61	10,240	785	Combined shear and cross-grain tension
12-F-D-C-CH-1	[5]13.1	[5].62	[6]9,480	.....	Cross-grain tension; combined slope of grain 1:5
12-F-D-C-CH-6	[5]13.2	[5].60	[6]7,630	[7]585	Combined shear and cross-grain tension
14-F-D-C-CH-1	[5]13.4	[5].48	[6]7,870	.....	Brittle tension
14-F-D-C-CH-6	12.4	.43	.....	495	Shear along long check
16-F-D-C-CH-2	12.8	.51	7,980	615	Combined compression, cross-grain tension and shear
16-F-D-C-CH-7	[5]12.1	[5].43	[6]5,140	.....	Cross-grain tension, combined slope 1:4
Av.....	12.2	.50	.....	610	

[1] Specimens 2 by 4 by 43 inches with artificial checks at midheight, reducing width by one-half, were tested in bending by loading at third points of 39-inch span.

[2] Based on volume and weight when ovendry.

[3] Shear strength on actual net cross section approximately 2 times value shown.

[4] From matched fatigue specimen,

[5] Not included in average.

[6] Not used as control for fatigue.

[7] Not used as control for fatigue because of effect of tension failure on shear, nor included in average.

Table 36.--Summary of results of fatigue tests of air-dry, artificially checked, quarter-scale, Douglas-fir bridge stringers[1] with 1:12 slope of grain

Specimen No.	Moisture content	Specific gravity[2]	Control strength		Maximum repeated stress[4]			Cycles to failure	Type of failure
			Bending	Shear[3]	Ratio	Bending	Shear[3]		
	Percent		P.s.i.	P.s.i.	Percent of control	P.s.i.	P.s.i.		
1-F-D-F-CH-9	11.6	0.49	.....	530	70	.....	370	14,500	Shear along long check
3-F-D-F-CH-7	11.6	.57	.....	645	70	.....	450	45,200	Do.
4-F-D-F-CH-6	11.9	.50	.....	575	60	.....	345	41,200	Do.
5-F-D-F-CH-10	11.8	.56	.....	710	60	.....	425	52,000	Do.
8-F-D-F-CH-10	12.8	.49	.....	590	50	.....	295	1,878,000	Do.
8-F-D-F-CH-15	12.7	.50	.....	685	40	.....	275	26,400	Cross-grain tension in vertical plane along weak ring
10-F-D-F-CH-18	12.1	.37	5,920	455	50	.....	225	2,460,600	Shear along long check
11-F-D-F-CH-9	13.2	.61	.....	[5]760	56	.....	425	1,510,100	Do.
11-F-D-F-CH-10	13.5	.63	10,240	785	70	7,170	550	10,600	Cross-grain tension failure combined slope 1:7
12-F-D-F-CH-8	13.0	.62	.....	[5]780	37	.....	290	10,610,000	No failure
12-F-D-F-CH-13	13.6	.63	.....	[5]790	30	.....	235	10,257,000	Do.
14-F-D-F-CH-8	13.7	.50	7,870	[5]600	51	.....	305	2,410,500	Shear along short check
14-F-D-F-CH-13	13.1	.44	.....	495	40	.....	200	9,271,400	Shear along long check
16-F-D-F-CH-9	13.1	.53	.....	615	40	.....	245	3,494,600	Do.
16-F-D-F-CH-14	13.1	.46	.....	[5]540	44	.....	235	2,656,200	Do.
Av.....	12.7	.53		610					

[1] Specimens 2 by 4 by 43 inches with artificial checks at midheight, reducing width by one-half, loaded at third points of 39-inch span at 500 cycles per minute.

[2] Based on volume and weight when ovendry.

[3] Shear stress calculated on gross cross section; stress on actual net section was approximately 2 times value shown.

[4] Minimum repeated stress 0.10 of maximum.

[5] Estimated on basis of specific gravity.

Table 37.--Summary of results of static control tests of treated, straight grained, artificially checked, quarter-scale, Douglas-fir bridge stringers[1]

Specimen No.	Specific gravity[2]	Modulus of rupture	Shear strength (gross section)[3]	Type of failure
		P.s.i.	P.s.i.	
1-F-T-C-CH-15	0.50	.....	540	Shear along long check
2-F-T-C-CH-9	.52	.....	580	Do.
4-F-T-C-CH-7	.50	.....	580	Do.
5-F-T-C-CH-13	.49	.....	590	Do.
7-F-T-C-CH-18	.50	.....	545	Do.
9-F-T-C-CH-21	.48	.....	535	Do.
9-F-T-C-CH-26	.42	.....	490	Do.
10-F-T-C-CH-20	.40	.....	[4]425	Do.
11-F-T-C-CH-18	.60	9,710	[4]740	Compression at knot and tension, no shear
14-F-T-C-CH-15	.41	.....	480	Shear along long check
16-F-T-C-CH-20	.50	7,480	575	Combination shear and splintering cross-grain tension
Av.....	.47		535	

[1] Specimens 2 by 4 by 43 inches with artificial checks at midheight, reducing width by one-half, were tested in bending by loading at third points of 39-inch span.

[2] From adjacent untreated specimen; based on volume and weight when ovendry.

[3] Shear strength on actual net cross section approximately 2 times value shown.

[4] Not included in average.

Table 38.--Summary of results of fatigue tests of treated, straight-grained, artificially checked, quarter-scale, Douglas-fir bridge stringers[1]

Specimen No.	Specific gravity[2]	Control strength		Maximum repeated stress[4]		Cycles to failure	Type of failure
		Bending	Shear[3]	Ratio	Shear[3]		
		P.s.i.	P.s.i.	Percent of control	P.s.i.		
1-F-T-F-CH-10	0.50	.....	540	70	380	73,600	Shear along long check
2-F-T-F-CH-14	.52	.....	580	60	350	417,800	Do.
4-F-T-F-CH-12	.50	.....	580	50	290	787,500	Do.
5-F-T-F-CH-8	.50	.....	590	40	235	12,618,000	No failure
7-F-T-F-CH-26	.50	.....	545	70	380	176,500	Shear along long check
9-F-T-F-CH-30	.52	.....	535	60	325	765,900	Do.
9-F-T-F-CH-35	.43	.....	490	50	245	779,000	Do.
10-F-T-F-CH-29	.39	.....	425	70	295	172,900	Do.
11-F-T-F-CH-25	.62	9,710	[5]740	50	370	3,964,500	Do.
14-F-T-F-CH-23	.40	.....	480	50	240	2,100,800	Do.
16-F-T-F-CH-27	.50	.....	575	45	260	10,049,000	No failure
Av.....	.49		535				

[1] Specimens 2 by 4 by 43 inches with artificial checks at midheight, reducing width by one-half, loaded at third points of 39-inch span at 500 cycles per minute.

[2] From adjacent untreated specimen; based on volume and weight when ovendry.

[3] Shear stress calculated on gross cross section; stress on actual net section was approximately 2 times value shown.

[4] Minimum repeated stress 0.10 of maximum.

[5] Not included in average but used as estimate of control strength because of high specific gravity.

Table 39.--Summary of results of static control tests of treated, artificially checked, quarter-scale Douglas-fir bridge stringers[1] with 1:12 slope of grain

Specimen No.	Specific gravity[2]	Modulus of rupture	Shear strength (gross section)[3]	Type of failure
		P.s.i.	P.s.i.	
1-F-T-C-CH-5	0.49	.....	455	Shear along long check
7-F-T-C-CH-5	[4].53	7,160	[4]555	Combined shear and cross-grain tension influenced by knot
8-F-T-C-CH-3	.48	.....	545	Shear along long check
8-F-T-C-CH-8	.48	.....	550	Do.
9-F-T-C-CH-1	[4].50	6,440	.....	Brittle tension; not typical
12-F-T-C-CH-2	[4].62	8,370	.....	Cross-grain tension 1:6 combined slope
12-F-T-C-CH-7	.60	7,850	600	Combined shear and cross-grain tension
14-F-T-C-CH-2	[4].48	6,000	.....	Brittle tension; not typical
14-F-T-C-CH-7	.43	.....	410	Shear along long check
15-F-T-C-CH-5	.50	.....	540	Do.
16-F-T-C-CH-3	.51	.....	540	Do.
Av.....	.50		520	

[1]Specimens 2 by 4 by 43 inches with artificial checks at midheight, reducing width by one-half, were tested in bending by loading at third points of 39-inch span.

[2]From adjacent untreated specimen; based on volume and weight when ovendry.

[3]Shear strength on actual net cross section approximately 2 times value shown.

[4]Not included in average.

Table 40.--Summary of results of fatigue tests of treated, artificially checked, quarter scale Douglas-fir bridge stringers[1] with 1:12 slope of grain

Specimen No.	Specific gravity[2]	Control strength		Maximum repeated stress[4]			Cycles to failure	Type of failure
		Bending	Shear[3]	Ratio	Bending	Shear[3]		
		P.s.i.	P.s.i.	Percent of control	P.s.i.	P.s.i.		
1-F-T-F-CH-10	0.49	.....	455	40	.....	180	10,343,000	No failure
7-F-T-F-CH-12	.49	.....	[5]510	75	.....	385	9,000	Shear along long check
8-F-T-F-CH-11	.49	.....	545	60	.....	330	276,200	Do.
8-F-T-F-CH-16	.50	.....	550	50	.....	275	609,000	Do.
9-F-T-F-CH-10	.47	6,440	.....	70	4,510	345	297,200	Brittle tension not typical
12-F-T-F-CH-9	.62	8,370	.....	60	5,020	380	1,138,600	Cross-grain tension combined slope 1:6
12-F-T-F-CH-14	.63	.....	600	50	.....	300	3,623,200	Shear along long check
14-F-T-F-CH-9	.50	.....	[5]520	40	.....	210	10,483,000	No failure
14-F-T-F-CH-14	.44	.....	410	60	.....	245	5,089,000	Shear along long check
15-F-T-F-CH-12	.50	.....	540	45	.....	245	1,121,000	Do.
16-F-T-F-CH-10	.53	.....	540	40	.....	215	2,684,500	Shear along short check
Av.....	.51		520					

[1] Specimens 2 by 4 by 43 inches with artificial checks at midheight reducing width by one-half, loaded at third points of 39-inch span at 500 cycles per minute.

[2] From adjacent untreated specimens; based on volume and weight when ovendry.

[3] Shear stress calculated on gross cross section; stress on actual net section was approximately 2 times value shown.

[4] Minimum repeated stress 0.10 of maximum.

[5] Control shear strength estimated on basis of specific gravity; not included in average.

Table 41.--Summary of estimated fatigue strength values at 2 million cycles of stress for quarter-scale bridge stringers

Condition	Grain	Checked or unchecked	Moisture content	Specific gravity[1]	Bending values: Average static strength	Bending values: Fatigue strength at 2 million cycles		Shear values[2]: Average static strength	Shear values[2]: Fatigue strength at 2 million cycles	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
			Percent		P.s.i.	Percent of control[3]	P.s.i.	P.s.i.	Percent of control[3]	P.s.i.
SOUTHERN PINE										
Green	Straight	Unchecked	79.0	0.54	7,450	50	3,700	.....	.....	.....
Do.....	1:12	...do....	74.6	.57	7,020	55	3,900	.....	.....	.....
Air-dry	Straight	...do....	10.4	.56	13,540	60	8,000	.....	.....	.....
Do.....	1:12	...do....	10.7	.57	10,150	50	5,200	.....	.....	.....
Treated	Straight	...do....	11.4	[4].56	12,370	45	5,400	.....	.....	[5]425
Do.....	1:12	...do....	11.2	[4].57	8,640	45	4,100	.....	.....	.....
Air-dry	Straight	Checked	11.0	.56	.....	.....	.....	885	45	390
Do.....	1:12	...do....	11.2	.60	.....	.....	.....	[6]840	40	320
Treated	Straight	...do....	11.5	[4].56	.....	.....	.....	690	40	260
Do.....	1:12	...do....	11.8	[4].57	.....	.....	.....	655	30	210
DOUGLAS-FIR										
Green	Straight	Unchecked	44.4	.49	6,760	55	3,700	.....	.....	.....
Do.....	1:12	...do....	35.3	.50	5,990	60	3,600	.....	.....	.....
Air-dry	Straight	...do....	13.1	.47	10,660	60	6,300	.....	.....	.....
Do.....	1:12	...do....	12.5	.51	7,980	55	4,200	.....	.....	.....
Treated	Straight	...do....	.....	[4].49	10,830	50	5,400	.....	.....	[5]400
Do.....	1:12	...do....	.....	[4].50	7,170	55	3,900	.....	.....	.....
Air-dry	Straight	Checked	13.2	.50	.....	.....	.....	660	45	310
Do.....	1:12	...do....	12.7	.53	.....	.....	.....	610	45	280
Treated	Straight	...do....	.....	[4].49	.....	.....	.....	535	50	270
Do.....	1:12	...do....	.....	[4].51	.....	.....	.....	520	45	240

[1] Based on volume and weight when ovendry.

[2] Calculated on gross cross section with no reduction In width for artificial checks; actual stresses about 2 times.

[3] Percentage values rounded to nearest 5 percent.

[4] From adjacent untreated specimens.

[5] Based on actual width of unchecked specimen; footnote[2] does not apply.

[6] Estimated on basis of average specific gravity.

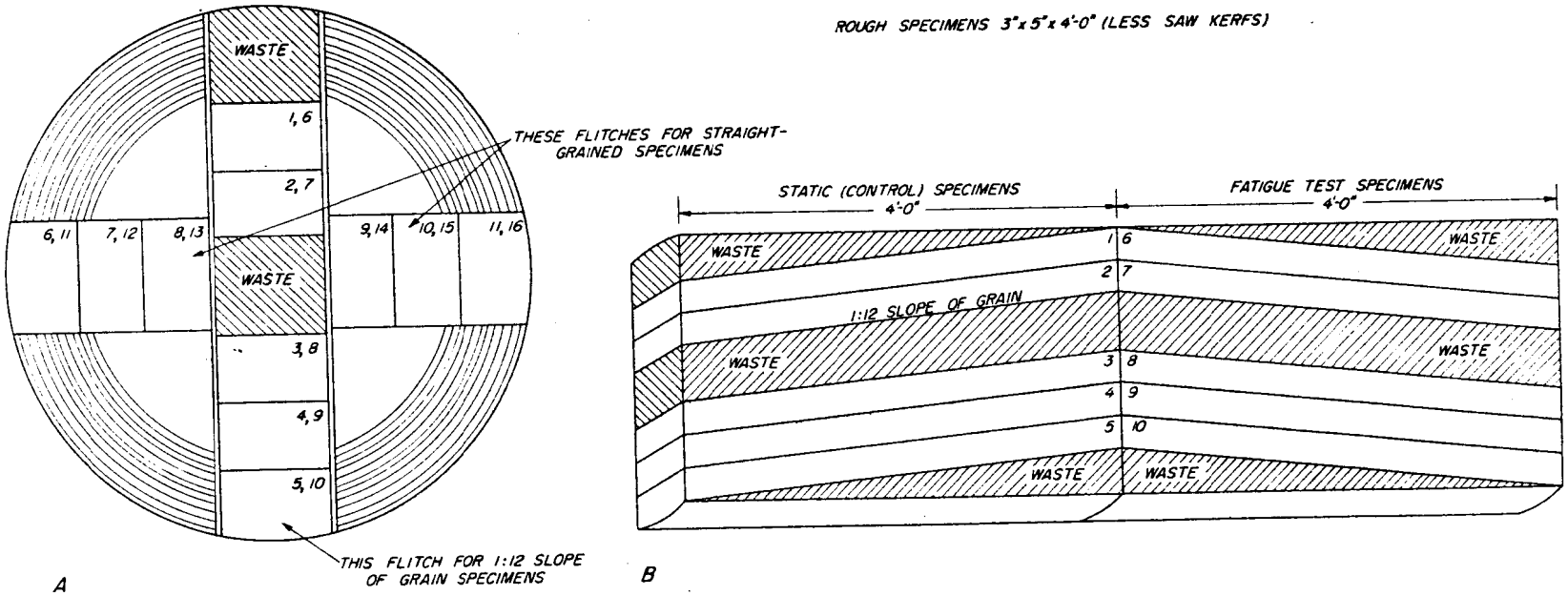

Figure 1.--Matching diagram for fatigue study of quarter-scale bridge stringers: A, Layout of flitches for log 24 inches in diameter; more pairs of specimens were obtained from logs of larger diameter. B, Plan for cutting slope-of-grain specimens from flitches.

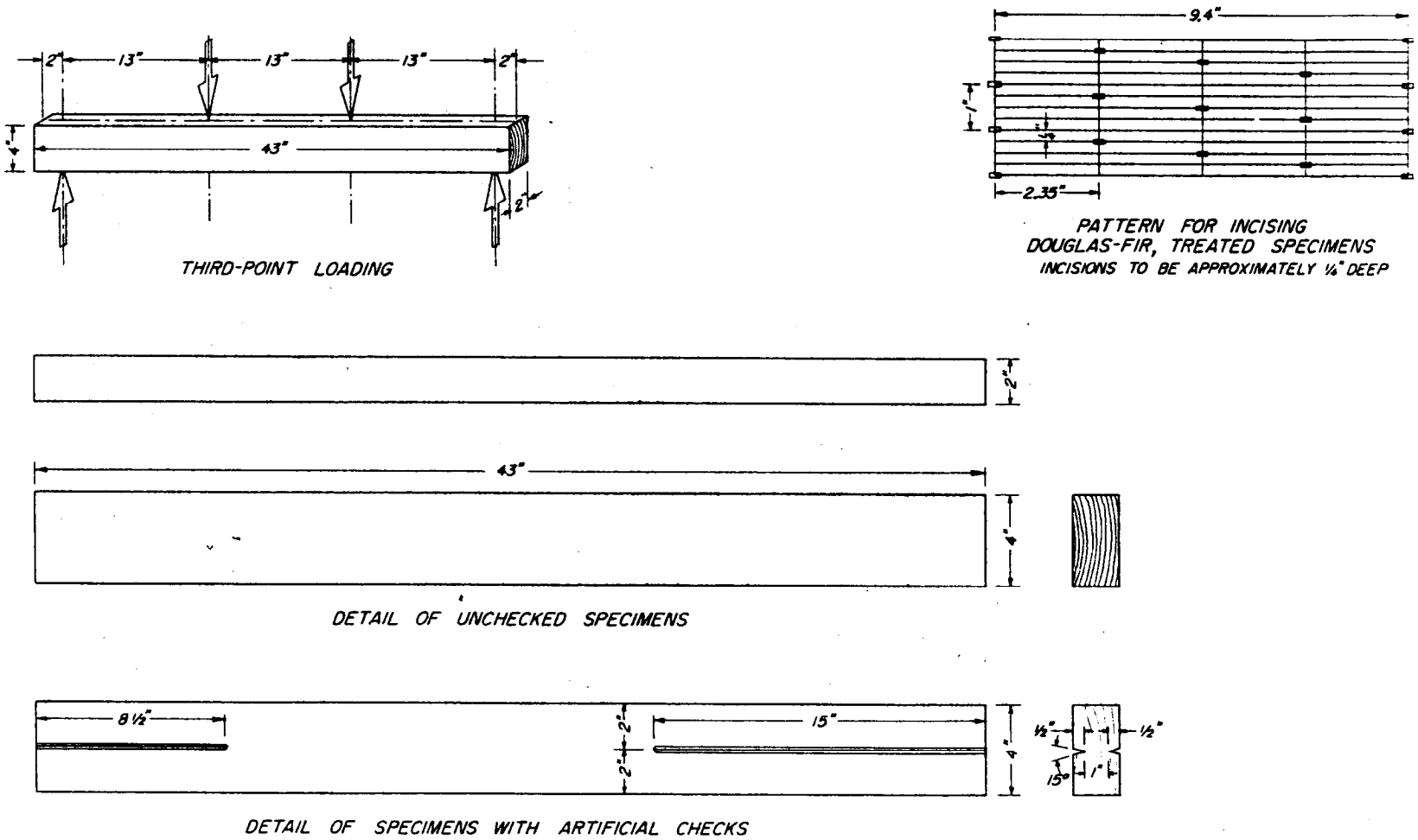

Figure 2.--Specimens for fatigue tests of quarter-scale bridge stringers.

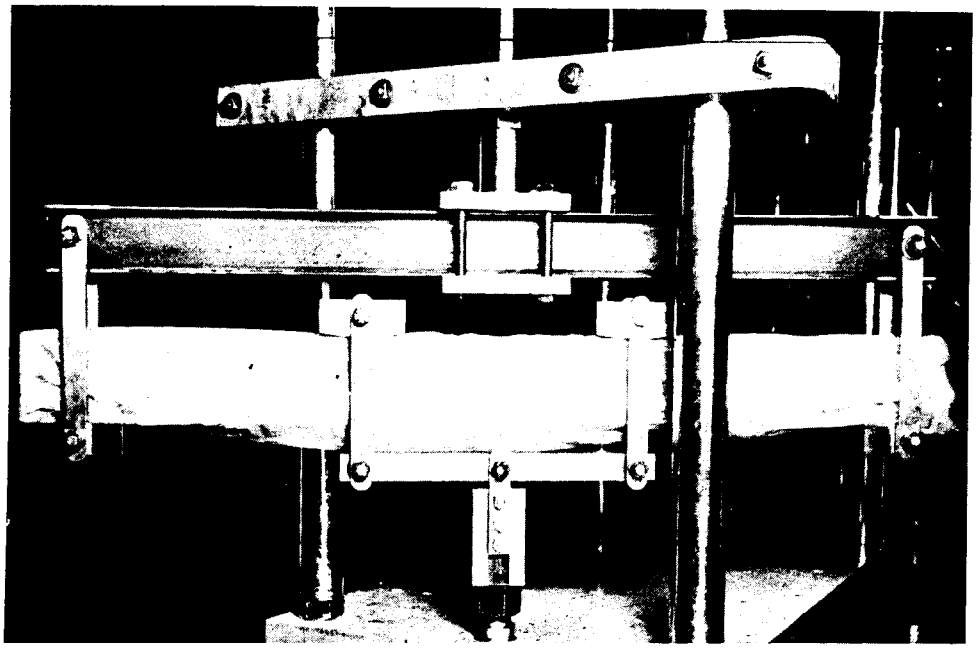

Figure 3. --Assembly for fatigue test of quarter-scale bridge stringers. Yoke and load blocks distribute loads to third points of the specimen. The plastic cocoon is used to maintain the specimen in a green condition.

Figure 4.--Assembly for static control test of quarter-scale bridge stringers.

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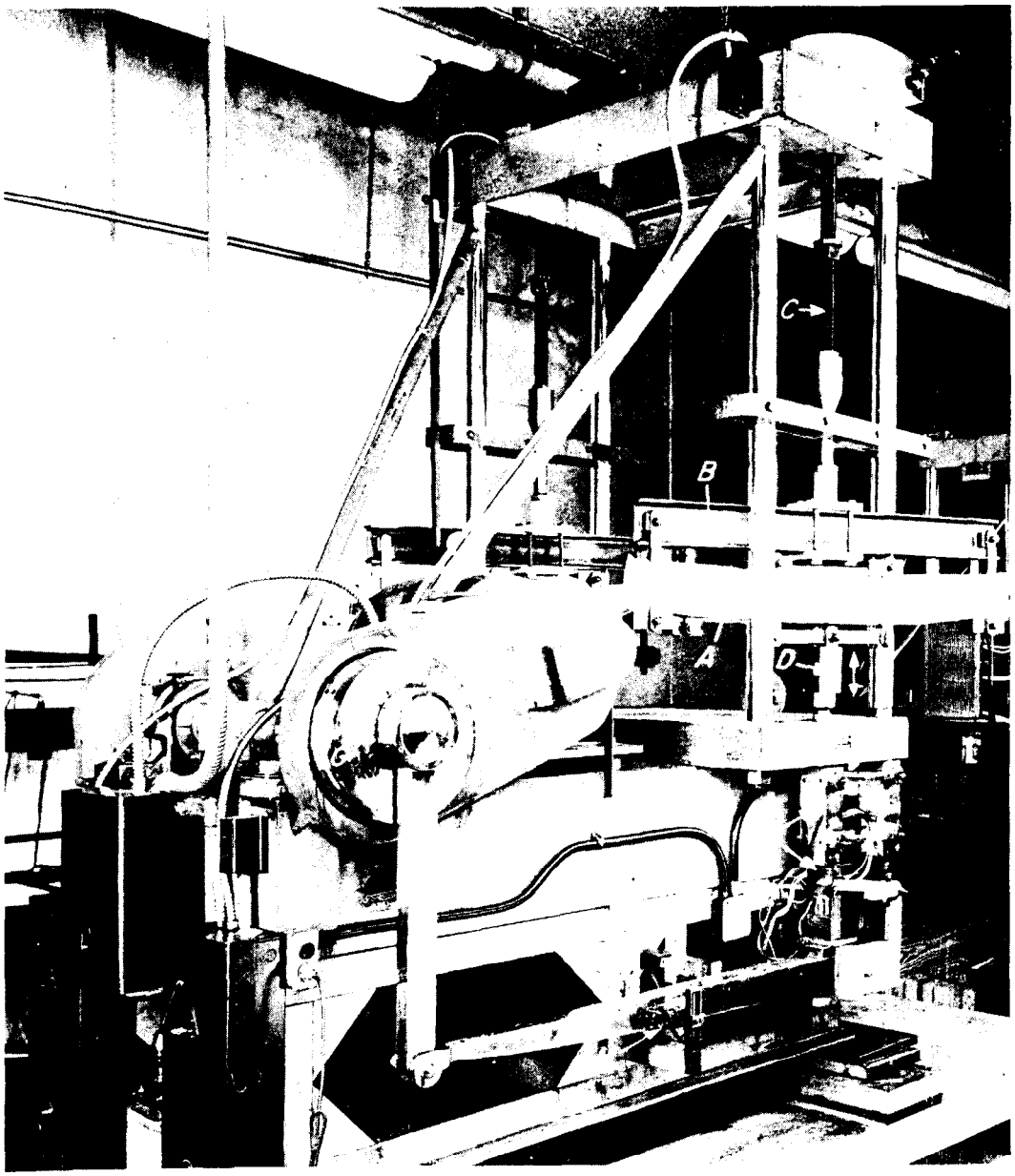

Figure 5.--Axial loading fatigue machine for repeated loading of quarter-scale bridge stringers. Essential parts of machine are: A, Specimen; B, Beam and yoke to support specimen at ends; C, Static loading screw to apply and adjust mean load on specimen; D , Loading yoke to apply alternating stress to specimen at third points; E, Linkage and flex-plate system to transfer loading from cantilever arm to loading yoke; F, Cantilever loading arm; G, Adjustable cam for required alternating load; H, Electronic adjustable cutoff switch to control machine or shut off drive when specimen failed or load was reduced.

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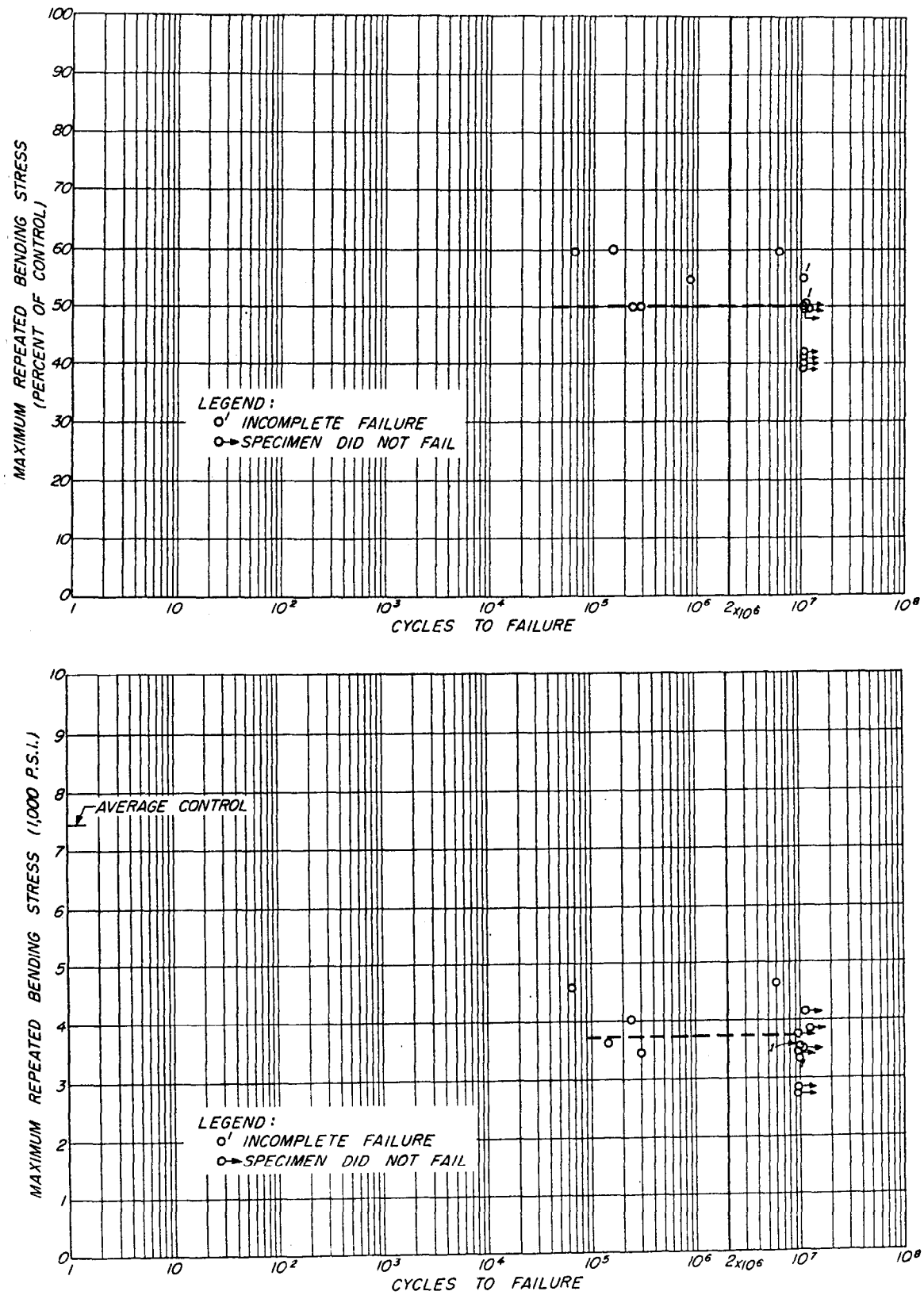

Figure 6. -- (Top) Relation of stress to number of cycles to failure for fatigue tests of green straight-grained, unchecked southern pine. Values for maximum repeated stress are expressed as percentages of static strength. Stress ratio 0.10. (Bottom) Same relationship with values of maximum repeated stress expressed in pounds per square inch.

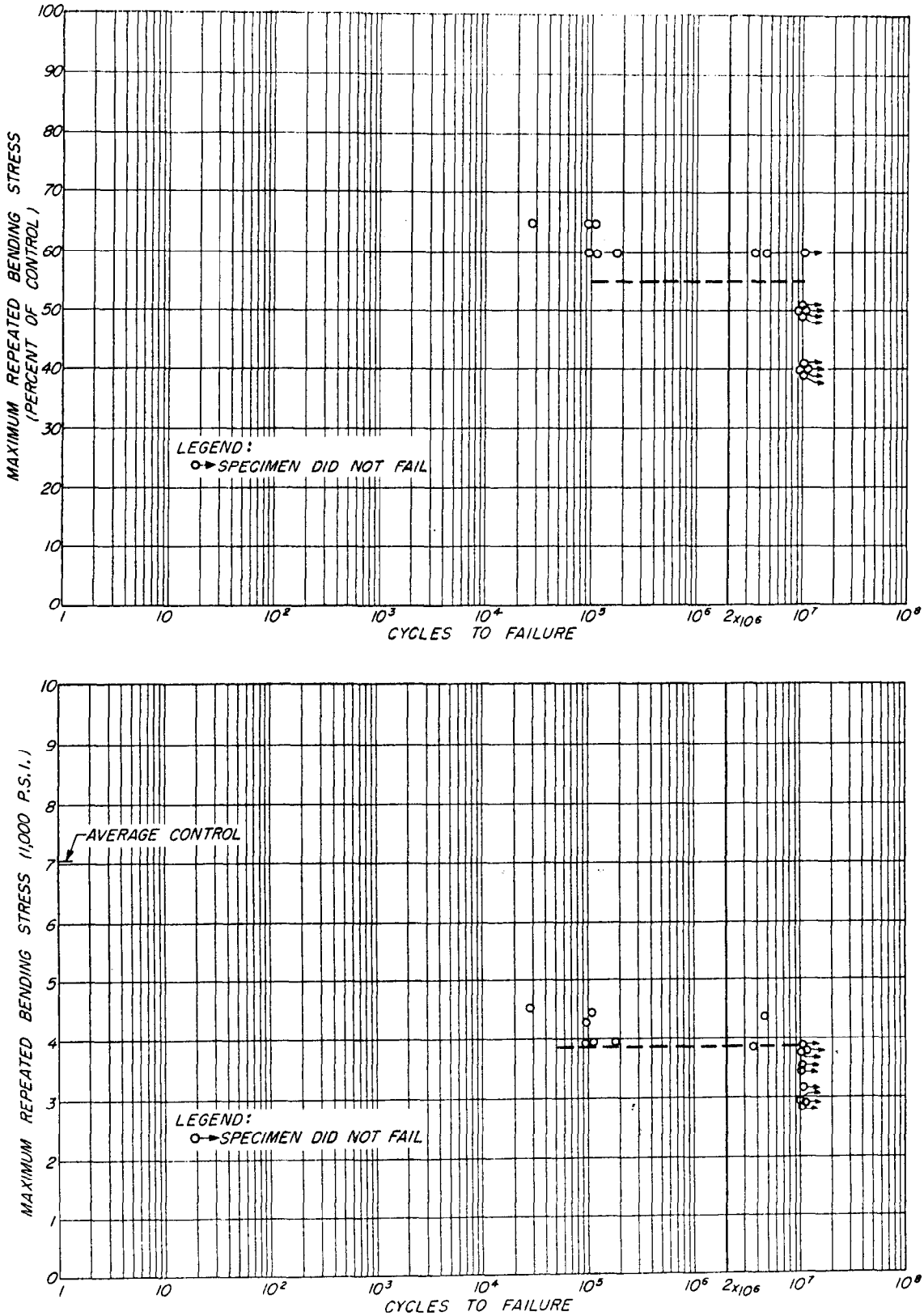

Figure 7. --(Top) Relation of stress to number of cycles to failure for fatigue tests of green, unchecked southern pine with 1:12 slope of grain. Values for maximum repeated stress are expressed as percentages of static strength. Stress ratio 0.10. (Bottom) Same relationship with values of maximum repeated stress expressed in pounds per square inch.

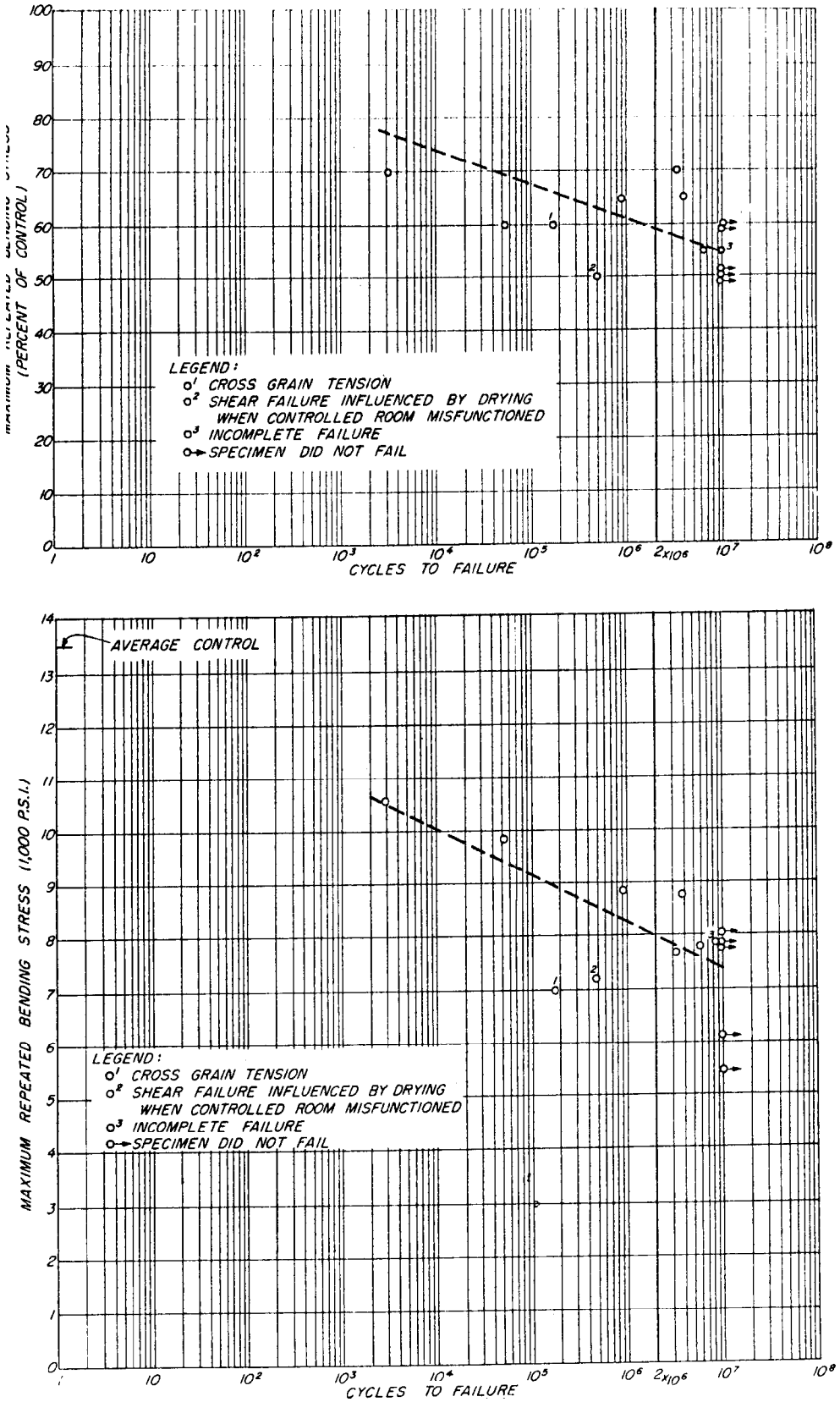

Figure 8.--(Top) Relation of stress to number of cycles to failure for fatigue tests of air-dry, straight-grained, unchecked southern pine. Values for maximum repeated stress are expressed as percentages of static strength. Stress ratio 0.10. (Bottom) Same relationship with values of maximum repeated stress expressed in pounds per square inch.

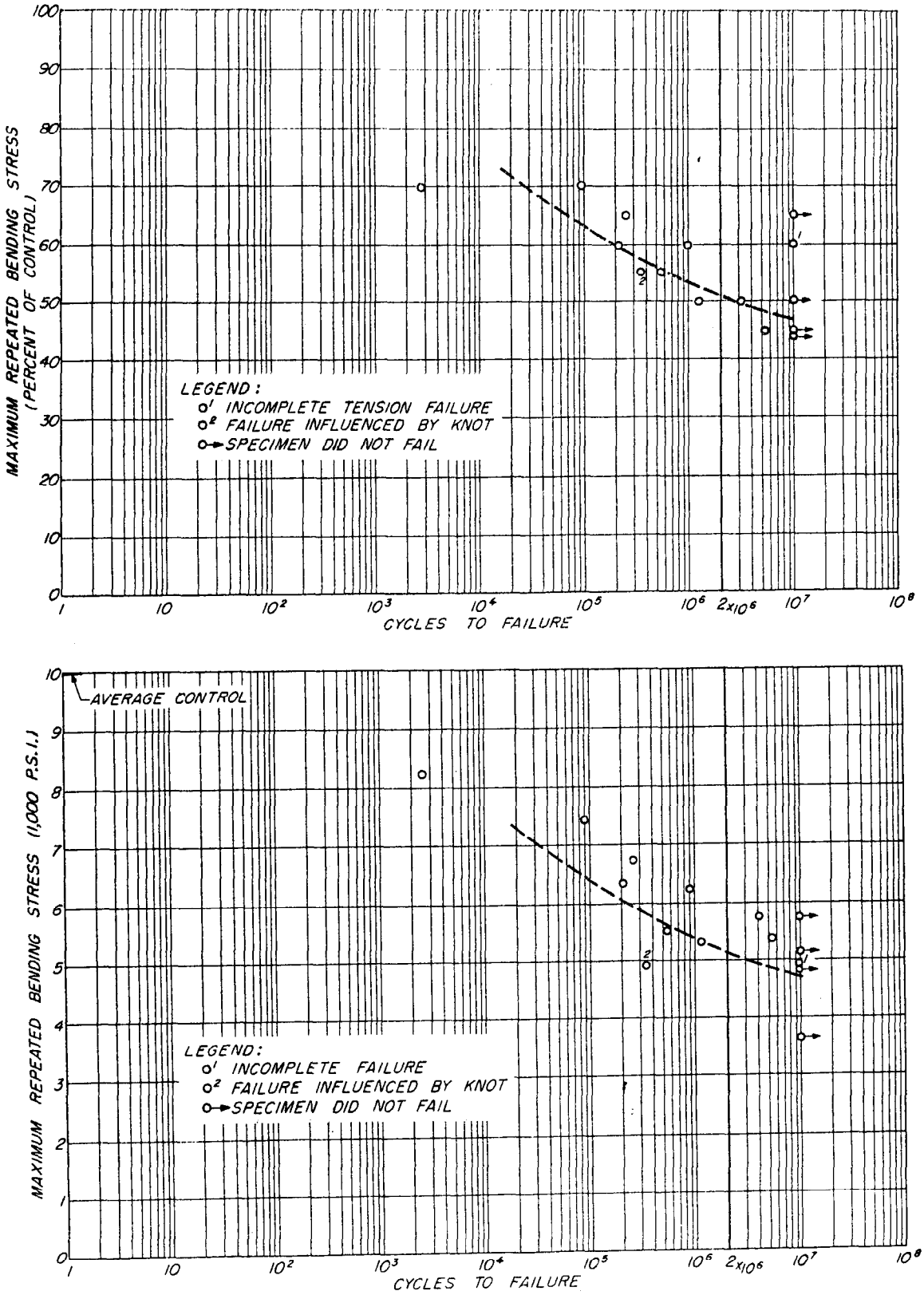

Figure 9. -- (Top) Relation of stress to number of cycles to failure for fatigue tests of air-dry, unchecked southern pine with 1:12 slope of grain. Values for maximum repeated stress are expressed as percentages of static strength. Stress ratio 0.10. (Bottom) Same relationship with values of maximum repeated stress expressed in pounds per square inch.

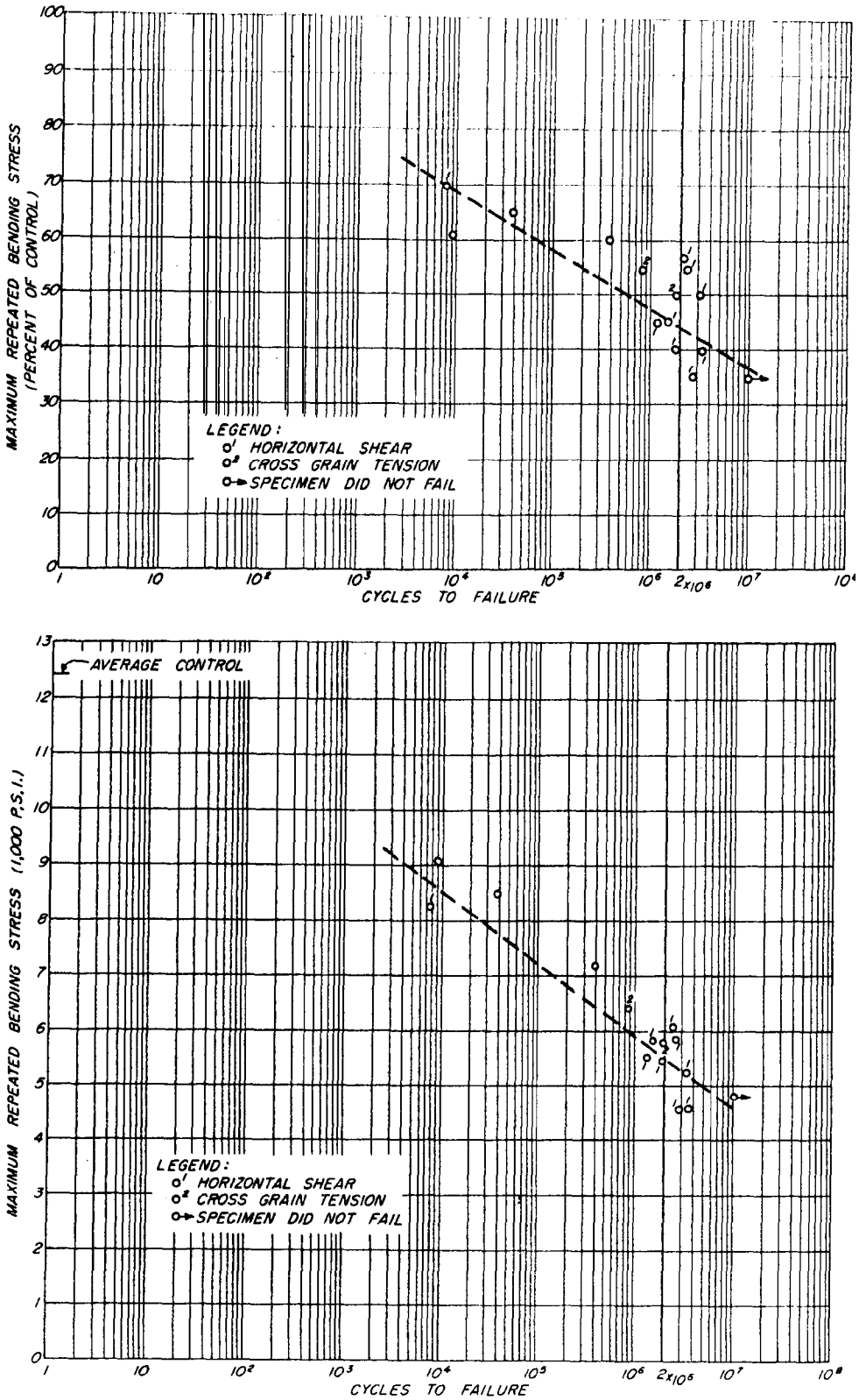

Figure 10.--(Top) Relatlon of stress to number of cycles to failure for fatigue tests for treated, straight-grained, unchecked southern pine. Values for maximum repeated stress are expressed as percentages of the static bending strength. Stress ratio 0.10. (Bottom) Same relationship with values of maximum repeated flexure stress expressed in pounds per square inch.

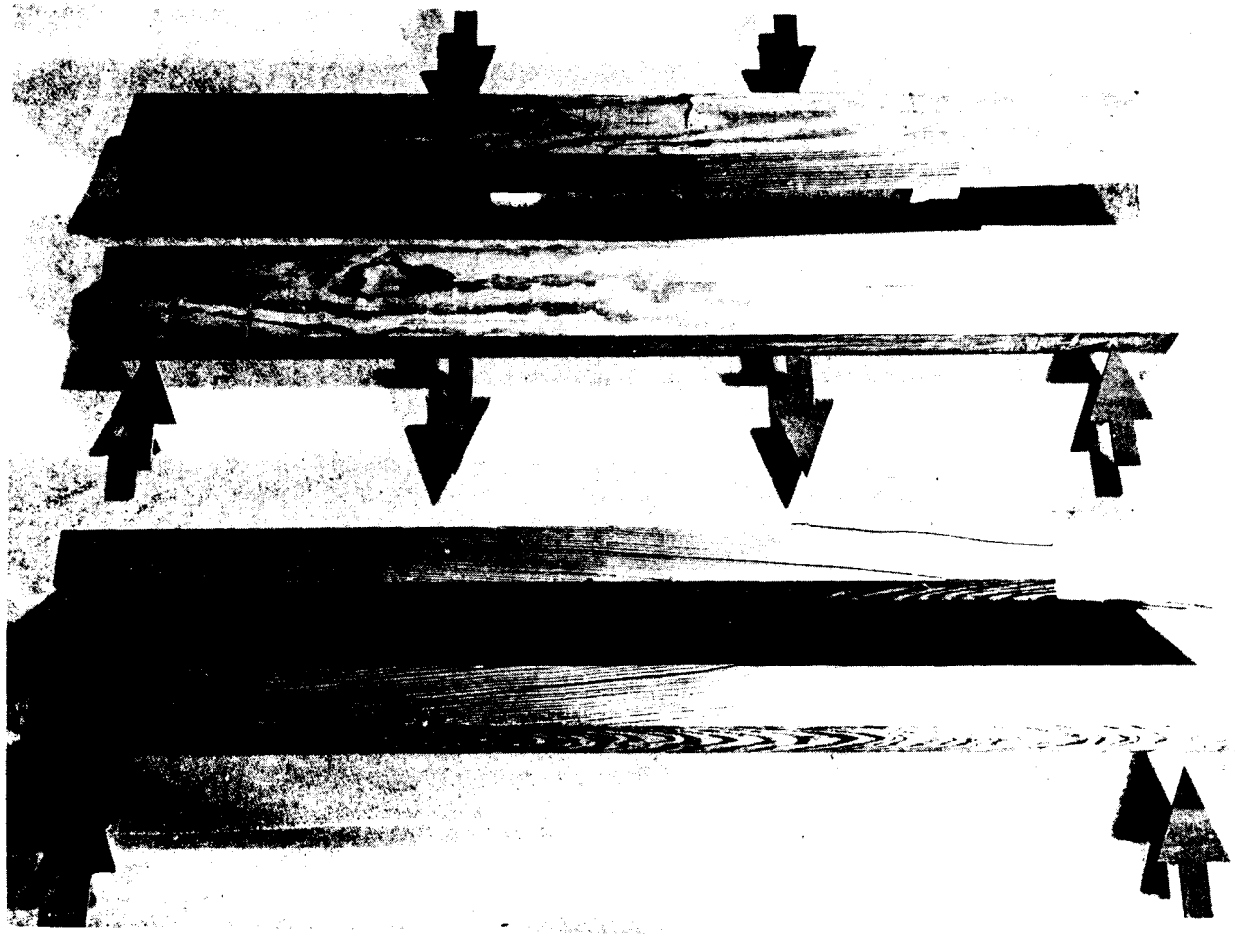

Figure 11.--Typical static and fatigue failures in treated, unchecked southern pine. (Top pair) Compression followed by tension failure in straight-grained control and horizontal shear failure in fatigue. (Bottom pair) Cross-grained tension failure in both control and fatigue specimens.

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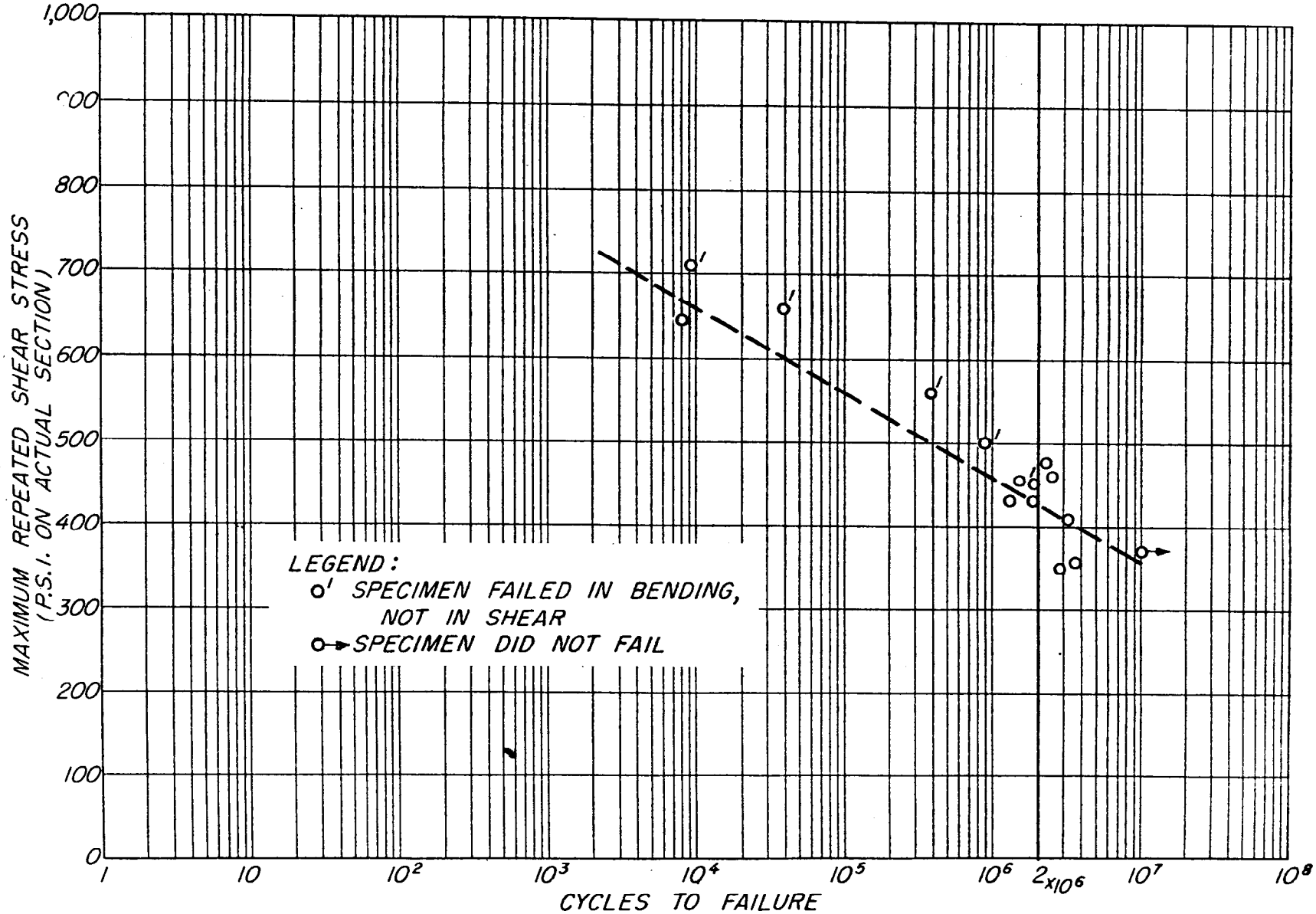
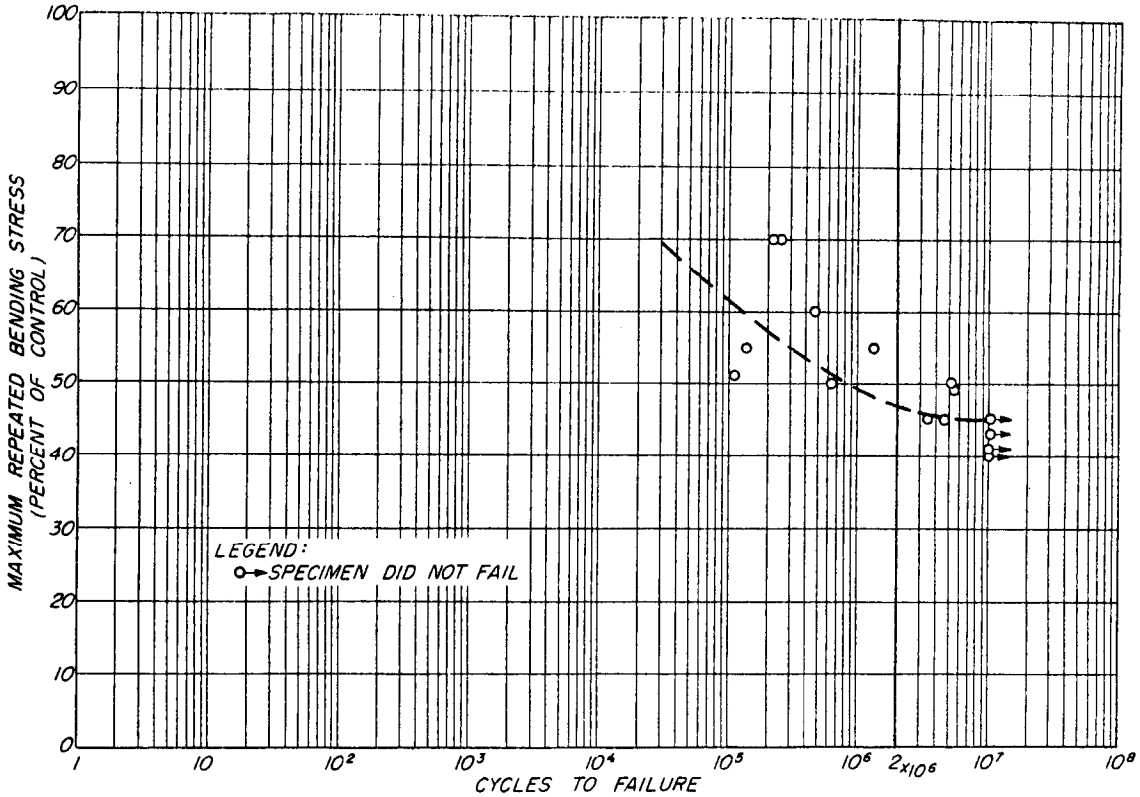


Figure 12.--Relation of stress to number of cycles to failure for treated, straight-grained, unchecked southern pine. Since specimens that withstood a large number of cycles before failing developed horizontal shear failures, values of maximum repeated stress are expressed in shear in pounds per square inch.



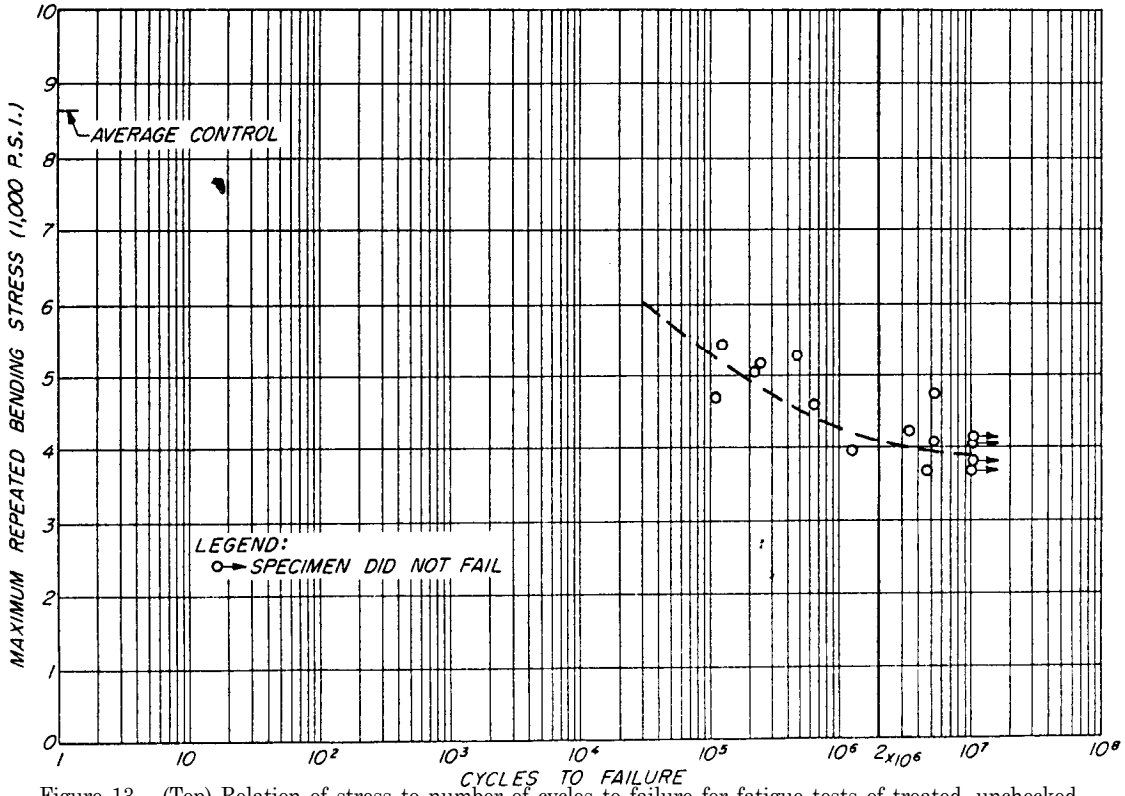


Figure 13. --(Top) Relation of stress to number of cycles to failure for fatigue tests of treated, unchecked southern pine with 1:12 slope of grain. Values for maximum repeated stress arc expressed as percentages of the static bending strength. Stress ratio 0.10. (Bottom) Same relationship with values of maximum repeated stress expressed in pounds per square inch.

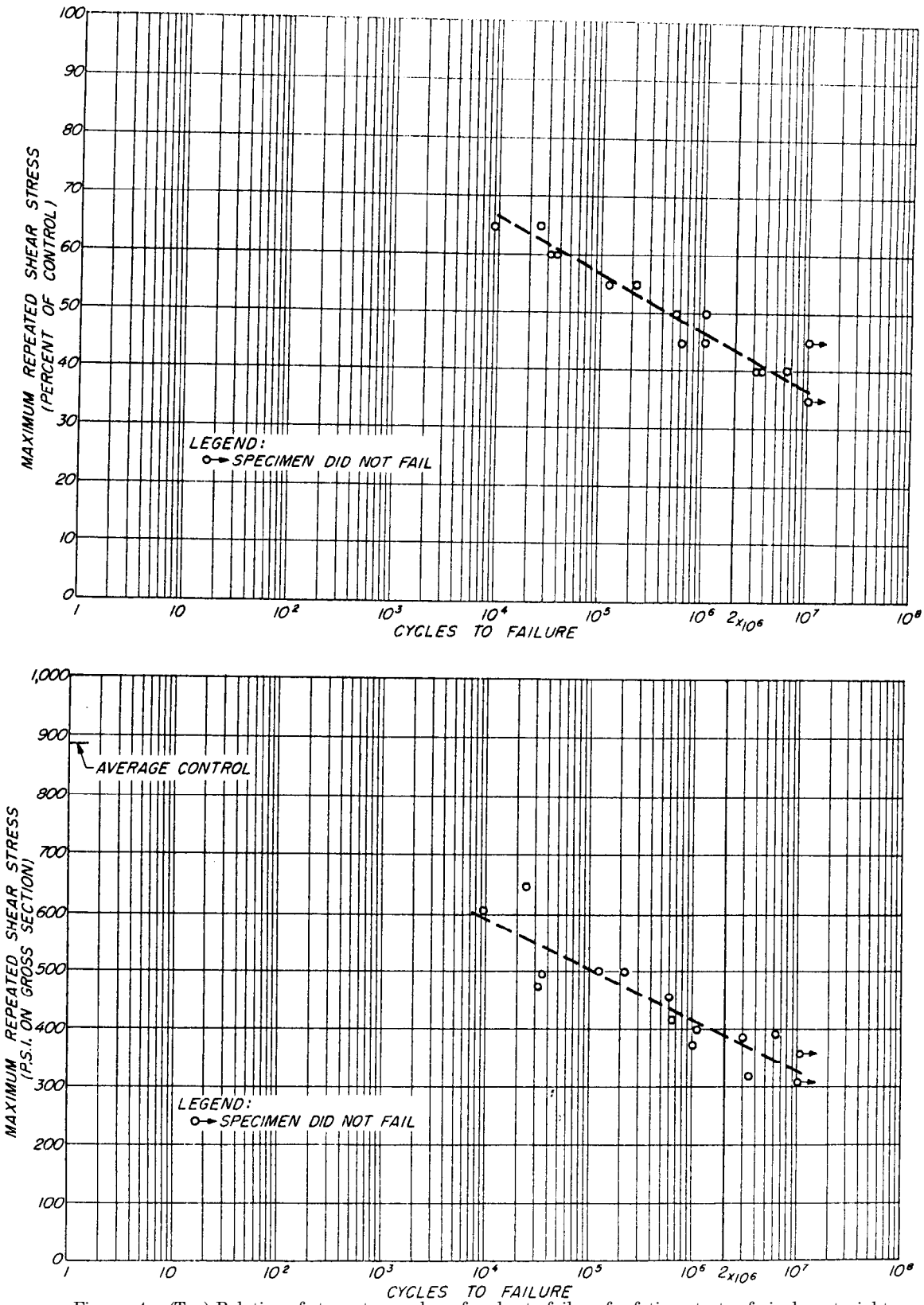


Figure .4. --(Top) Relation of stress to number of cycles to failure for fatigue tests of air-dry, straight-grained, artificially checked southern pine. Values for maximum repeated stress are expressed as percentages of static shear strength. Stress ratio 0.10. (Bottom) Same relationship with values of maximum repeated stress expressed in pounds per square inch.

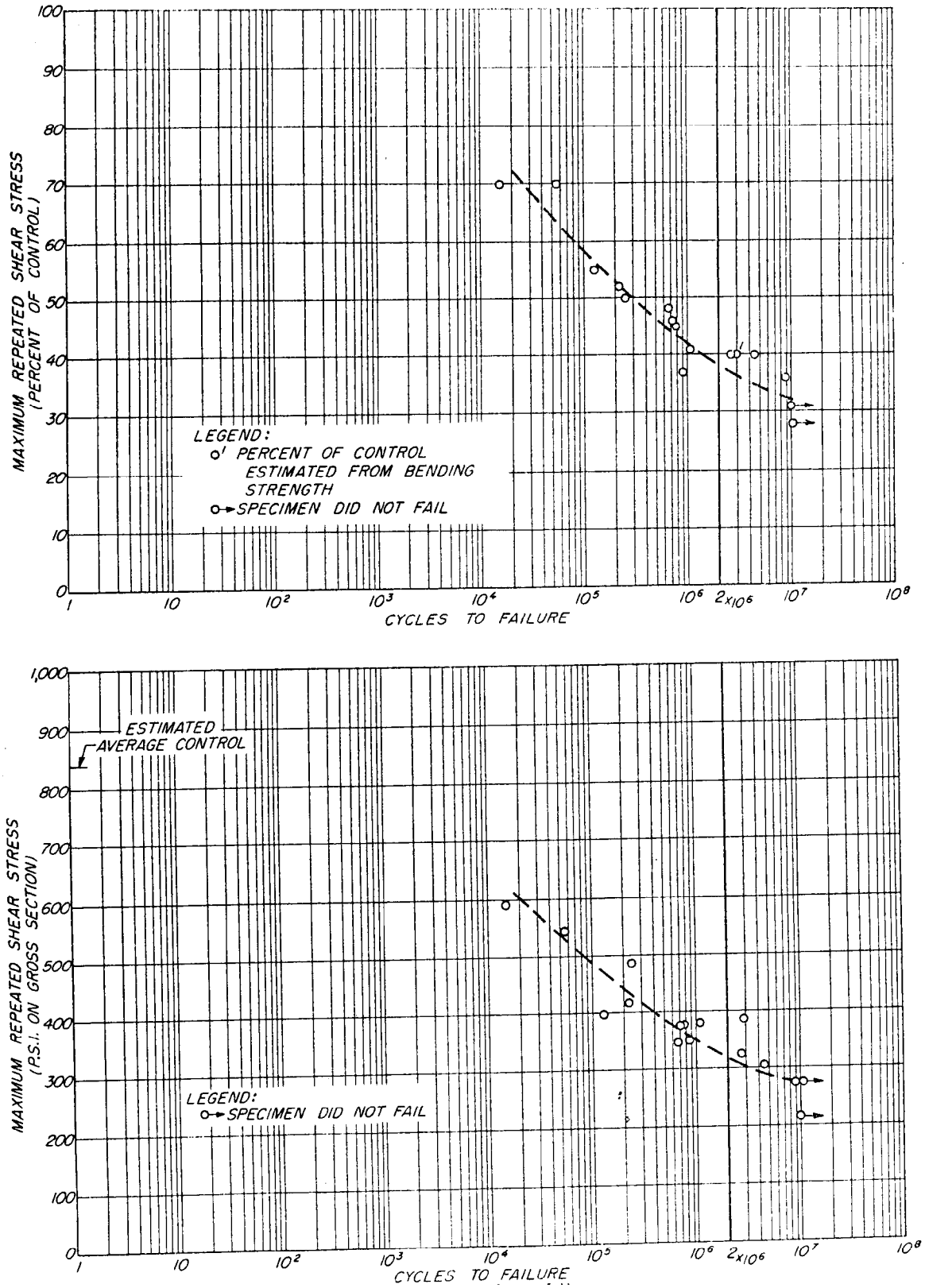


Figure 15. --(Top) Relation of stress to number of cycles to failure for fatigue tests of air-dry, aritficially checked southern pine with 1:12 slope of grain. Values for maximum repeated stress are expressed as percentages of static shear strength. Stress ratio 0.10. (Bottom) Same relationship with values of maximum repeated stress expressed in pounds per square inch.

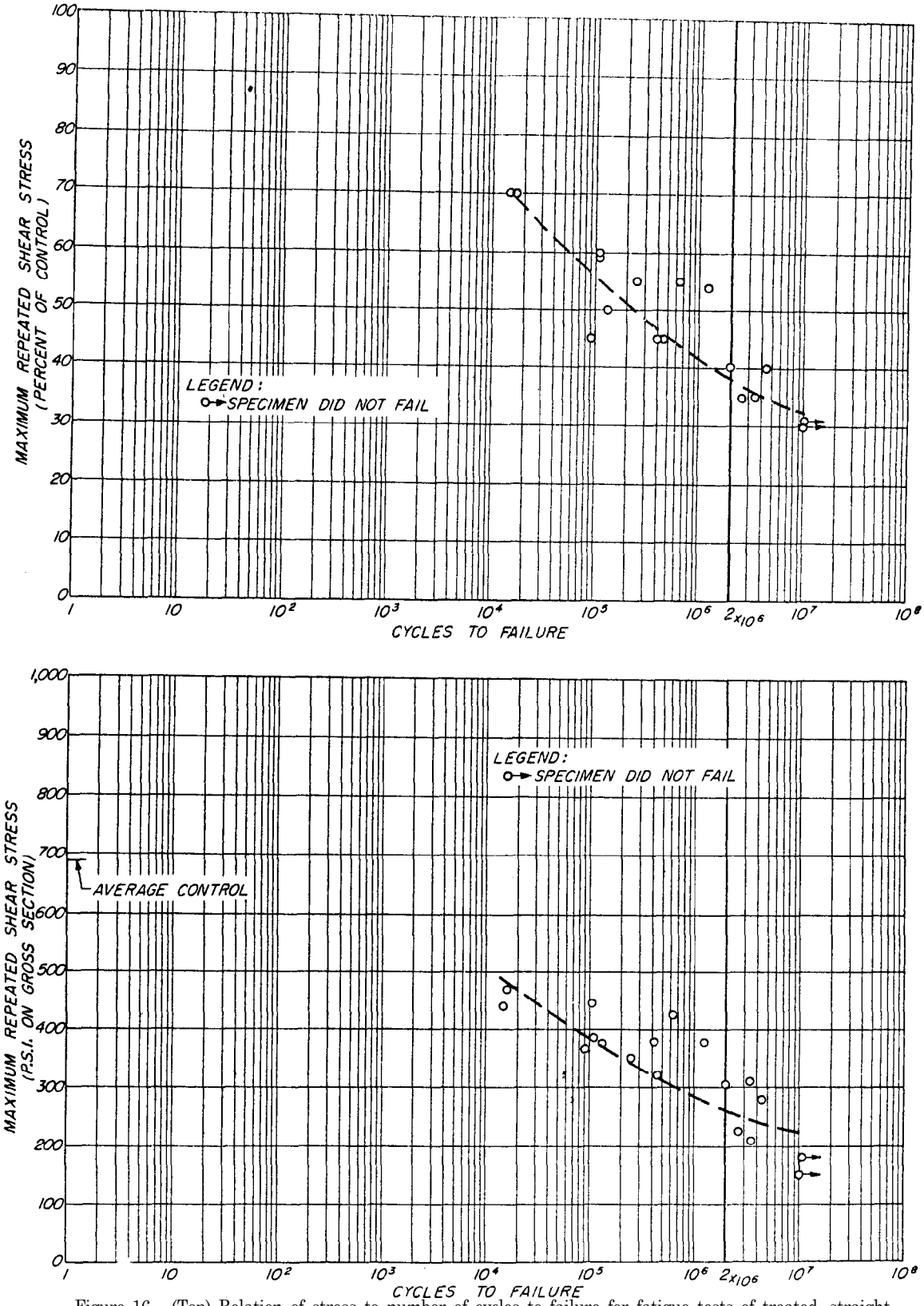


Figure 16. --(Top) Relation of stress to number of cycles to failure for fatigue tests of treated, straight-grained, artificially checked southern pine. Values of maximum repeated stress are expressed as percentages of static shear strength. Stress ratio 0.10. (Bottom) Same relationship with values of maximum repeated stress expressed in pounds per square inch.

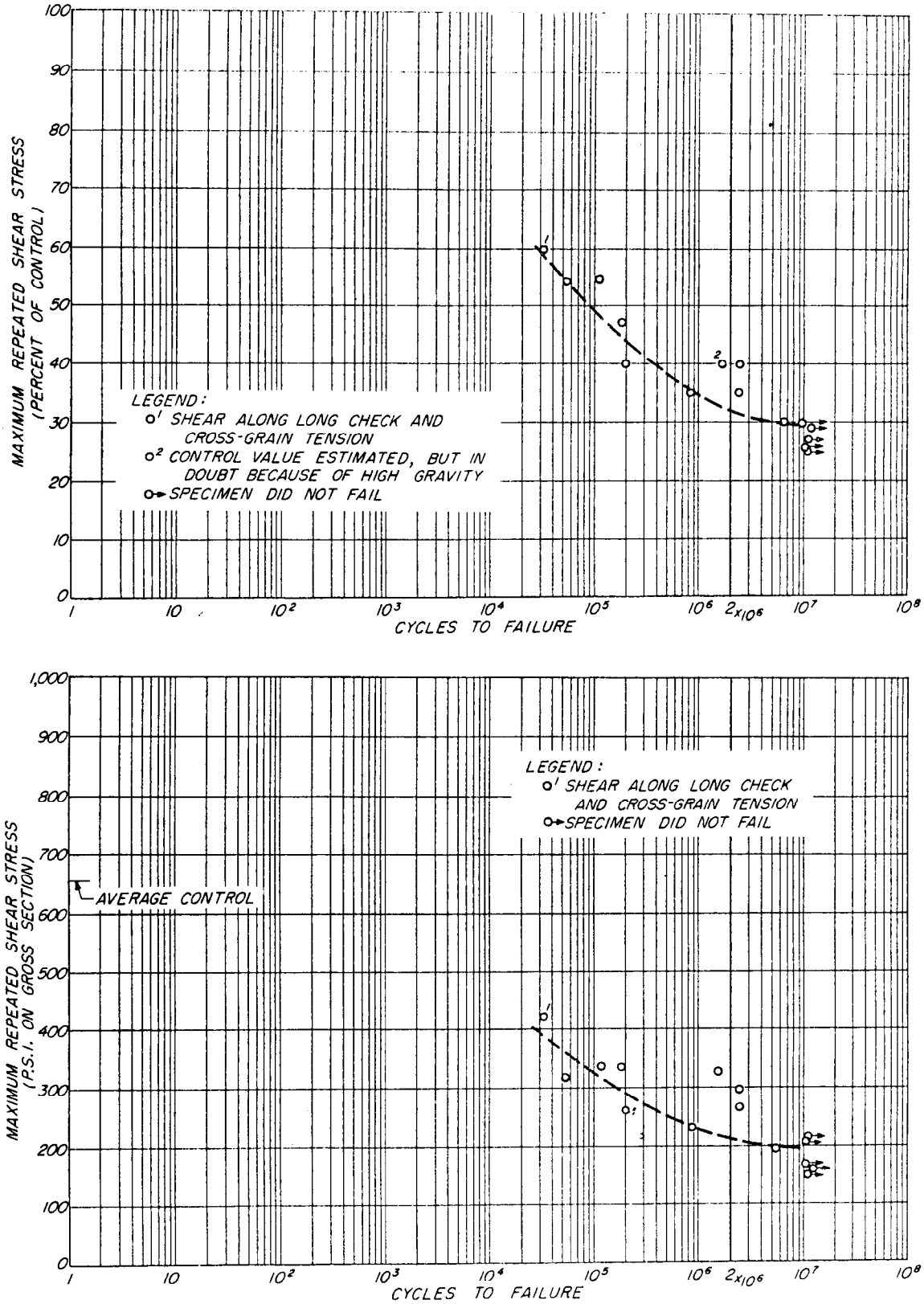
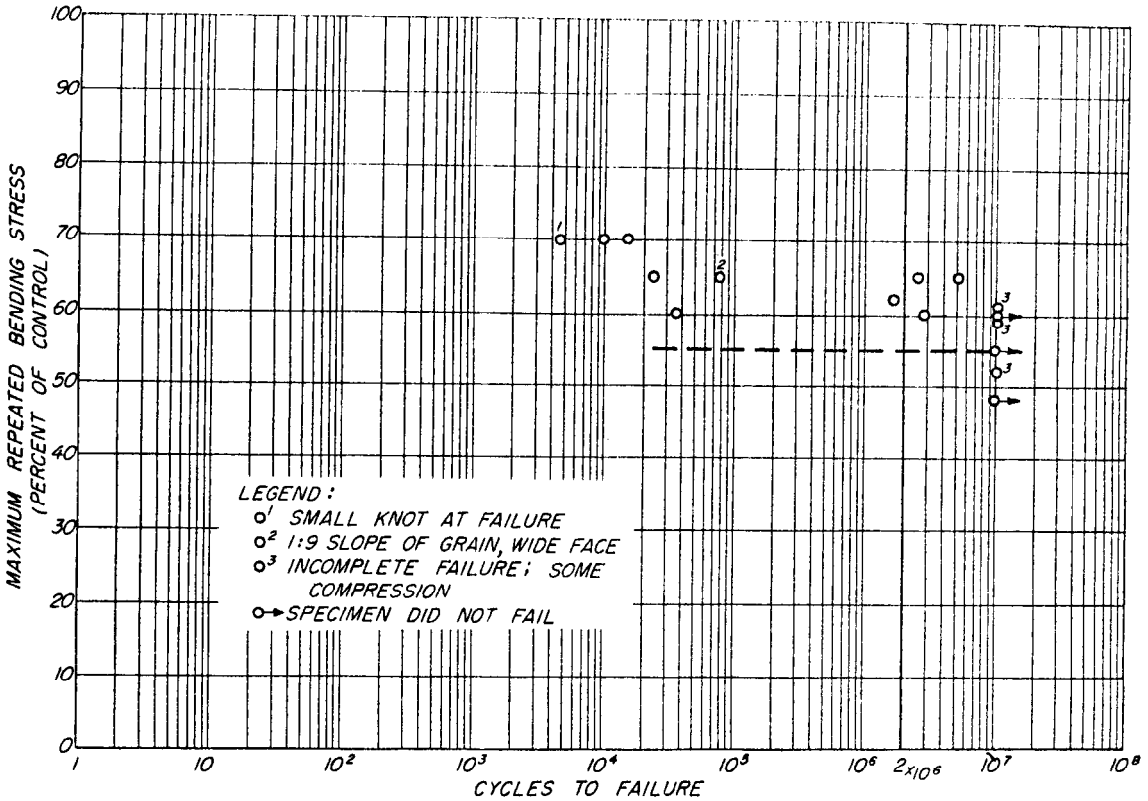


Figure 17.--(Top) Relation of stress to number of cycles to failure for fatigue tests of treated, artificially checked southern pine with 1:12 slope of grain. Values for maximum repeated stress are expressed as percentages of the static shear strength. (Bottom) Same relationship with values of maximum repeated stress expressed in pounds per square inch.



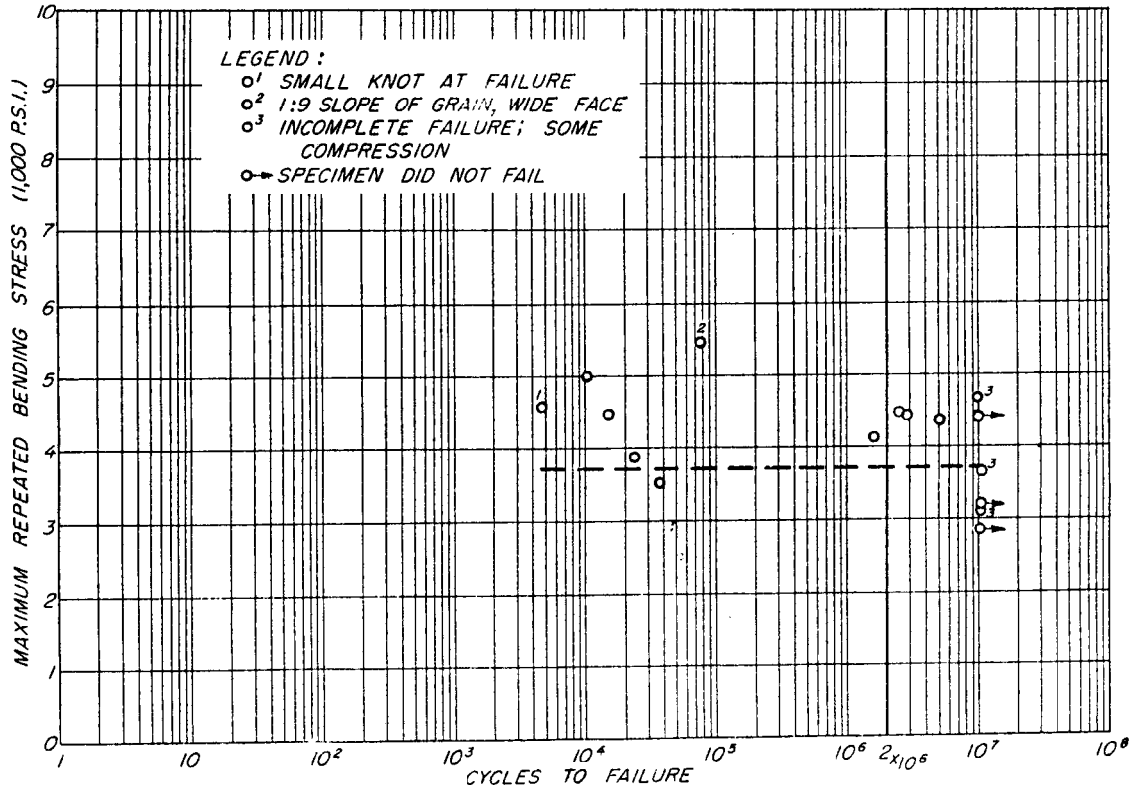


Figure 18. --(Top) Relation of stress to number of cycles to failure for fatigue tests of green, straight-grained, unchecked Douglas-fir. Values for maximum repeated stress are expressed as percentages of static strength. Stress ratio 0.10. (Bottom) Same relationship with values of maximum repeated stress expressed in pounds per square inch.

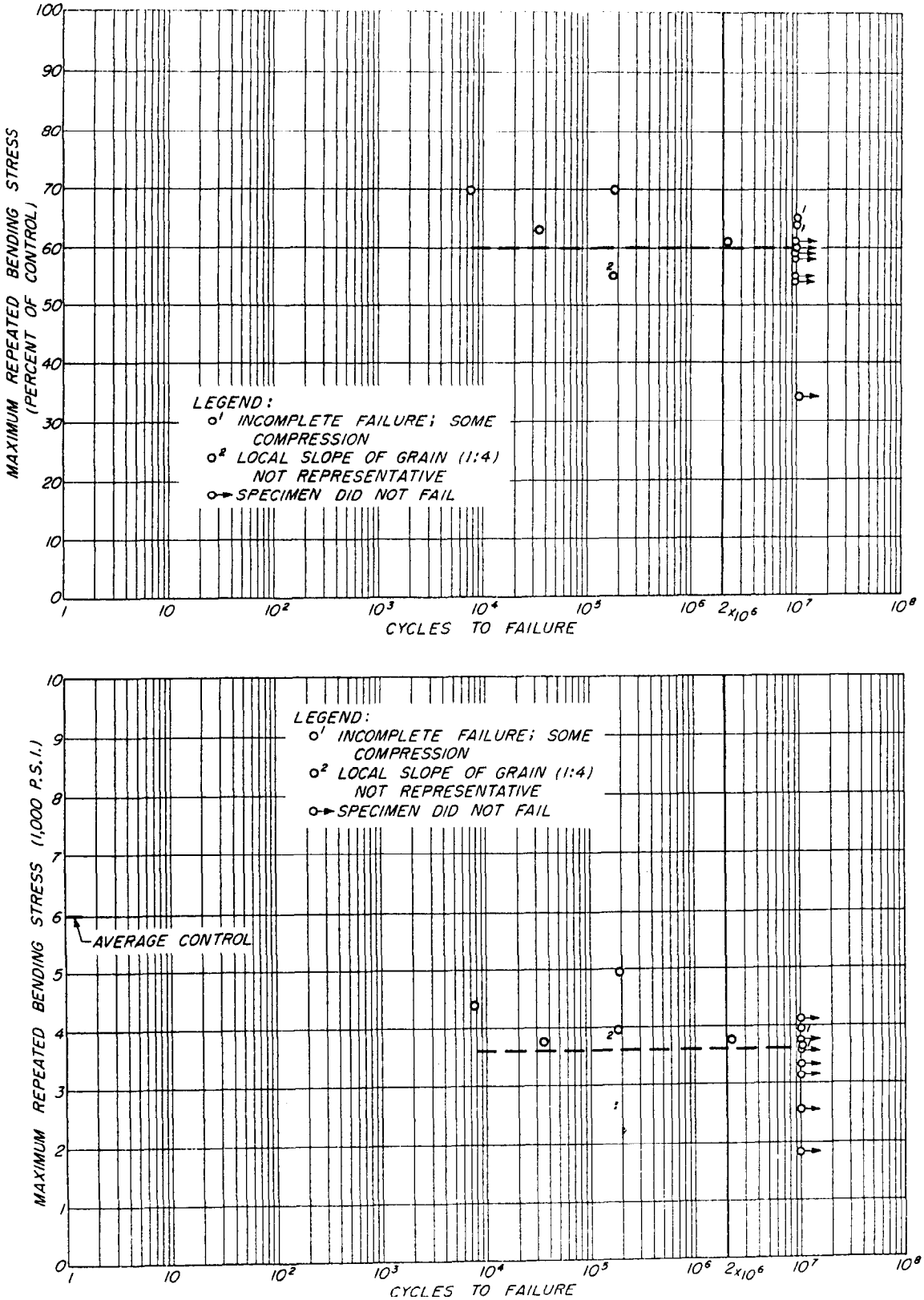


Figure 19. --(Top) Relation of stress to number of cycles to failure for fatigue tests of green, unchecked Douglas-fir with 1:12 slope of grain. Values of maximum repeated stress are expressed as percentages of static strength. Stress ratio 0.10. (Bottom) Same relationship with values of maximum repeated stress expressed in pounds per square inch.

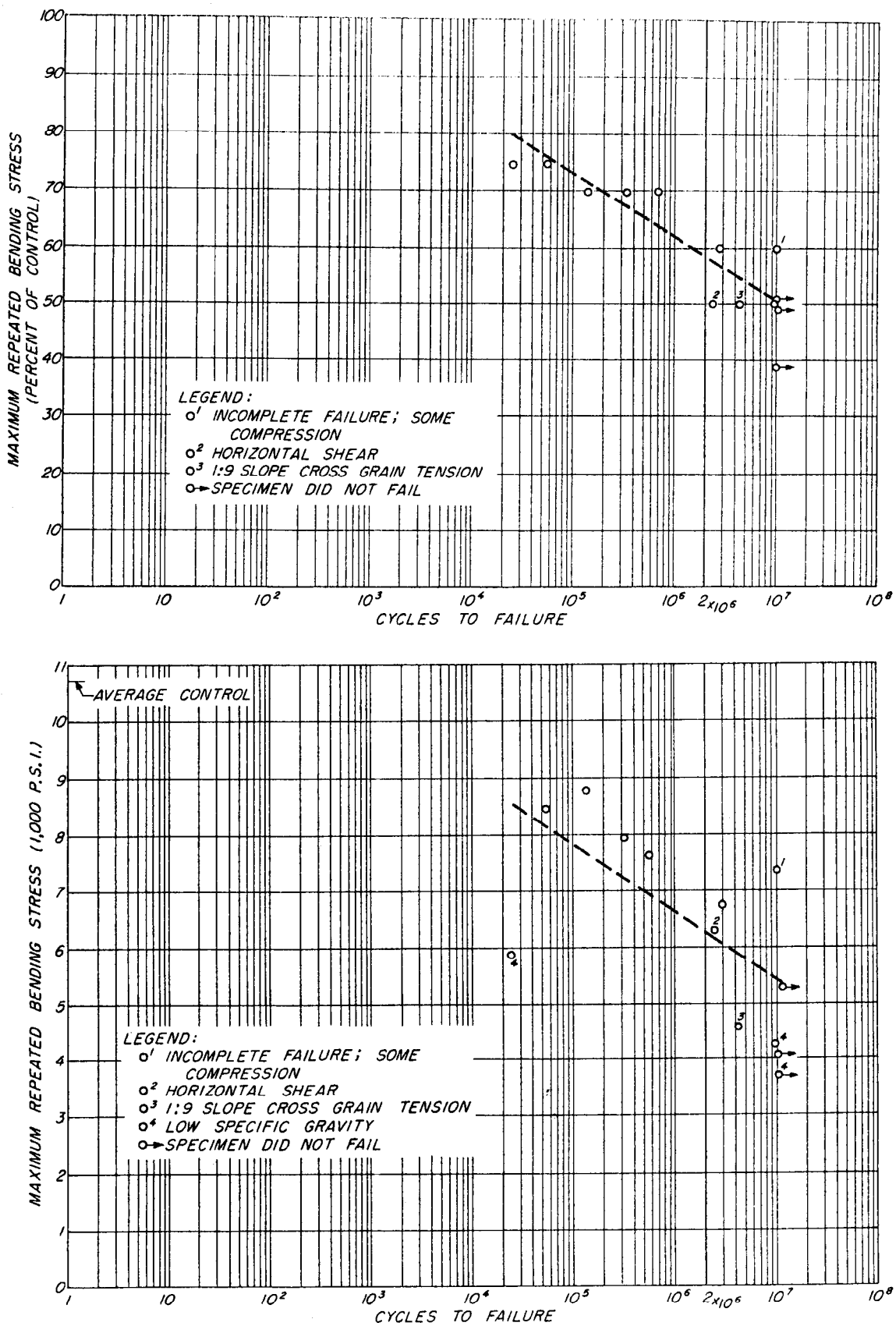
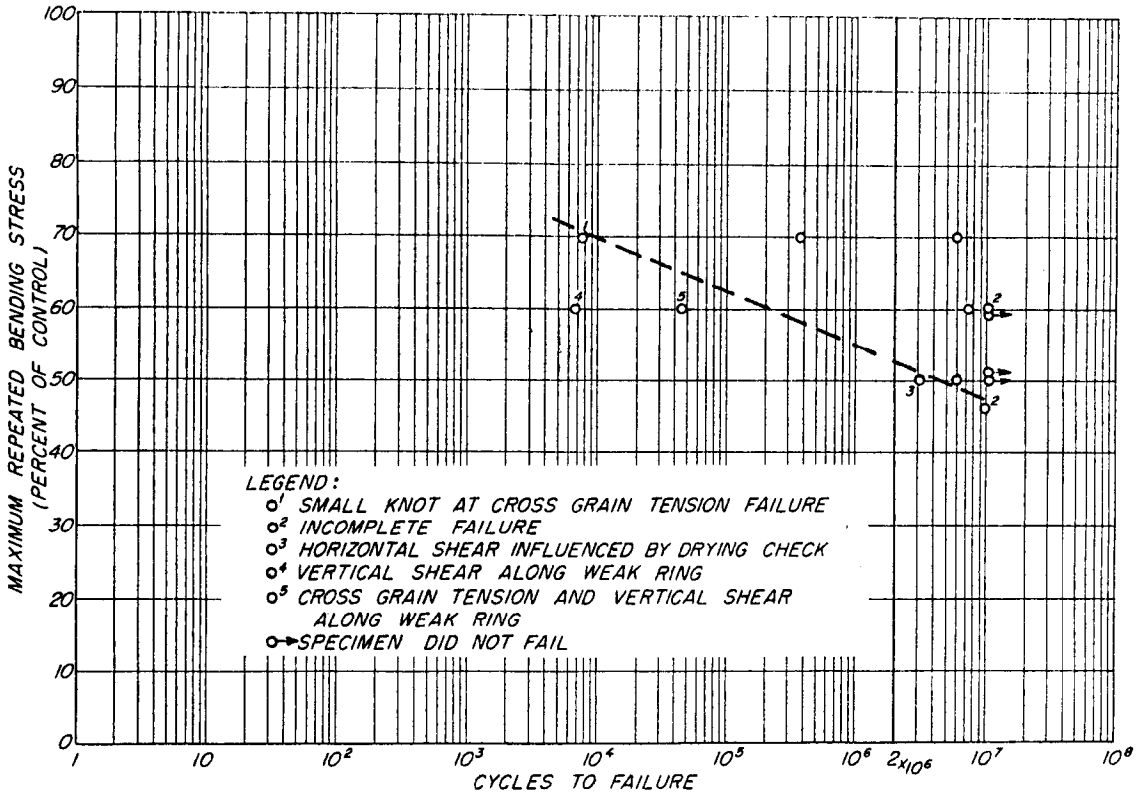


Figure 20. --(Top) Relation of stress to number of cycles to failure for fatigue tests of air-dry, straight-grained, unchecked Douglas-fir. Values for maximum repeated stress are expressed as percentages of static strength. Stress ratio 0.10. (Bottom) Same relationship with values of maximum repeated stress expressed in pounds per square inch.



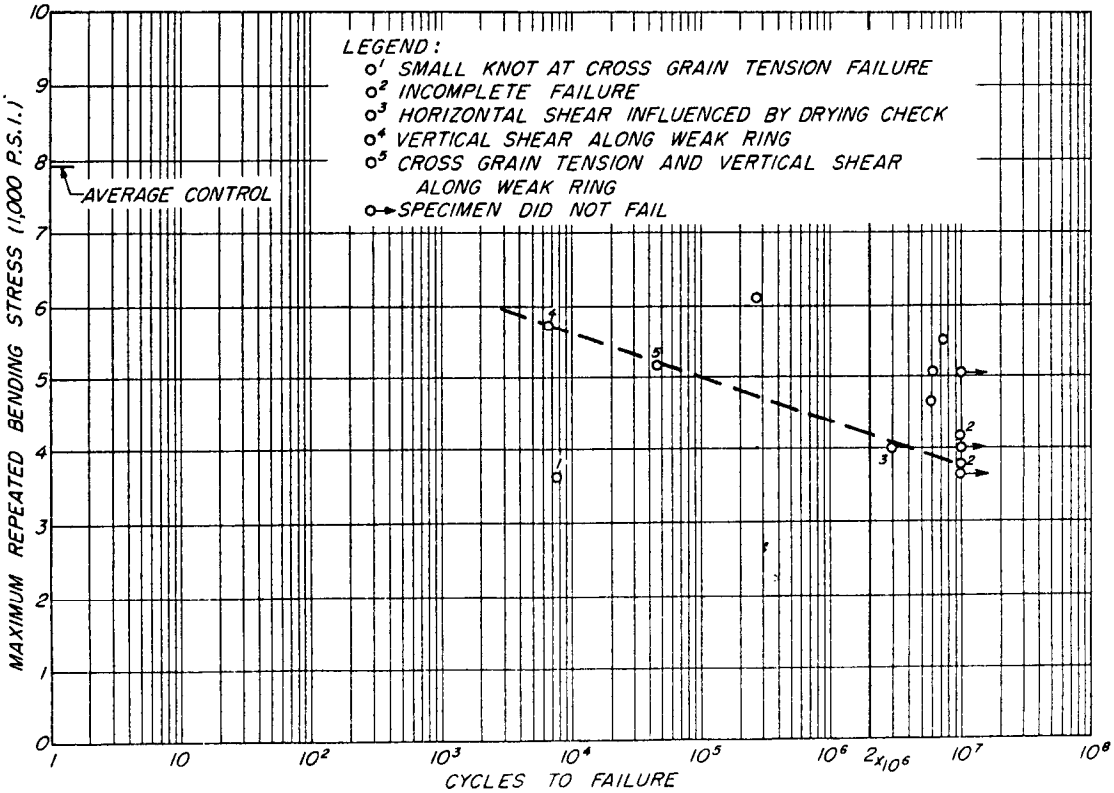


Figure 21. --(Top) Relation of stress to number of cycles to failure for fatigue tests of air-dry, unchecked Douglas-fir with 1:12 slope of grain. Values are expressed as percentages of static strength. Stress ratio 0.10. (Bottom) Same relationship with values of maximum repeated stress expressed in pounds per square inch.

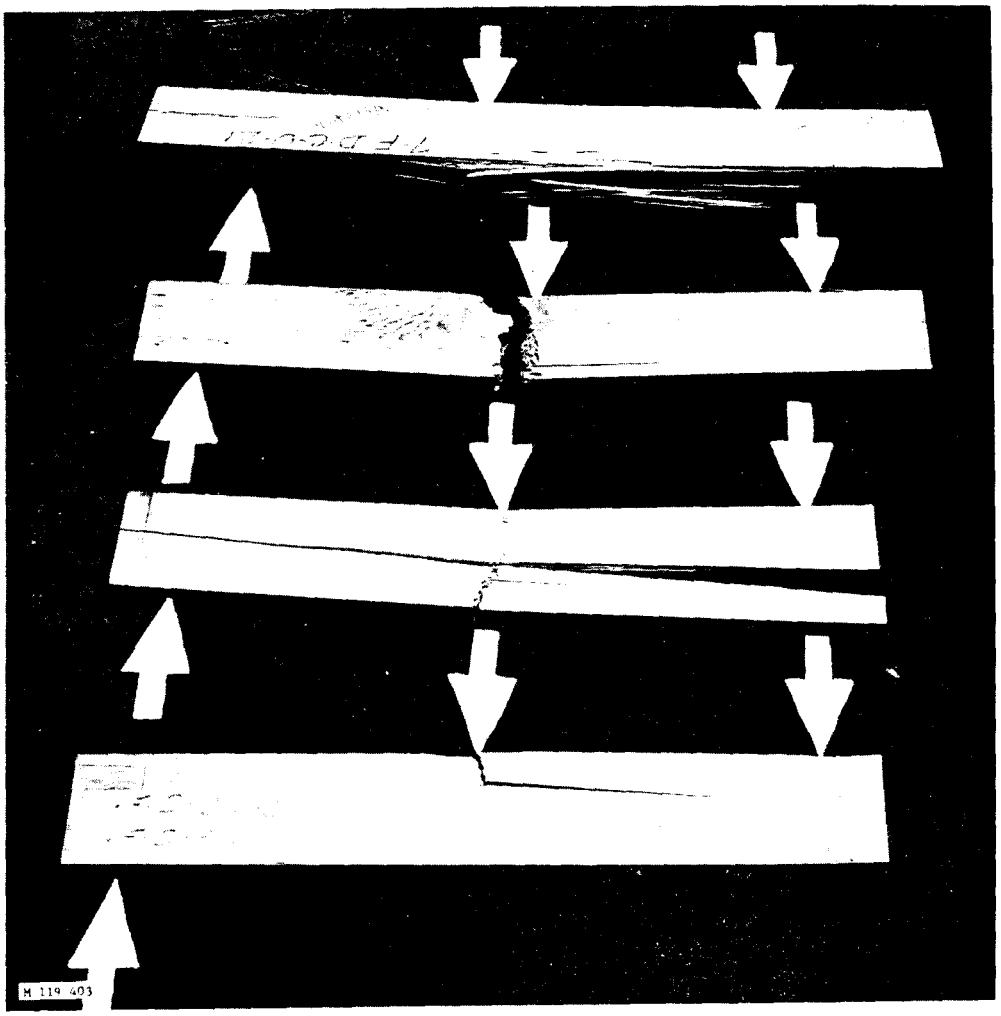


Figure 22.--Typical static and fatigue failures of air-dry, straight-grained Douglas -fir. Upper specimen of each pair is from static control test; lower one of each pair from fatigue test.

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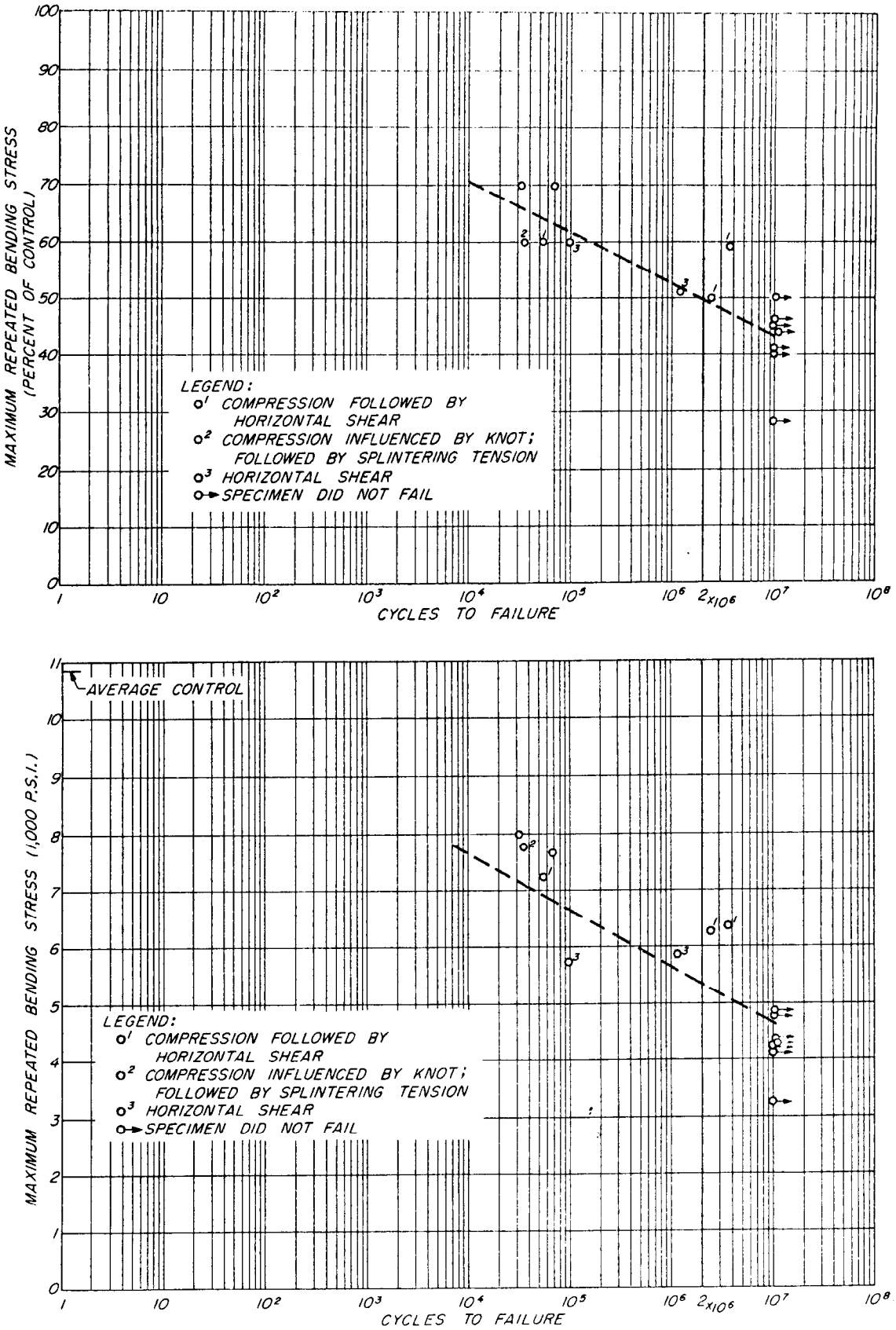


Figure 23. --(Top) Relation of stress to number of cycles to failure for treated, straight-grained unchecked Douglas -fir. Values for maximum repeated stress are expressed as percentages of the static strength. Stress ratio 0.10. (Bottom) Same relationship with values of maximum repeated flexure stress expressed in pounds per square inch.

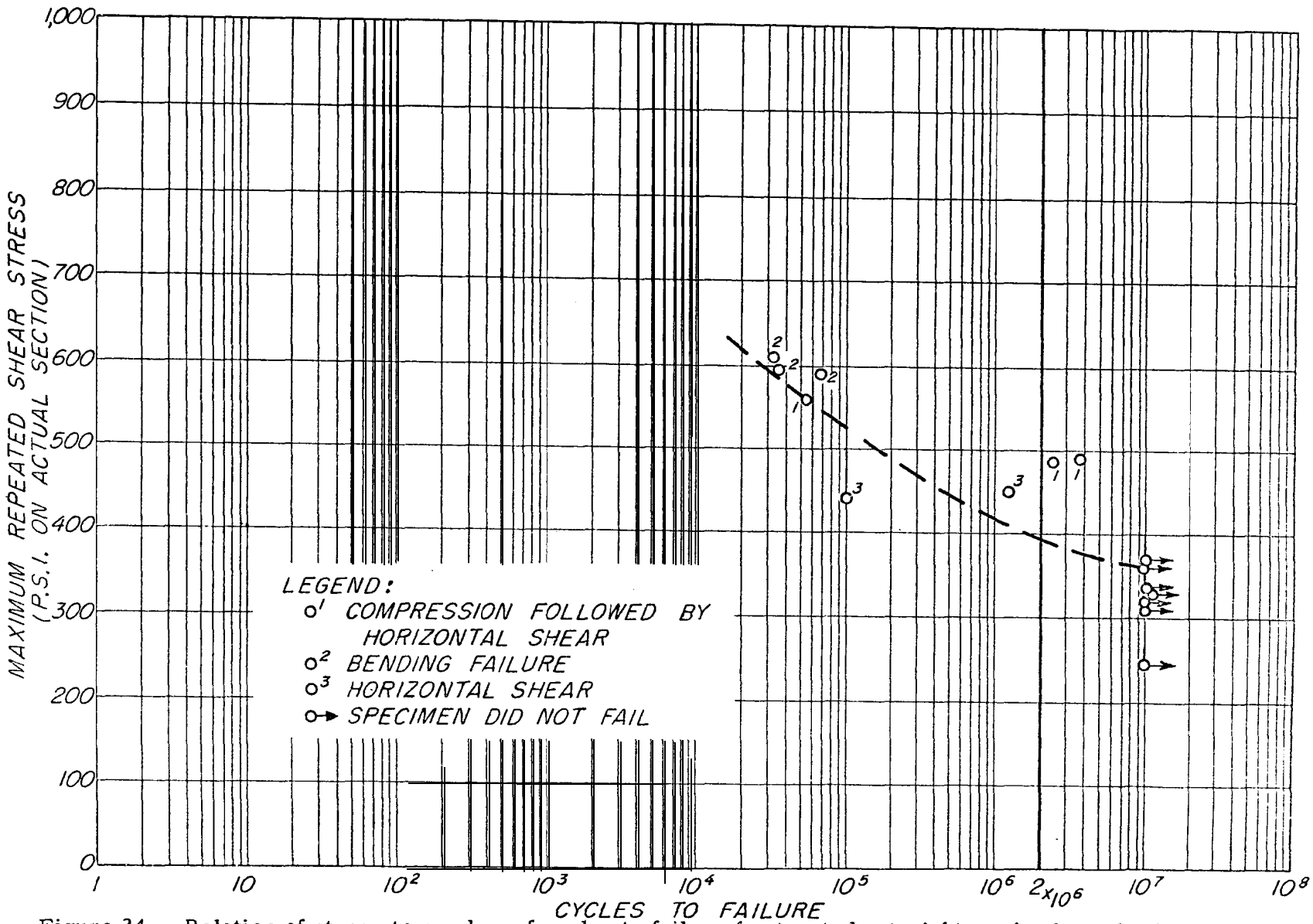


Figure 24.--Relation of stress to number of cycles to failure for treated, straight-grained, unchecked Douglas-fir. Since specimens that withstood a large number of cycles before failing developed horizontal shear failures, values of maximum repeated stress are expressed in shear in pounds per square inch.

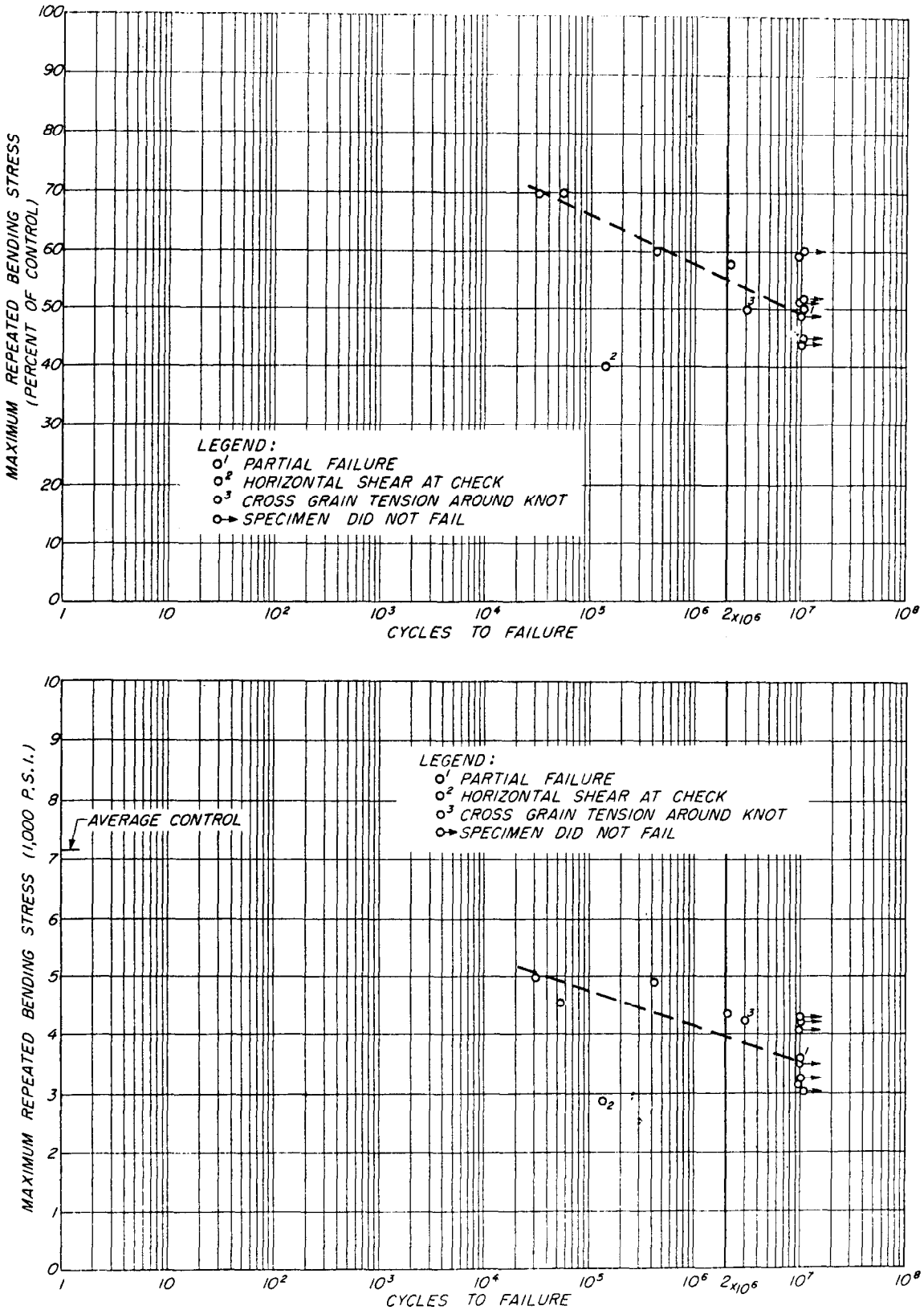
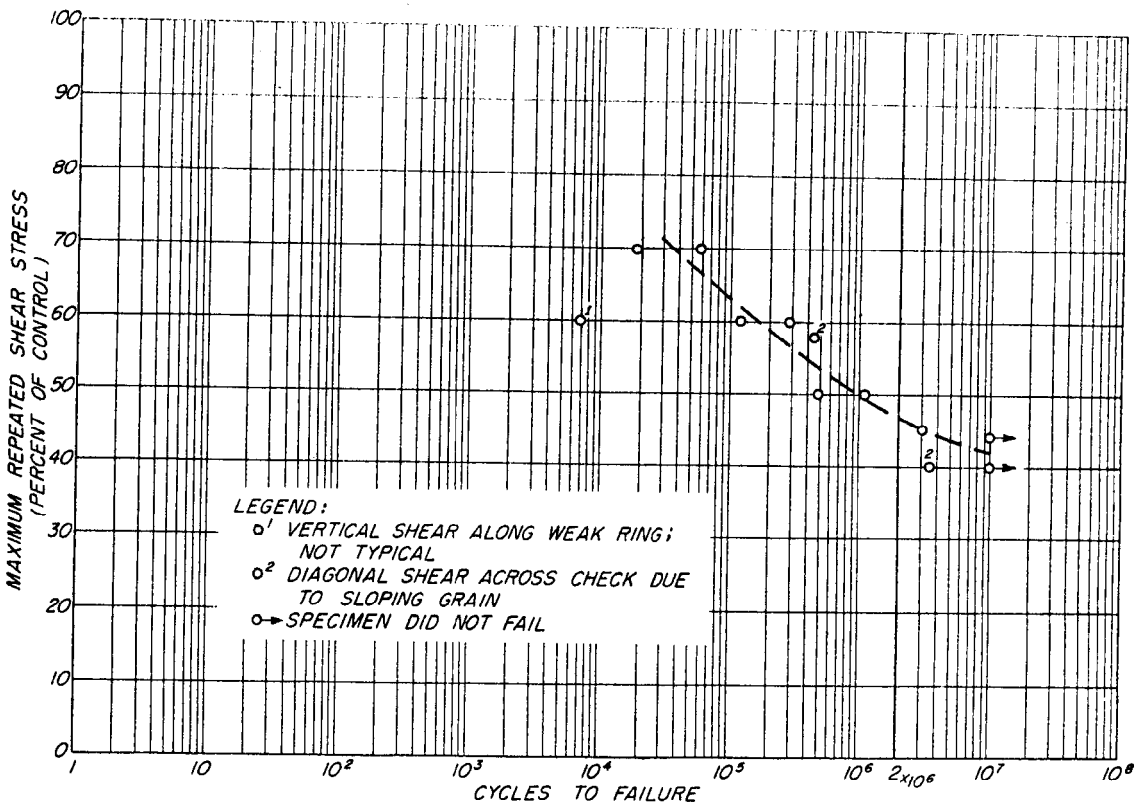


Figure 25. --(Top) Relation of stress to number of cycles to failure for fatigue tests of treated Douglas-fir with 1:12 slope of grain. Values of maximum repeated stresses are expressed as percentages of static strength. Stress ratio 0.10. (Bottom) Same relationship with values of maximum repeated stress expressed in pounds per square inch.



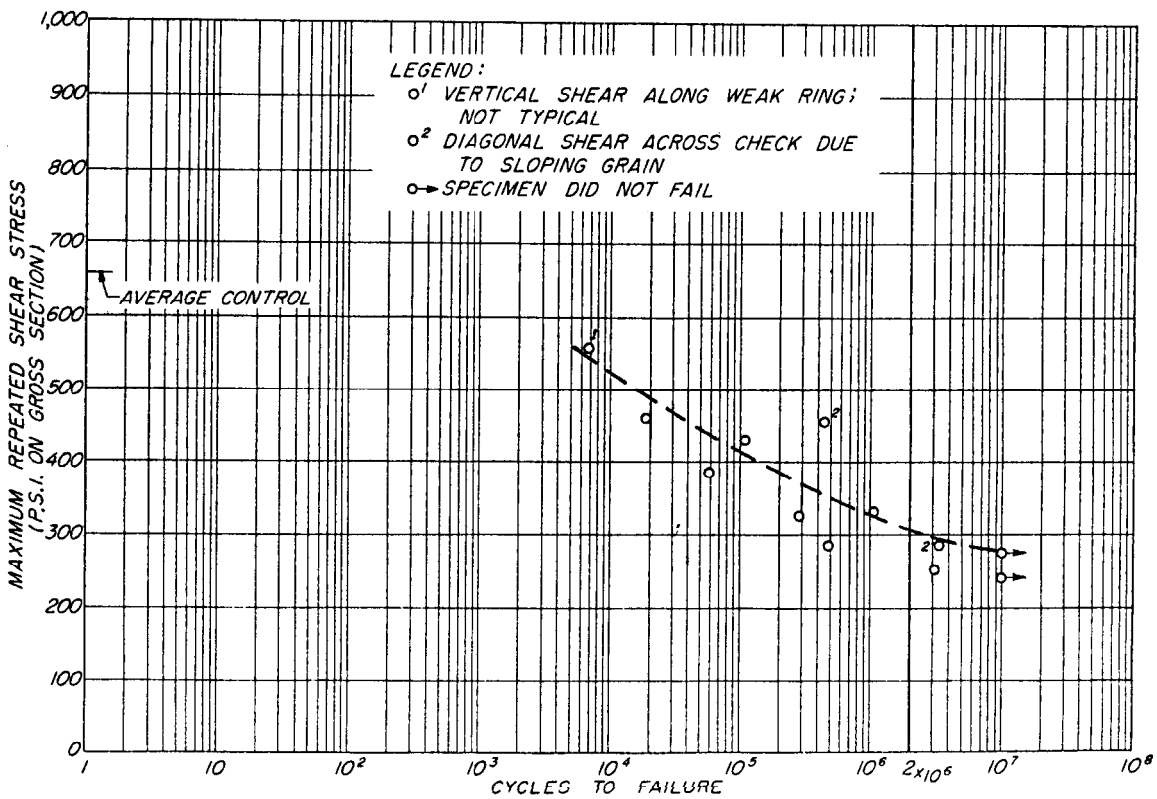


Figure 26. --(Top) Relation of stress to number of cycles to failure for fatigue tests of air-dry, straight-grained, artificially checked Douglas-fir. Values for maximum repeated stress are expressed as percentages of static shear strength. Stress ratio 0.10. (Bottom) Same relationship with values of maximum repeated stress expressed in pounds per square inch.

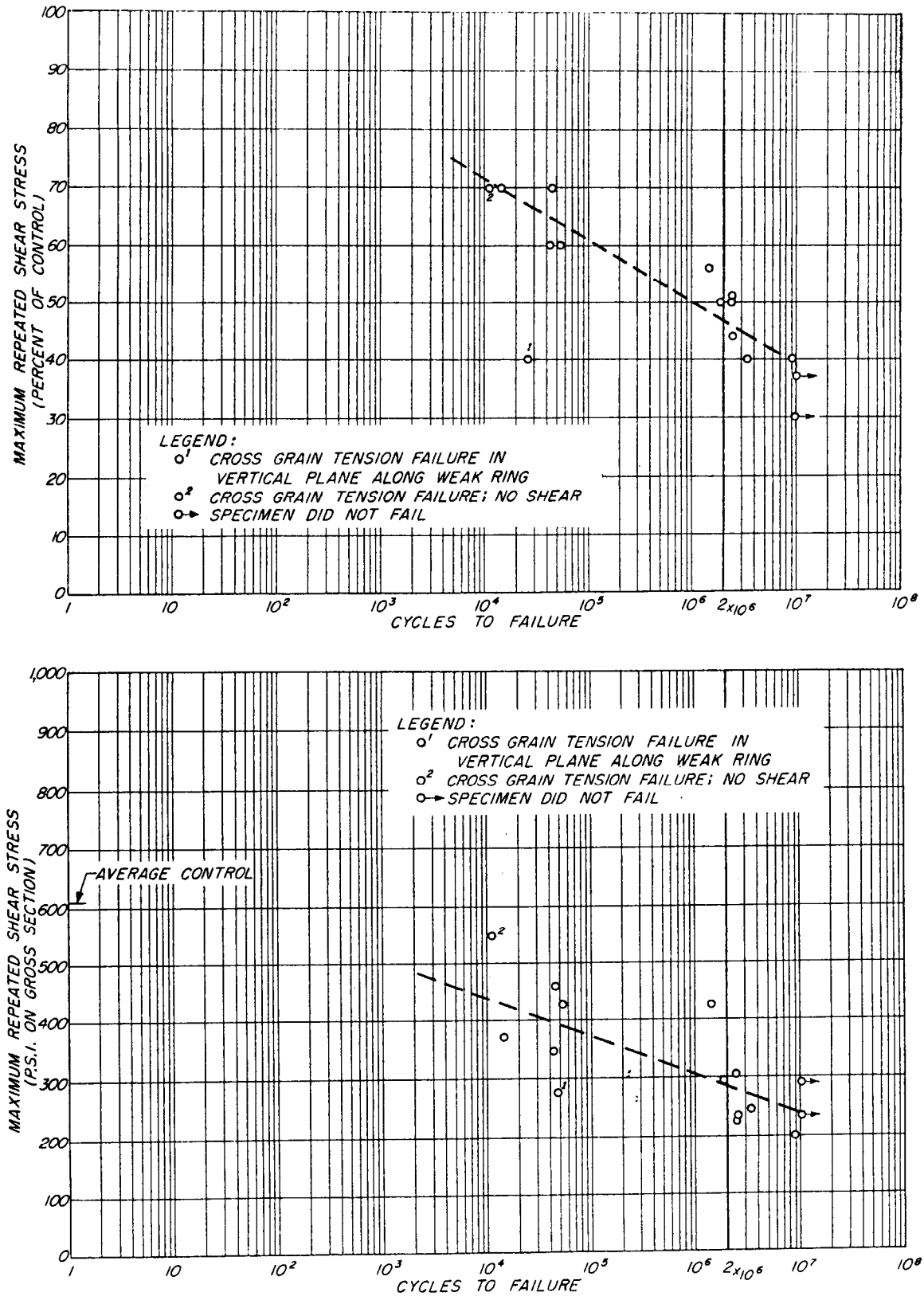


Figure 27. --(Top) Relation of stress to number of cycles to failure for fatigue tests of air-dry, artificially checked Douglas-fir with 1:12 slope of grain. Values for maximum repeated stress are expressed as percentages of static shear strength. Stress ratio 0.10. (Bottom) Same relationship with values of maximum repeated stress expressed in pounds per square inch.

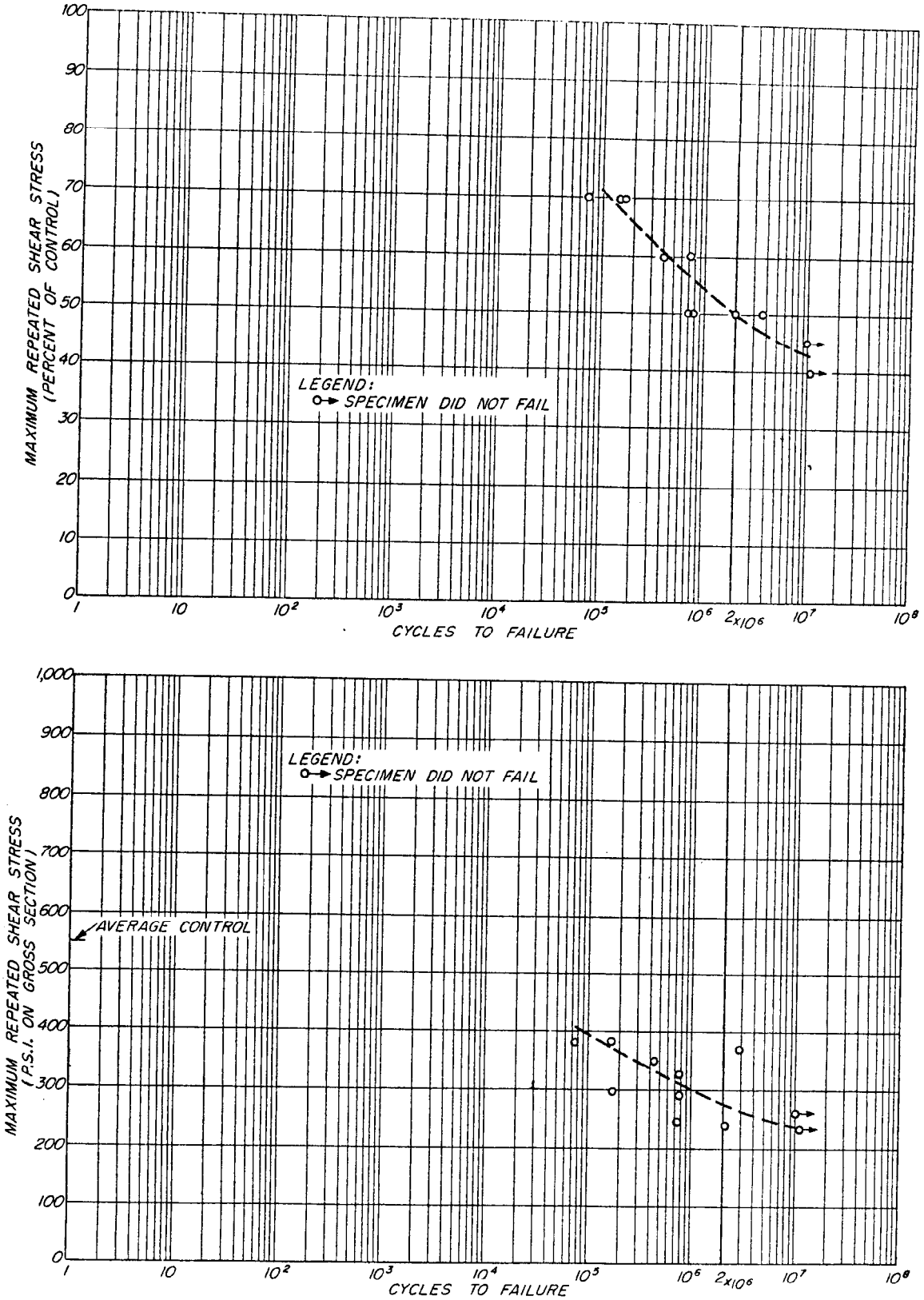


Figure 28. --(Top) Relation of stress to number of cycles to failure for fatigue tents of treated, straight-grained, artificially checked Douglas, -fir. Values for maximum repeated stresses are expressed at percentages of static shear strength. Stress ratio 0.10. (Bottom) Same relationship with values of maximum repeated stress expressed in pounds per square inch.

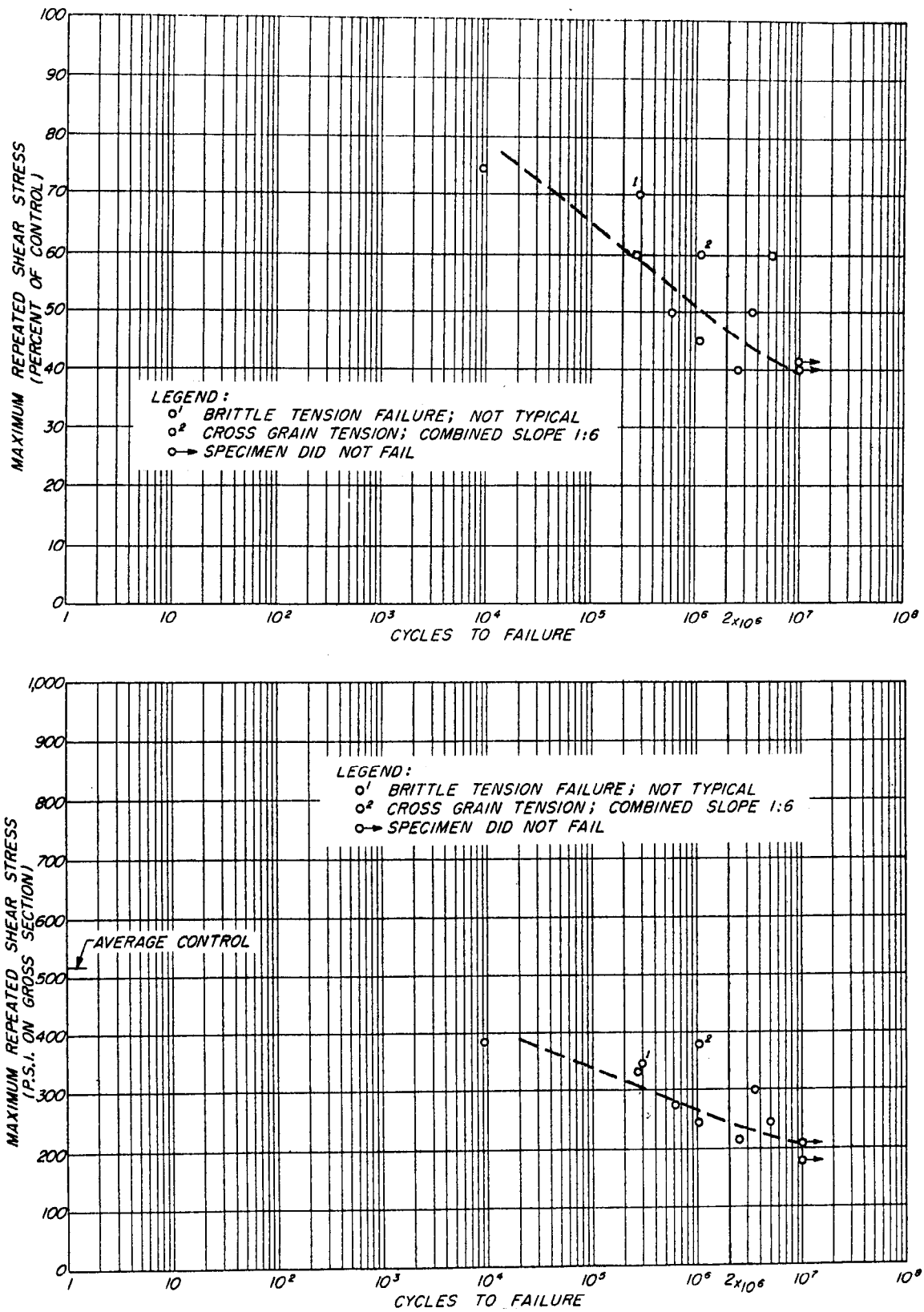


Figure 29. --(Top) Relation of stress to number of cycles to failure for fatigue tests of treated, artificially checked Douglas-fir with 1:12 slope of grain. Values for maximum repeated stress are expressed as percentages of static shear strength. Stress ratio 0.10. (Bottom) Same relationship with values of maximum repeated stress expressed in pounds per square inch.

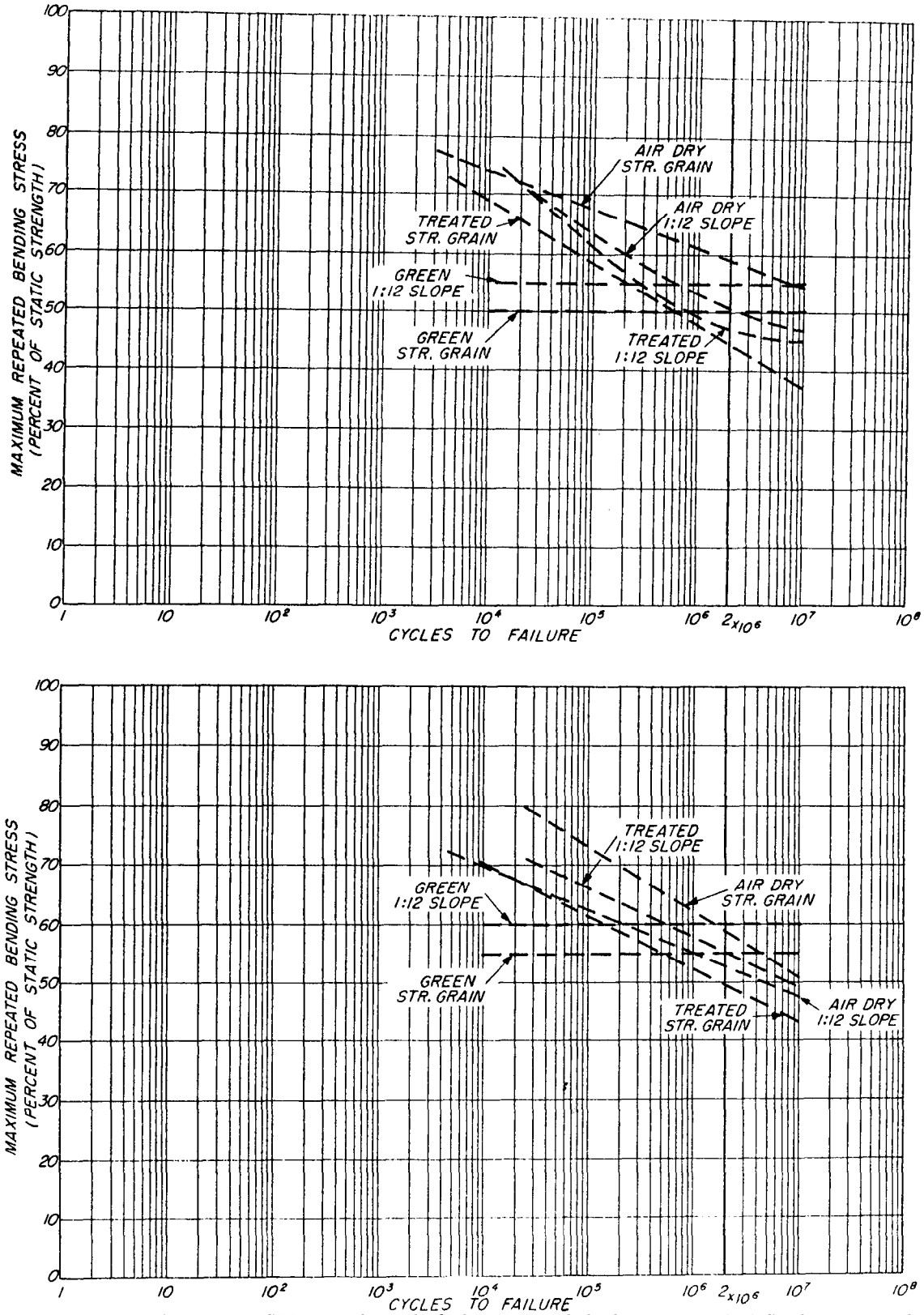


Figure 30. -- Approximate S-N curves for unchecked, quarter-scale bridge stringers; (top) Southern pine and (bottom) Douglas-fir. Values of maximum repeated stress are expressed as percentages of static bending strength. Stress ratio 0.10.

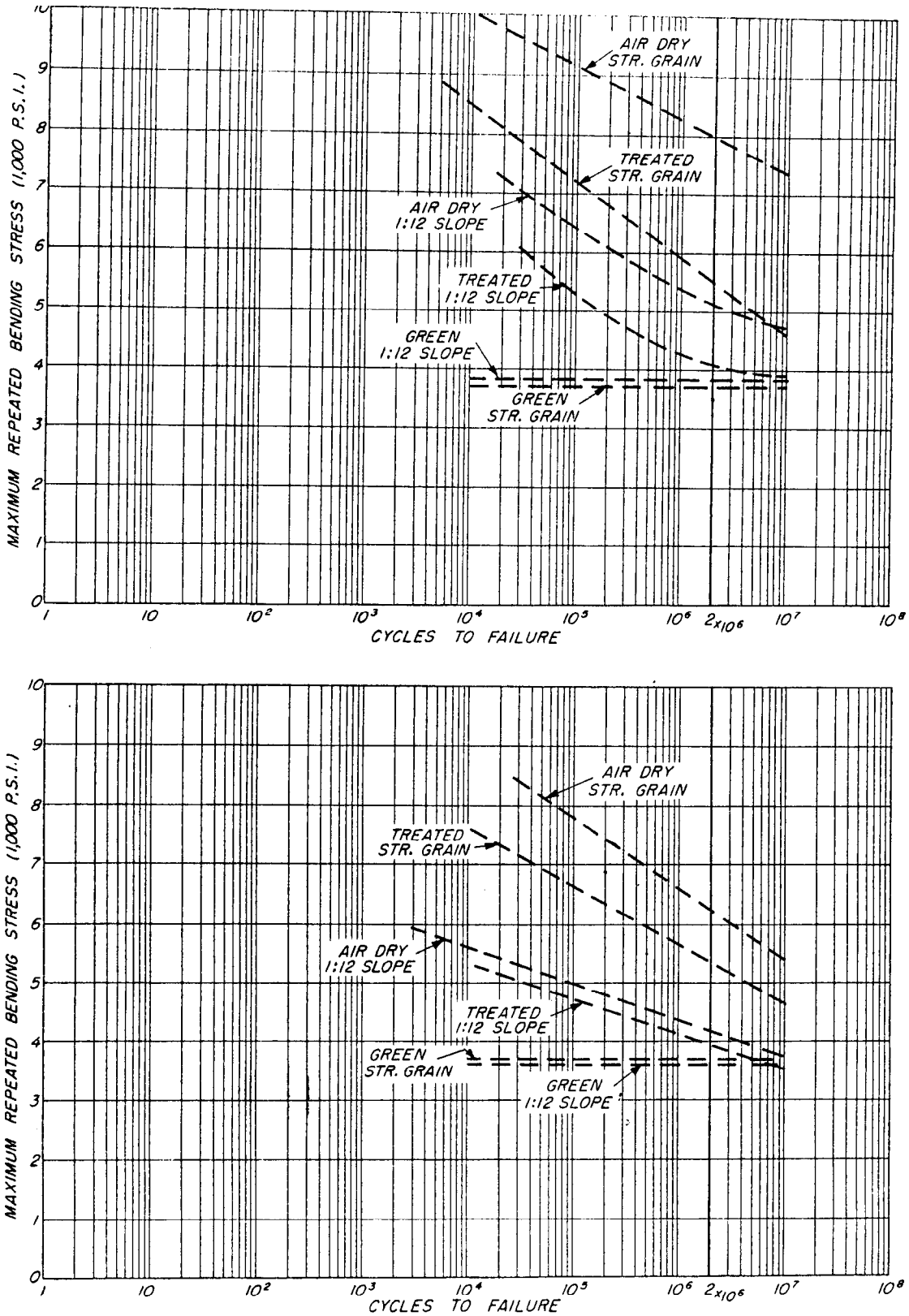
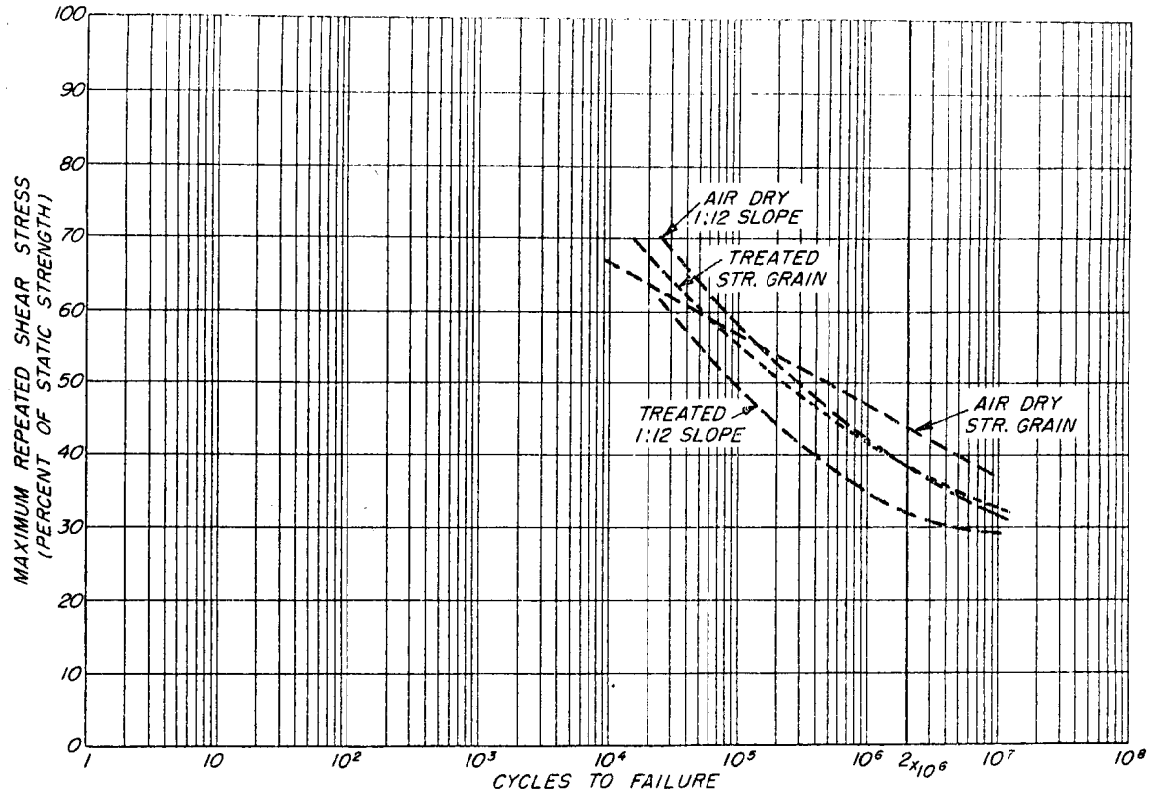


Figure 31. --Approximate S-N curves for unchecked, quarter-scale bridge stringers; (top) southern pine and (bottom) Douglas-fir. Values of maximum repeated bending stress are in pounds per square inch. Stress ratio 0.10.



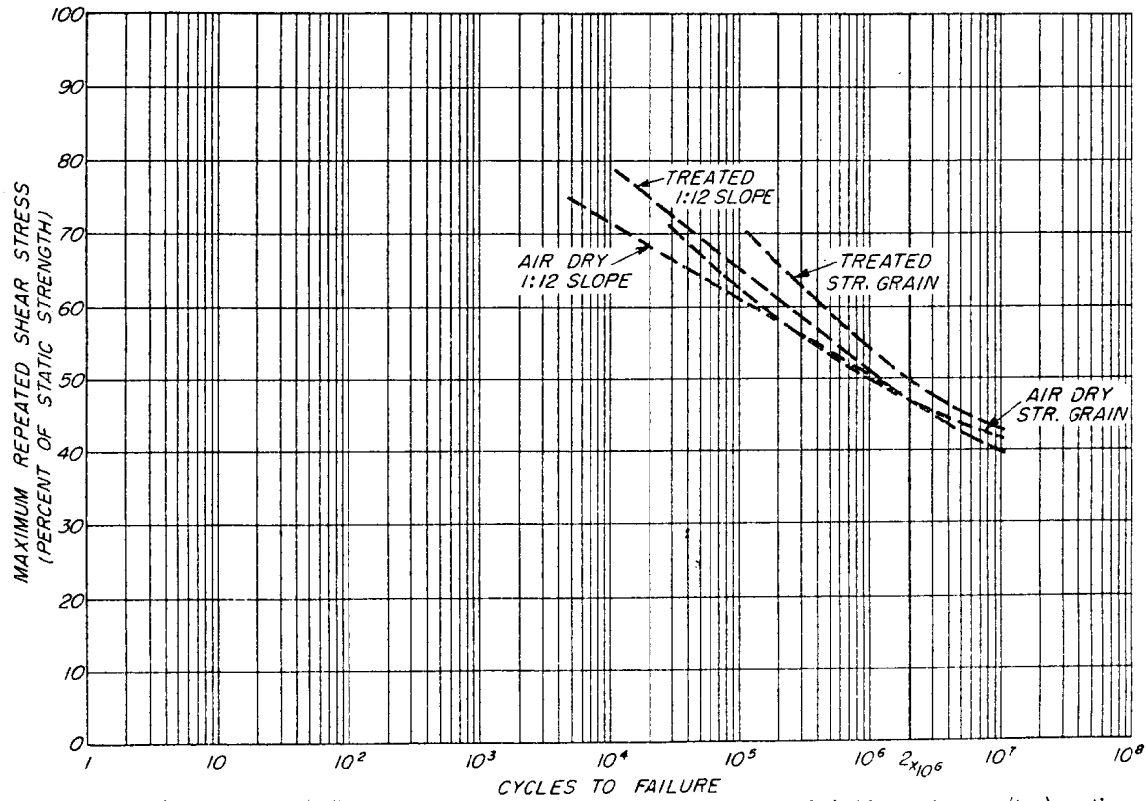


Figure 32.--Approximate S-N curves for artificially checked, quarter-scale bridge stringers; (top) southern pine and (bottom) Douglas-fir. Values of maximum repeated stress are expressed as percentages of the static shear strength. Stress ratio 0.10.

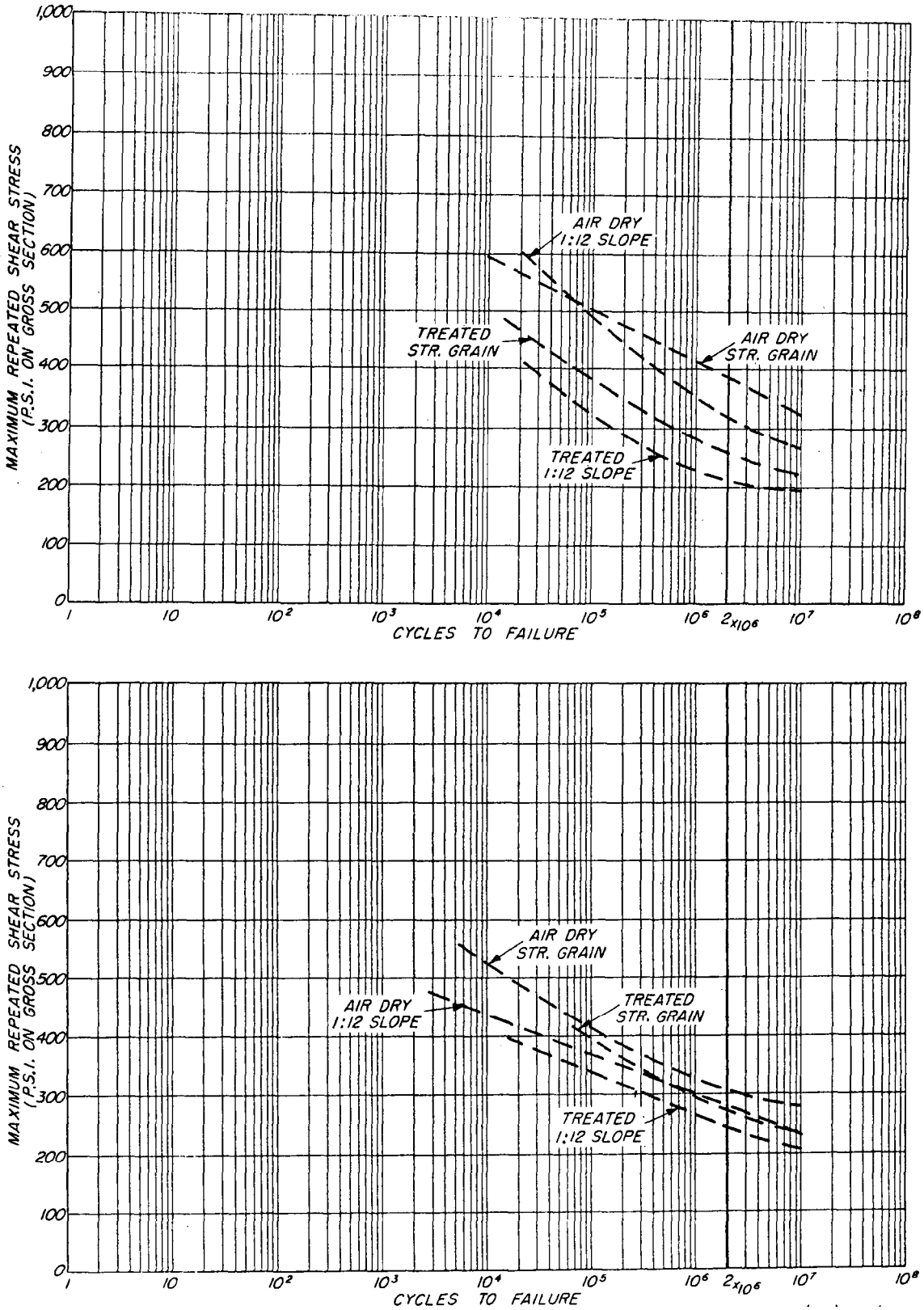


Figure 33. --Approximate S-N curves for artificially checked, quarter-scale bridge stringers; (top) southern pine and (bottom) Douglas-fir. Values of maximum repeated shear stress are in pounds per square inch, calculated on the basis of the gross width with no reduction in width for notches, so actual stresses were about twice those shown. Stress ratio 0.10.