EFFECT OF RAPID LOADING ON THE COMPRESSIVE AND FLEXURAL STRENGTH OF WOOD

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Summary

Rapid loading tests in flexure and compression parallel to grain on Sitka spruce, Douglas-fir, maple, and birch specimens at approximately 12 percent moisture content show that the modulus of rupture and ultimate compressive strength are increased as the time to ultimate load is decreased. For loading times of 0.3 to 750 seconds, the increase or decrease is approximately 8 percent for a tenfold decrease or increase in loading time. Fiber stress at proportional limit values are generally increased to a greater extent than ultimates, but are much more variable. The effect of rapid loading on modulus of elasticity is small and no increase in modulus with rate of loading should be considered. Deflections and deformations to maximum load are about the same regardless of loading rate for softwoods, but they tend to increase as loading time is decreased for hardwoods. The duration of maximum load in compression varies inversely as the time to maximum load, and at rapid loading rates it is about one-tenth of the time to maximum load. The flexural work to maximum load is greater for the rapid loading rates, but only in hardwoods is the increase greater as the loading time becomes less.

Introduction

The period in which a load or force acts on a wood member and the duration of application of this force have an important effect on the strength properties of the member in question. This factor must be considered when designing with

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[1]The testing and initial analysis of the data on Sitka spruce and Douglas-fir specimens tested in compression and flexure were done by G. W. Foster and M. P. Brokaw. Testing of the maple and birch specimens was done by G. W. Foster, M. P. Brokaw, L. A. Yolton, and D. L. Harker. Data were obtained during the wartime testing program to provide needed information to the Armed Forces.

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

wood, whether it be for a warehouse where the loads imposed on the structural members may be applied for weeks or months; or in aircraft where the load, during ordinary maneuvers, such as a change in direction of flight or flatten-out after a dive, is applied in a fraction of or a few seconds. Early investigators were conscious of this effect, and in 1908 McGarvey Cline[3] and H. D. Tiemann[4] published results of tests to evaluate the effect of rate of application of load on strength and stiffness of wood members and proposed speed of testing requirements for several basic test procedures.

These studies and others made at the Forest Products Laboratory over a number of years have indicated that the load to cause failure in a wood member that is continuously loaded for years, is approximately 60 percent of that required for failure in a standard flexure test that is completed in about 10 minutes. It was also determined that the load to cause failure in impact, where the load is applied in a few thousandths of a second, was about double the failing load in a standard flexure test. Other studies had been made to evaluate the effect of loading times between a fraction of a second and the standard testing time; but during World War II, when wood was used to a considerable extent for structural members for training aircraft and gliders, it became evident that additional test data were necessary in this range. Accordingly, a test program was initiated at the Forest Products Laboratory in cooperation with the ANC Committee on Aircraft Design Criteria, and studies were made to determine the effect of rate of loading on the flexural and compression-parallel-to-grain strength properties of Sitka spruce, Douglas-fir, maple, and birch. The results of the studies on those species, representing some 640 rapid loading tests and more than 900 tests of matched controls, are presented and analyzed to evaluate the effects of these loading rates.

Materials and Procedures

Material

Two softwood and two hardwood species were included in the investigations made to evaluate the effect of rapid loading on the compressive and flexural strength properties of wood. The softwoods, Sitka spruce and Douglas-fir, were obtained from trees 250 to 400 years old felled in the Washington-Oregon area. Logs of those two species were shipped to the Forest Products Laboratory, where they were sawed into planks that were subsequently kiln dried to about 12 percent moisture content. Maple and birch logs from Wisconsin were also cut into planks and kiln dried at the Laboratory. Planks having the desired specific gravity characteristics were selected from this source of material to be fabricated into test specimens.

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[3] McGarvey Cline, "Forest Service Tests to Determine the Influence of Different Methods and Rates of Loading on the Strength and Stiffness of Timber." Proceedings Amer. Soc. Testing Materials, Vol.8, p.535, 1908.

[4] Harry D. Tiemann, "The Effect of Speed of Testing Upon the Strength of Wood and the Standardization of Tests for Speed." Proceedings Amer. Soc. Testing Materials, Vol.8, p.541, 1908.

Matching

The planks chosen for fabrication into test specimens were in all instances free of defects and as straight grained as possible. The grain direction of each plank was determined and the individual specimens were oriented so that the direction of grain was parallel to their edges.

Compression-parallel-to-grain specimens were nominally 1 by 1 inch in cross section and 4 inches in length parallel to the grain. One-inch-square sticks were cut from the selected plank and were in turn cut into 4-inch lengths. From these, end-matched test specimens, controls, and rapid loading specimens were selected alternately. By this procedure it was possible to compare the properties of the rapid loading specimens with the average of those of the two end-matched controls. The variation in control strength between the two controls for each rapid loading specimen was limited to 5 percent, and if this limit was exceeded the results were not used.

Flexural specimens, nominally 1 inch by 2 inches in cross section for the softwoods and 1 inch square for the hardwoods, were 16 inches in length. The depth of specimen was the 1-inch dimension in all cases, and the annual rings were oriented parallel to the specimen width. In all of the planks except some of the Sitka spruce, the flexural specimens were cut so as to obtain end matching between rapid loading specimens and controls. Selection of controls and rapid loading specimens from these planks was carried out in a manner identical with that used for the compression specimens. Test results obtained on the rapid loading specimens were compared with average properties from adjacent end-matched controls. The variation in properties of the controls was held to a minimum, but the results were not so consistent nor limited so closely as in the compression tests. In a few of the Sitka spruce planks the grain orientation was such that end matching was not possible, and in these instances the specimens were side matched tangentially. The properties of the rapid loading specimens were compared with those of the side-matched controls.

After fabrication, the specimens were stored in a humidity room maintained at a temperature of 70° F. and a relative humidity of 64 percent until they reached constant weight. Depending on species and previous conditioning, the specimens came to equilibrium at moisture contents of about 9 to 14 percent. The specimens were kept under these conditions until removed one at a time for test.

Methods of Test

Compression-parallel-to-grain tests of the controls were made according to standard procedures, except that the special compressometer developed for the rapid loading tests was used to measure the deformation over a 2-inch gage length. The specimens were loaded on the 1- by 1-inch ends, in a 10,000-pound-capacity, mechanical-type testing machine, at a rate of free head movement of 0.003 inch per inch of specimen length per minute. Actual rate of strain was less than this figure, particularly during the early part of the test. Other experiments have shown, however, that after the proportional limit stress has been exceeded, the rate of loaded cross-head movement of mechanical machines approaches the rate of free head movement.

Rapid loading tests were made at nominal rates of free head movement of 0.087, 0.394, 0.773, 1.905, 2.799, and 5.87 inches per minute in a mechanical-type testing machine. Since at these rates it was impossible to measure load and deformation increments in the conventional manner, other techniques were devised.

Increments in load were measured by the deformation of a calibrated steel tube that was also used as a support for the specimen in the testing machine. This tube was 3 inches in diameter and 37 inches long and had a wall thickness of 0.073 inch. A machined steel bearing cap 1 inch thick was fitted to each end of the tube. A pivoted collar near the bottom of the tube and a rigid collar near the top were connected by two 1/4-inch round steel rods. One rod was attached to a dial indicator mounted rigidly on the upper collar. This dial indicator, graduated to 0.001 inch, measured the deformation of the tube resulting from the load applied to the specimen as shown in figures 1 and 2. This deformation was converted to applied load from the relationship of load and deformation that had previously been obtained from calibration tests of the tube.

Strain measurements on the compression test specimens were made with the compressometer specially developed for this study. The compressometer was attached to the specimen, over a 2-inch gage length, by conically pointed thumb screws bearing on small steel pins imbedded in the tangential face of the specimen. As shown in figure 3, one arm of the compressometer was fixed by means of a flexure pivot, while a dial graduated to 0.0001-inch was mounted on the other to measure deformations. A locking pin to maintain the 2-inch gage length was removed once the compressometer was firmly attached to the specimen.

An electric timer reading directly to 0.01 second was used to measure the time of each test.

The loading periods from 0.8 to 50 seconds were too short to permit observation and recording of load, deformation, and time increments by normal procedures. Therefore a 35-millimeter motion-picture camera (fig. 2), operated at an appropriate speed for each test, was used to record simultaneous dial gage and electric-timer readings. The camera was operated for the period just prior to contact of the loading head and the specimen to the point after ultimate load when the load decreased to less than the ultimate value. Thirty or 40 pictures were taken to ultimate load in each test, and the test data were subsequently transcribed from the film to data sheets for study.

Flexural tests were made on 1- by 2- by 16-inch softwood specimens and 1- by 1- by 16-inch hardwood specimens tested over a 14-inch span. Depth of specimen was always 1 inch, and load was applied perpendicular to the growth rings at the center of the span through a maple block curved to a 3-inch radius. Control specimens were tested in a mechanical-type testing machine at a rate of free head movement of 0.05 inch per minute. This rate produces a theoretical rate of straining in the outermost fiber, within the proportional limit, of 0.0015 inch per inch per minute. Actual rate of straining is somewhat less than this, but during the portion of the test beyond proportional limit, the loaded head speed compares closely with the free running head speed.

The rapid loading tests in flexure were made on a hydraulic-type testing machine at nominal rates of loaded head movement of 0.2, 1, 3, 6, 12, 18, and 80 inches per minute. Rates up to 6 inches per minute were obtained by conventional operation of the testing machine. The rate of 18 inches per minute was made possible by operating the motor-driven adjusting head at about 12 inches per minute in opposition to movement of the lower platen of 6 inches per minute. A bellows arrangement was designed to obtain the 80-inch-per-minute rate of loading. Air was admitted from a surge tank (fig. 4) through a quick-opening valve to the bellows. The valve regulated the flow of air to the bellows and thus the rate at which load was applied.

Conventional procedures for measuring and recording load, strain, and time increments were impracticable, and, therefore, special equipment was developed for this purpose. Load was measured by the deflection of a calibrated steel ring (fig. 5) that was substituted for the maple loading block. This ring, machined from a section of steel pipe, was 6.5 inches in outside diameter and had a wall thickness of 5/16 inch. A dial gage, reading to 0.0001 inch, was attached along the vertical diameter of the ring and measured the change in ring diameter as load was applied to the specimen. This deformation was converted to load from calibration data previously obtained on the ring.

A dial gage, measuring center deflections to 0.001 inch, was mounted on a yoke supported at the neutral axis of the specimen over the supports. Time intervals during each test were measured by a stop watch graduated to 0.01 second. The test apparatus, including load, time, and deflection measuring equipment, is shown in figures 5 and 6.

When the bellows was used to apply load, as shown in figure 7, the calibrated steel ring was used as one of the reactions of the test specimen and the deformations of the ring in this position were converted to applied load increments.

The 35 millimeter motion-picture camera used in the compression tests was also used to record load, time, and deflection increments for the flexure tests. Loading times varied from about 0.3 to 150 seconds, and the camera was operated at an appropriate constant speed to obtain an adequate test record, which was subsequently transcribed from the film.

Results and Analysis

Compression Parallel to Grain

The effects of rapid loading on the compression-parallel-to-grain strength properties of wood are presented in tables 1 to 4, inclusive, wherein the results are summarized by species, rate of loading, and plank number. The plank summary is essentially by specific gravity, since the evaluation of specific gravity effects on variation in properties with rate of loading was introduced in the program by proper selection of test plank. The tables show that the specific gravity and moisture content values for rapid loading specimens and controls were in good agreement and that no adjustment in property values was required prior to evaluation of rate-of-loading effects. While the results are averages for the number of rapid loading specimens indicated and a greater number of control specimens, the method of matching has provided excellent agreement in moisture content and specific gravity values for individual sets of matched specimens.

A resummary of a portion of the data in tables 1 to 4, inclusive, is given in table 5, together with an indication of the uniformity of the data. The results are tabulated by species and within each species by nominal rates of deformation. A more precise indication of loading time, however, is afforded by the time-to-ultimate-load values. The effect of rapid loading on compression-parallel-to-grain strength properties is indicated as an average ratio of the rapid loading properties to the average properties of their matched controls. Since such ratios alone do not completely describe test results, an indication of the uniformity of the data is given by standard deviation figures for each result presented. An analysis of the data shows that the maximum crushing strength values for each species are increased as the time of loading is decreased and that the amount of increase for any specific rate of loading is much the same, regardless of species. The fiber stress at proportional limit also increases as the rate of loading is increased, and, in general, this increase is more than that for maximum crushing strength at any given loading rate. The results, however, are more variable than those obtained for maximum crushing strength, and there is less correlation between species. Modulus of elasticity values show some increase as time of loading is decreased, although examination of the data in tables 1 to 4, inclusive, will show that this is not always true. The magnitude of increase shows no tendency to become greater as the loading time is decreased, but rather that the increase is uniform for at least the four most rapid rates of loading. Considering the magnitude of the increase and the variability of results, it would seem logical to assume no increase in modulus of elasticity with decrease in loading time.

To determine the trend of the variation of maximum crushing strength with loading time to maximum load, the individual strength ratios were plotted against time on semilogarithmic coordinates. The charts of figures 8 to 11, inclusive, present this data, each for a single species. The results were also plotted according to specific gravity groups to aid in evaluating the specific gravity effect, but no consistent trend could be established. The plotted points show scatter within a band, and it was possible to determine a straight line that determines the slope of this band and that also passes through a point based on results of control tests. The intercepts and slopes of the lines so determined for all four species are quite uniform; and based on these data, an average curve for all compression-parallel-to-grain test results would have the equation:

$$P = 121 - 8.5 \log T$$

where

P = ratio of ultimate compressive stress of rapidly loaded specimen to that of controls

T = time to ultimate compressive stress in seconds

Behavior of typical rapidly loaded compression-parallel-to-grain specimens and matched controls is pictured in the curves of figures 12 to 17, inclusive, for Sitka spruce and maple. Stress-strain, stress-time, and deflection-time curves are shown. The stress-strain curves for both species (figs. 12 and 15) are similar, and the relationships between rapidly loaded specimens and controls are also much the same. The modulus of elasticity of the rapid loading specimen is slightly greater than that of the control, as shown by the slopes of the initial portions of the curve. This straight-line portion of the curve also defines a proportional limit stress that is higher for the specimen tested in the shorter time. Ultimate compressive strength values are shown to be about 20 percent higher for the rapid loading specimens.

The stress-time curves of figures 13 and 16 show a uniform increase of stress with time during the early part of the test. If the difference in time scales is noted, the much greater duration of maximum load for the control specimen is readily apparent. If the higher strength values are used in design because of more rapid loading conditions, the fact that the ultimate load can only be carried for a very short time must also be taken into consideration.

Strain-time characteristics are evident in the curves of figures 14 and 17; and it may be noted that the deformation proceeds uniformly with time during the early part of the test, but at a rate much slower than that determined by the free running head speed chosen as the nominal rate of deformation. Other investigations have shown that this behavior is typical and depends on the capacity and elastic constants of the testing machine and the strength and stiffness of the test specimen. These studies also show that after the proportional limit stress is exceeded, the rate of deformation tends to increase and approach the free running head speed in magnitude as the ultimate load is attained. This condition is evident in the curves of figure 17. It is not so apparent in figure 14, however, particularly for the control specimen, but it was noted that in this species final failures occurred outside the gage length of the compressometer, so that the strains obtained do not truly measure the deformation taking place in the specimen as ultimate load is reached.

Comparisons of specimen deformation and rate of loading in compression parallel to grain are made in table 6. The average unit strain values tabulated are those obtained between gage points and may not, for species that tend to fail near the ends, give exact values of total deformation, since the deformations at the point of failure are not included. Within a species, however, all failures exhibit the same pattern, and the values given do afford an indication of behavior with loading time. Average results show that deformation at ultimate is approximately a uniform value regardless of loading rate for the softwood species, but tends to increase as the loading time is decreased for the hardwoods. The time that maximum load can be sustained is very clearly a function of loading rate, as shown by the duration of maximum load periods of table 6. As the rate of loading is increased, the duration at maximum load is markedly lessened, and for rapid rates of loading it is approximately 10 percent of the time to maximum load.

Flexure

Flexural properties of rapid loading specimens and comparisons with their matched controls are tabulated in tables 7 to 10, inclusive, by species, rate of loading, and plank number. The data presented are similar to those for the compression-parallel-to-grain tests given in tables 1 to 4 and discussed previously. A portion of the data are resummarized in table 11 according to species and nominal rate of center deflection, and a more exact indication of the rate of loading is presented in the form of average time to maximum load. The effect of rate of loading on flexural strength properties is given in the form of average ratios of the property values, as determined in rapid loading tests, to the average properties of their matched controls. To afford an indication of the uniformity of the results obtained, standard deviation figures were computed and are presented for each property listed. The data indicate that the flexural modulus of rupture increases as the rate of loading increases for all of the species tested, and that the ratios are of the same order of magnitude for a given loading rate regardless of species. The fiber stress at proportional limit also increases as the loading time is decreased; and for softwood species, this increase is greater than that obtained for modulus of rupture. For the hardwood species, however, the increase is less than that obtained for modulus of rupture; and for the slowest rate of rapid loading in this study, the proportional limit stress value is less than that obtained for the matched controls. In all instances the variability of results, as measured by standard deviations, is greater for the fiber stress at proportional limit than for modulus of rupture. Examination of the data of table 11, as well as those of tables 7 to 10, inclusive, shows that the modulus of elasticity of the rapid loading specimens is usually, though not always, greater than that of the matched controls. The modulus of elasticity does not increase as the loading time is decreased, however, but rather is quite uniform over the range of testing speeds studied. The magnitude of the increase is small, and if this, together with the variability of results, is considered, it would seem logical to assume that the flexural modulus of elasticity is not changed with rate of loading.

The variation in modulus of rupture with loading time is illustrated graphically in figures 18 to 21, inclusive. The ratios of modulus of rupture of rapid loading specimens to modulus of rupture of controls were plotted on semi-logarithmic coordinates against time to modulus of rupture for each of the species studied. The data for each species are also separated into specific gravity groups to permit evaluation of specific gravity effect on specimen behavior, but no well-defined effect was evident from the data obtained. While the scatter of the test data is somewhat greater than that obtained for compression-parallel-to-grain tests, a trend of increased modulus of rupture with decreased loading time is clearly evident. The trend is defined by the straight line determined for each group of data that represents the mean condition for rapid load tests and that passes through the average control test value. Intercepts and slopes of the lines determined are similar for each of the species tested; and based on the data available, an average curve for modulus of rupture would have the equation:

$$P = 121 - 7.5 \log T$$

where

P = ratio of modulus of rupture of rapidly loaded specimen to that of controls

T = time to modulus of rupture in seconds

The slope of the equation thus derived is slightly less than that obtained for the compression-parallel-to-grain studies (8.5 to 7.5); but if consideration is given to the variability of results, it would seem that an equation with an average slope of 8 is justified. Thus for flexure and compression-parallel-to-grain loading conditions, which are more rapid than those used in standard tests, the maximum strength properties are increased by 8 percent as a tenfold decrease is made in the loading time. Stated another way, a 100 percent change in loading time causes a change in ultimate strength properties of approximately 2.5 percent in the opposite direction.

Typical behavior of rapidly loaded flexure test specimens and matched controls is shown graphically in the load-deflection, load-time, and deflection-time curves for Douglas-fir and birch in figures 22 to 27, inclusive. The load-deflection curves of figures 22 and 25 substantiate previously made statements on the equality of modulus of elasticity values for rapidly loaded test specimens and controls by the similar slopes for the initial portion of the test curves. The fiber stress at proportional limit comparisons can be made by noting the extent of the straight-line portions of the curves, and the increase of modulus of rupture with decrease in loading time is clearly discernible. Center deflections at maximum load are much the same for rapidly loaded specimens and controls, but the increase in modulus of rupture with decrease in loading time causes the area under the rapidly loaded test specimens to be greater; and since this area represents energy absorbed, the work to maximum load is greater for the rapidly loaded specimens.

The load-time diagrams of figures 23 and 26 show a uniform increase of load with time during the early portion of the test. They further show that the load at or near maximum is maintained for a much longer period of time in the control tests than at more rapid rates of loading; and this is a factor that should be given adequate consideration when the rapid loading increases are used in design, since failures will then give less warning and occur suddenly.

The deflection-time curves (figs. 24 and 27) are two straight-line segments joined by a short curved section. The initial straight-line portion represents the deflection characteristics at loads below the fiber stress at proportional limit value, which show about a 15 percent slower rate of deflection than the theoretically applied rate. Above the proportional limit the rate increases to about that determined as the nominal rate of deflection.

Table 12 is a tabultion of the average deflection at maximum load and work to maximum load values, as they vary with rate of loading, that substantiates the statements made on typical specimens. There is no consistent relationship between time of loading and center of deflection at ultimate, but rather the deflections are quite uniform and independent of loading time. In the hardwoods tested there is some indication of increased deflections at increased rate of loading, but the magnitude of the change is small. With center deflections much the same and ultimate stresses increasing as loading time is decreased, the energy absorbed to maximum load will also increase as time of loading becomes less. This is essentially true as shown by the work to maximum load values, which are generally greater than those of the matched controls. The increase is not related specifically to time of loading for the softwoods, however, although this trend is indicated by the tests of hardwoods.

Conclusions

1. The maximum crushing strength in compression parallel to grain and the modulus of rupture in flexure are increased as the time of loading decreases below that used in standard testing procedures for wood members. This increase is approximately 8 percent for tenfold decrease in loading time; or, to express it another way, if the loading time is changed by 100 percent, a change in strength in the opposite direction of about 2.5 percent will result.

2. The fiber stress at proportional limit in compression parallel to grain is increased to a greater extent than maximum crushing strength for any given loading rate, but the variation in results is much greater.

3. The fiber stress at proportional limit in flexure is increased more rapidly than the modulus of rupture for softwoods, but the reverse is true for the hardwoods tested. Greater variability in results for proportional limit stress data was found.

4. The modulus of elasticity in compression parallel to grain is generally greater at rapid loading rates, but this increase seems to be uniform for all rapid rates of loading and does not increase as loading time is decreased. Comparisons of the magnitude of the increase with variability of results suggest that no increase in stiffness be considered as loading time is decreased.

5. The modulus of elasticity in flexure is approximately the same for all rates of loading.

6. The unit strain at ultimate load in compression parallel to grain is approximately the same for all loading rates in softwoods, but it tends to increase as the loading time is decreased for hardwoods.

7. The duration of maximum load in compression parallel to grain decreases as the loading time is decreased, and for rapid loading tests it is found to be approximately 10 percent of time to maximum load.

8. The deflection at maximum load in flexure is about the same regardless of loading rates in softwoods, but it tends to increase as loading time is decreased for hardwoods.

9. The work to maximum load in flexure is greater for more rapid loading conditions, but only in the hardwoods is there any indication of greater increases as the time of loading is reduced.

Table 1.--Effect of rapid loading on the compressive strength properties of Sitka spruce

Nominal rate of deformation[1] ....in. per min....	0.087	0.087	0.394	0.394	0.773	0.773	1.905	1.905	2.799	2.799
Plank number..	25-18	36-23	25-18	36-23	25-18	36-23	25-18	36-23	25-18	36-23
Number of tests.......................................	4	12	4	15	4	17	5	6	5	15
Moisture content..............................percent...	13.0	13.2	12.7	12.9	12.6	13.4	12.7	12.6	13.2	13.4
Moisture content of controls................percent...	12.4	12.9	12.5	13.1	12.6	13.1	12.4	13.6	12.5	12.9
Specific gravity[2].......................................	0.342	0.402	0.342	0.403	0.338	0.402	0.334	0.403	0.332	0.404
Specific gravity of controls[2].............................	0.339	0.404	0.340	0.402	0.341	0.402	0.332	0.403	0.334	0.404
Time to maximum load..............................sec....	27.0	35.8	5.74	7.44	2.77	4.02	1.31	1.63	0.88	1.18
Time to maximum load of controls..................sec....	248	311	232	322	226	323	242	309	235	332
Maximum crushing strength.......................p.s.i....	4,680	5,430	4,980	5,800	4,990	6,010	5,000	6,190	5,090	6,150
Maximum crushing strength of controls.........p.s.i....	4,410	5,060	4,450	5,080	4,410	5,100	4,250	5,090	4,310	5,110
Percent of control strength................................	106.0	107.4	112.0	114.4	113.2	117.8	117.6	121.4	118.1	120.4
Strain at maximum load.......................in. per in....	0.00370	0.00318	0.00330	0.00340	0.00340	0.00335	0.00363	0.00350	0.00338	0.00353
Strain at maximum load of controls........in. per in....	0.00328	0.00323	0.00335	0.00328	0.00313	0.00327	0.00317	0.00341	0.00303	0.00329
Duration at maximum load..............................sec....	1.2	3.8	0.35	0.35	0.11	0.38	0.05	0.19	0.04	0.11
Duration at maximum load of controls..............sec....	9.6	15.8	9.5	14.4	6.4	14.9	4.8	16.8	3.6	14.6
Time to proportional limit............................sec....	16.3	19.9	3.74	4.50	1.91	2.30	0.88	0.97	0.64	0.69
Time to proportional limit of controls............sec....	144	158	144	164	144	163	144	161	143	160
Stress at proportional limit....................p.s.i....	3,650	3,810	3,840	4,180	4,010	4,300	4,120	4,570	4,290	4,490
Stress at proportional limit of controls......p.s.i....	3,410	3,520	3,460	3,540	3,520	3,520	3,330	3,560	3,410	3,510
Percent of control proportional limit......................	107.2	108.4	110.8	118.0	114.0	122.4	123.7	128.5	125.9	128.1
Modulus of elasticity.............................p.s.i....	1,465,000	1,860,000	1,590,000	1,850,000	1,585,000	1,900,000	1,470,000	1,895,000	1,540,000	1,910,000
Modulus of elasticity of controls..............p.s.i....	1,479,000	1,780,000	1,495,000	1,746,000	1,535,000	1,773,000	1,443,000	1,697,000	1,487,000	1,803,000
Percent of control modulus................................	99.5	104.2	106.4	106.0	103.3	107.5	102.1	111.8	103.3	106.3

[1] Nominal rate of deformation of controls -- 0.012 inch per minute.

[2] Based on volume at test and oven-dry weight.

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Table 2.--Effect of rapid loading on the compressive strength properties of Douglas-fir

Nominal rate of deformation[1]............in. per min....	0.087	0.394	0.773	1.905	2.799
Plank number....................................	39-59	39-59	39-59	39-59	39-59
Number of tests.................................	7	8	8	8	8
Moisture content.........................percent...	12.4	12.2	12.1	12.3	12.3
Moisture content of controls...............percent...	12.7	12.4	12.2	12.6	12.6
Specific gravity[2]..................................	0.434	0.431	0.431	0.439	0.434
Specific gravity of controls[2].........................	0.433	0.429	0.431	0.435	0.431
Time to maximum load.........................sec....	30.6	6.69	3.27	1.47	0.99
Time to maximum load of controls...............sec....	266	268	267	265	263
Maximum crushing strength...................p.s.i....	6,170	6,440	6,530	6,870	6,830
Maximum crushing strength of controls..........p.s.i....	5,700	5,670	5,710	5,760	5,660
Percent of control strength...........................	108.4	113.4	114.4	119.3	120.6
Strain at maximum load..................in. per in....	0.00416	0.00438	0.00440	0.00429	0.00442
Strain at maximum load of controls........in. per in....	0.00463	0.00496	0.00472	0.00451	0.00452
Duration at maximum load.......................sec....	3.1	0.58	0.31	0.14	0.13
Duration at maximum load of controls............sec....	10.4	7.4	8.3	8.6	10.1
Time to proportional limit......................sec....	17.7	3.94	2.09	0.96	0.66
Time to proportional limit of controls..........sec....	151	153	152	155	156
Stress at proportional limit..................p.s.i....	4,410	4,570	4,820	5,220	5,330
Stress at proportional limit of controls.......p.s.i....	4,090	4,060	4,090	4,190	4,150
Percent of control proportional limit..................	107.9	112.4	117.8	124.6	128.4
Modulus of elasticity.......................p.s.i....	1,733,000	1,740,000	1,740,000	1,810,000	1,790,000
Modulus of elasticity of controls.............p.s.i....	1,649,000	1,618,000	1,661,000	1,689,000	1,671,000
Percent of control modulus............................	105.2	107.4	104.6	107.4	107.2

[1]Nominal rate of deformation of controls -- 0.012 inch per minute.

[2]Based on volume at test and oven-dry weight.

Z M 84952 F

Table 3.--Effect of rapid loading on the compressive strength properties of maple

Nominal rate of deformation[1]......in. per min	0.087	0.087	0.087	0.394	0.394	0.394	0.773	0.773	0.773	1.905	1.905	1.905	5.87	5.87	5.87
Plank number	M-3	M-2	M-1	M-3	M-2	M-1	M-3	M-2	M-1	M-3	M-2	M-1	M-3	M-2	M-1
Number of tests	6	5	6	6	6	6	6	6	6	6	6	6	6	6	6
Moisture content......percent	9.4	10.0	9.4	9.6	9.4	9.5	9.5	9.4	9.3	9.2	9.4	9.9	9.4	9.5	10.3
Moisture content of controls......percent	9.1	9.0	9.6	9.2	9.0	9.6	9.3	9.1	9.6	9.3	9.3	9.8	9.2	9.2	9.6
Specific gravity[2]	0.596	0.635	0.672	0.595	0.638	0.674	0.595	0.636	0.677	0.596	0.640	0.674	0.590	0.642	0.674
Specific gravity of controls[2]	0.594	0.637	0.671	0.594	0.642	0.675	0.597	0.637	0.674	0.592	0.638	0.674	0.591	0.640	0.674
Time to maximum load......sec	45.0	44.4	48.0	10.66	10.69	12.08	5.36	5.42	6.02	2.46	2.52	2.82	0.88	0.96	1.13
Time to maximum load of controls......sec	323	333	378	323	338	370	319	339	373	320	335	370	314	332	377
Maximum crushing strength......p.s.i.	8,740	9,540	9,550	9,380	10,010	10,140	9,300	10,050	10,350	9,610	10,500	10,540	9,970	11,050	11,000
Maximum crushing strength of controls......p.s.i.	8,190	8,830	9,070	8,220	8,880	9,000	8,090	8,840	9,020	8,040	9,030	9,000	8,050	9,050	9,050
Percent of control strength	106.8	108.0	105.3	114.1	112.8	112.8	115.0	113.6	114.7	119.5	116.3	117.1	123.9	122.2	121.6
Strain at maximum load......in. per in.	0.00664	0.00562	0.00720	0.00740	0.00696	0.00837	0.00819	0.00714	0.00871	0.00812	0.00713	0.00973	0.00914	0.00773	0.01188
Strain at maximum load of controls......in. per in.	0.00596	0.00520	0.00731	0.00617	0.00554	0.00706	0.00603	0.00560	0.00662	0.00580	0.00523	0.00730	0.00611	0.00525	0.00718
Duration at maximum load......sec	6.0	4.5	8.7	1.34	1.26	1.93	0.68	0.64	0.89	0.32	0.20	0.45	0.08	0.06	0.14
Duration at maximum load of controls......sec	7.1	7.5	9.9	6.8	7.3	10.8	8.7	7.2	11.1	9.2	7.6	14.0	6.7	7.0	17.2
Time to proportional limit......sec	27.6	27.3	27.2	6.46	6.44	6.00	3.07	3.22	3.05	1.44	1.47	1.43	0.51	0.58	0.55
Time to proportional limit of controls......sec	203	222	216	206	220	208	202	224	217	212	223	217	202	219	220
Stress at proportional limit......p.s.i.	6,730	7,060	7,060	7,260	7,550	7,060	6,800	7,490	7,360	7,340	7,720	7,750	7,760	8,560	8,120
Stress at proportional limit of controls......p.s.i.	6,160	6,720	6,380	6,250	6,660	6,270	6,050	6,750	6,470	6,340	6,800	6,490	6,140	6,700	6,530
Percent of control proportional limit	109.3	105.3	111.0	116.2	113.6	112.8	112.3	111.3	113.6	115.7	113.7	119.3	126.7	128.1	124.4
Modulus of elasticity......p.s.i.	2,099,000	2,418,000	2,331,000	2,177,000	2,368,000	2,467,000	2,031,000	2,346,000	2,460,000	2,137,000	2,373,000	2,391,000	2,164,000	2,493,000	2,427,000
Modulus of elasticity of controls......p.s.i.	2,050,000	2,291,000	2,291,000	2,062,000	2,285,000	2,279,000	2,021,000	2,267,000	2,259,000	2,024,000	2,356,000	2,252,000	2,131,000	2,346,000	2,273,000
Percent of control modulus	102.8	105.5	101.8	105.6	103.6	108.2	100.4	103.4	108.9	105.7	100.7	106.1	106.7	106.3	106.8

[1]Nominal rate of deformation of controls -- 0.012 inch per minute.

[2]Based on volume at test and oven-dry weight.

Z M 84953 F

Table 4. Effect of rapid loading on the compressive strength properties of birch

Nominal rate of deformation[1] ....in. per min.	0.087	0.087	0.087	0.394	0.394	0.394	0.773	0.773	0.773	1.905	1.905	1.905	5.87	5.87	5.87
Plank number	YB-3	YB-2	YB-1	YB-3	YB-2	YB-1	YB-3	YB-2	YB-1	YB-3	YB-2	YB-1	YB-3	YB-2	YB-1
Number of tests	7	2	5	7	3	5	7	3	5	7	3	5	7	3	5
Moisture content..........percent	9.2	9.8	9.8	9.2	9.7	9.9	9.5	9.6	9.7	9.4	9.7	9.9	9.2	9.6	9.7
Moisture content of controls..........percent	9.5	9.6	9.3	9.3	9.5	9.4	9.5	9.5	9.3	9.3	9.5	9.6	9.4	9.3	9.6
Specific gravity[2]	0.570	0.630	0.634	0.576	0.616	0.643	0.572	0.627	0.644	0.567	0.625	0.632	0.575	0.622	0.643
Specific gravity of controls[2]	0.569	0.631	0.634	0.573	0.620	0.642	0.575	0.625	0.651	0.572	0.623	0.635	0.572	0.616	0.648
Time to maximum load..........sec.	40.5	47.3	43.4	10.43	10.94	10.27	4.74	5.69	5.50	2.51	2.56	2.46	0.95	1.09	0.98
Time to maximum load of controls..........sec.	317	347	326	324	352	327	317	361	333	323	349	331	315	349	327
Maximum crushing strength..........p.s.i.	7,840	9,340	9,880	8,170	9,990	10,640	8,440	9,730	10,840	8,670	10,620	10,990	9,040	11,350	11,800
Maximum crushing strength of controls..........p.s.i.	7,520	8,510	9,370	7,330	8,890	9,570	7,350	8,580	9,490	7,480	8,990	9,340	7,440	9,270	9,630
Percent of control strength	104.2	109.7	105.5	111.5	112.6	111.3	115.0	113.4	114.3	116.1	118.4	117.7	121.6	122.4	122.6
Strain at maximum load..........in. per in.	0.00619	0.00690	0.00521	0.00735	0.00775	0.00503	0.00630	0.00869	0.00576	0.00764	0.00732	0.00596	0.00713	0.00873	0.00598
Strain at maximum load of controls..........in. per in.	0.00645	0.00688	0.00519	0.00689	0.00634	0.00551	0.00653	0.00694	0.00575	0.00688	0.00642	0.00537	0.00639	0.00610	0.00504
Duration at maximum load..........sec.	6.3	4.5	5.1	1.25	1.43	1.09	0.63	0.64	0.56	0.40	0.25	0.22	0.13	0.08	0.07
Duration at maximum load of controls..........sec.	12.6	11.8	7.4	12.8	7.8	6.3	6.6	10.3	11.0	8.6	9.5	8.6	10.2	14.7	6.6
Time to proportional limit..........sec.	23.5	25.2	27.1	4.87	5.90	6.40	2.91	2.94	3.05	1.44	1.37	1.40	0.52	0.52	0.54
Time to proportional limit of controls..........sec.	164	177	179	160	186	190	156	180	192	161	189	190	159	206	197
Stress at proportional limit..........p.s.i.	5,570	6,450	7,180	5,310	6,980	7,730	6,380	6,830	7,380	6,430	7,370	7,630	6,470	7,530	7,970
Stress at proportional limit of controls..........p.s.i.	4,770	5,480	5,910	4,600	5,800	6,300	4,570	5,510	6,370	4,700	6,040	6,170	4,610	6,610	6,620
Percent of control proportional limit	117.5	117.6	121.5	117.1	121.5	123.4	139.9	126.1	116.4	137.0	122.5	124.2	140.6	114.4	121.1
Modulus of elasticity..........p.s.i.	1,935,000	2,357,000	2,577,000	1,875,000	2,360,000	2,716,000	2,030,000	2,063,000	2,735,000	1,949,000	2,543,000	2,751,000	1,992,000	2,601,000	2,838,000
Modulus of elasticity of controls..........p.s.i.	1,989,000	2,260,000	2,641,000	1,884,000	2,401,000	2,599,000	1,940,000	2,310,000	2,550,000	1,930,000	2,377,000	2,585,000	1,958,000	2,396,000	2,707,000
Percent of control modulus	97.2	104.4	97.6	99.8	98.2	104.7	104.6	89.2	107.4	101.6	107.0	106.3	101.9	108.5	104.8

[1] Nominal rate of deformation of controls -- 0.012 inch per minute.

[2] Based on volume at test and oven-dry weight.

Z M 84954 F

Table 5.--Summary of the rate-of-loading effect on the properties of four species of wood tested in compression parallel to grain[1]

Nominal rate of deformation	Average time to maximum load	Number of tests	Maximum crushing strength		Fiber stress at proportional limit		Modulus of elasticity	
			Average ratio of control strength[1]	Standard deviation	Average ratio of control proportional limit[1]	Standard deviation	Average ratio of control modulus[1]	Standard deviation
In. per min.	Sec.		Percent	Percent	Percent	Percent	Percent	Percent
Sitka Spruce								
0.087	33.6	16	107.0	2.6	108.1	4.9	103.1	7.4
.394	7.08	19	113.9	2.1	116.5	3.6	106.0	5.0
.773	3.78	21	116.9	3.0	120.8	5.0	106.7	7.0
1.905	1.48	11	119.7	2.8	126.3	4.5	107.4	8.1
2.799	1.10	20	119.9	3.7	127.6	5.9	105.6	6.2
Douglas-fir								
.087	30.6	7	108.4	2.3	107.9	1.4	105.2	6.0
.394	6.69	8	113.4	1.9	112.4	1.9	107.4	3.3
.773	3.27	8	114.4	2.8	117.8	4.3	104.6	4.6
1.905	1.47	8	119.3	1.8	124.6	5.5	107.4	5.7
2.799	.99	8	120.6	2.8	128.4	3.4	107.2	3.1
Maple								
.087	45.9	17	106.6	2.0	108.7	5.8	103.2	2.7
.394	11.14	18	113.2	1.9	114.2	5.4	105.9	4.5
.773	5.60	18	114.4	1.8	112.5	5.0	104.2	5.1
1.905	2.60	18	117.6	2.8	116.2	5.6	104.2	4.1
5.87	.99	18	122.6	2.0	126.4	8.2	106.6	4.8
Birch								
.087	42.5	14	105.5	3.1	119.0	9.9	98.4	3.6
.394	10.48	15	111.6	2.0	120.1	14.7	101.1	7.4
.773	5.18	15	114.5	2.9	129.2	13.8	102.6	8.7
1.905	2.50	15	117.1	2.8	129.8	10.3	104.2	8.6
5.87	.99	15	122.1	2.7	128.9	15.1	104.2	8.2

[1] The properties obtained at rapid rates of loading are compared with those obtained on matched controls tested in compression parallel to grain at a nominal rate of deformation of 0.012 inch per minute. Average time to maximum load of controls was 300, 265, 345, and 325 seconds for spruce, fir, maple, and birch, respectively.

Z M 84955 F

Table 6.--Summary of the rate of loading effect on the strain at maximum load and duration of maximum load for four species of wood tested in compression parallel to grain

Nominal rate of deformation	Average time to maximum load	Number of tests	Average unit strain at maximum load	Average duration of maximum load
In. per min.	Sec.		In. per in.	Sec.
		Sitka spruce		
0.012	300	117	0.00326	12.9
.087	33.6	16	.00331	3.2
.394	7.08	19	.00338	.35
.773	3.78	21	.00336	.33
1.905	1.48	11	.00356	.13
2.799	1.10	20	.00349	.09
		Douglas-fir		
.012	265	57	.00466	8.9
.087	30.6	7	.00416	3.1
.394	6.69	8	.00438	.58
.773	3.27	8	.00440	.31
1.905	1.47	8	.00429	.14
2.799	.99	8	.00442	.08
		Maple		
.012	345	178	.00616	9.2
.087	45.9	17	.00654	6.5
.394	11.14	18	.00757	1.51
.773	5.60	18	.00801	.73
1.905	2.60	18	.00832	.33
5.87	.99	18	.00958	.09
		Birch		
.012	325	148	.00618	9.5
.087	42.5	14	.00594	5.6
.394	10.48	15	.00666	1.23
.773	5.18	15	.00660	.62
1.905	2.50	15	.00701	.31
5.87	.99	15	.00707	.10

Table 7.--Effect of rapid loading on the flexural strength properties of Sitka spruce

Nominal rate of deflection[1] ... in. per min.	0.2	0.2	0.2	1.0	1.0	1.0	3.0	3.0	6.0	6.0	12.0	18.0
Plank number	34-32	36-42	35-25	34-32	36-58	35-25	34-32	36-46	34-32	36-45	36-41	36-54
Number of tests	4	17	12	6	18	8	4	19	4	19	25	23
Moisture content ... percent	12.3	12.1	12.6	13.0	12.4	12.8	13.4	12.4	13.2	12.2	12.4	12.4
Mositure content of controls ... percent	12.5	14.0	12.1	12.6	13.0	12.3	13.2	12.7	13.2	12.8	13.0	12.9
Specific gravity[2]	0.350	0.383	0.408	0.372	0.395	0.406	0.370	0.379	0.366	0.379	0.386	0.379
Specific gravity of controls[2]	0.352	0.371	0.410	0.372	0.388	0.404	0.369	0.376	0.364	0.375	0.381	0.373
Time to ultimate load ... sec.	121	135	125	28.9	26.7	27.1	7.8	8.7	4.62	4.35	2.01	1.37
Time to ultimate load of controls ... sec.	607	597	523	562	543	531	613	535	583	528	553	543
Modulus of rupture ... p.s.i.	9,580	10,930	11,600	11,070	11,140	11,970	11,500	11,190	12,080	11,240	11,920	11,550
Modulus of rupture of controls ... p.s.i.	8,440	10,540	11,240	9,780	9,980	11,290	9,780	9,930	9,610	9,820	10,170	9,740
Percent of control modulus of rupture	113.1	103.9	103.2	113.4	111.6	106.2	117.7	112.7	125.6	115.1	116.6	118.6
Center deflection at ultimate load ... in.	0.390	0.397	0.395	0.414	0.397	0.406	0.426	0.391	0.471	0.415	0.433	0.412
Center deflection at ultimate load of controls ... in.	0.467	0.442	0.400	0.419	0.408	0.391	0.484	0.389	0.447	0.405	0.400	0.416
Work to ultimate load ... in.lb. per in.^{3}	8.9	....	10.6	10.8	....	11.0	9.7	10.2	13.7	10.9	12.1	11.6
Work to ultimate load of controls ... in.lb. per in.^{3}	10.3	....	10.4	10.1	....	10.6	12.2	9.6	11.1	10.0	10.4	10.3
Time to proportional limit ... sec.	46	50	46	12.1	10.6	12.2	3.8	3.3	1.84	1.81	0.80	0.50
Time to proportional limit of controls ... sec.	181	195	178	167	204	182	189	192	173	199	205	186
Stress at proportional limit ... p.s.i.	6,000	7,400	6,880	7,440	7,430	7,940	7,270	7,070	7,800	7,450	8,180	7,120
Stress at proportional limit of controls ... p.s.i.	5,100	6,740	6,320	5,250	6,490	6,640	5,700	6,090	5,600	6,300	6,740	5,860
Percent of control proportional limit	117.7	110.7	109.5	141.6	114.5	119.8	127.7	114.7	139.7	118.4	121.6	121.6
Modulus of elasticity ... p.s.i.	1,430,000	1,702,000	1,646,000	1,506,000	1,621,000	1,545,000	1,498,000	1,660,000	1,536,000	1,518,000	1,629,000	1,486,000
Modulus of elasticity of controls ... p.s.i.	1,330,000	1,692,000	1,610,000	1,462,000	1,508,000	1,698,000	1,406,000	1,633,000	1,499,000	1,500,000	1,621,000	1,548,000
Percent of control modulus of elasticity	107.6	100.7	102.3	103.1	107.6	91.0	106.6	101.7	102.6	101.3	100.5	96.2

[1] Nominal rate of deflection of controls -- 0.05 inch per minute.

[2] Based on volume at test and oven-dry weight.

Z M 84956 F

Table 8.--Effect of rapid loading on the flexural strength properties of Douglas-fir

Nominal rate of deflection[1] ....in. per min.	0.2	0.2	0.2	1.0	1.0	1.0	3.0	3.0	3.0	6.0	6.0	6.0	12.0	12.0	12.0	18.0	18.0	18.0
Plank number	39-82	39-87	38-9	39-82	39-87	38-9	39-82	39-87	38-9	39-82	39-87	38-9	39-82	39-87	38-9	39-82	39-87	38-9
Number of tests	4	4	6	4	5	3	4	5	7	4	5	7	4	5	4	4	5	5
Moisture content ....percent	12.4	12.2	11.1	13.0	13.0	12.5	12.0	12.9	12.8	12.2	12.1	12.5	13.2	13.1	12.2	12.1	13.0	11.0
Moisture content of controls ....percent	12.7	11.5	11.3	12.9	12.6	12.2	12.0	12.2	12.6	12.2	11.7	12.1	13.0	12.6	11.8	12.2	12.5	10.5
Specific gravity[2]	0.465	0.453	0.469	0.459	0.458	0.457	0.438	0.456	0.467	0.450	0.464	0.454	0.454	0.439	0.468	0.439	0.449	0.450
Specific gravity of controls[2]	0.452	0.463	0.468	0.465	0.453	0.460	0.446	0.459	0.470	0.448	0.466	0.456	0.453	0.446	0.469	0.438	0.448	0.453
Time to ultimate load ....sec.	137	122	116	25.1	25.6	25.3	8.9	8.0	10.1	4.19	4.34	4.22	1.90	1.85	1.92	1.39	1.23	1.25
Time to ultimate load of controls ....sec.	525	520	551	524	498	512	505	519	555	512	560	577	513	509	550	510	501	577
Modulus of rupture ....p.s.i.	13,890	12,770	14,130	14,030	12,770	14,880	13,350	13,110	15,360	14,190	14,700	14,410	14,040	12,990	15,790	13,340	13,710	15,520
Modulus of rupture of controls ....p.s.i.	12,580	12,660	12,940	12,600	11,770	12,180	11,890	12,160	12,290	11,940	12,880	11,990	12,080	11,360	12,000	11,720	11,480	12,370
Percent of control modulus of rupture	110.5	100.8	109.4	111.4	108.7	122.1	112.4	107.9	125.1	119.0	114.4	120.4	116.3	114.3	130.6	113.4	119.6	125.5
Center deflection at ultimate load ....in.	0.408	0.354	0.365	0.385	0.352	0.452	0.403	0.372	0.446	0.373	0.392	0.447	0.388	0.386	0.416	0.369	0.390	0.394
Center deflection at ultimate load of controls ....in.	0.380	0.372	0.410	0.387	0.379	0.372	0.369	0.385	0.419	0.392	0.401	0.423	0.364	0.356	0.420	0.380	0.374	0.432
Work to ultimate load ....in.lb. per $in.^3$	....	....	11.8	....	....	15.0	....	....	16.5	....	....	13.5	....	....	14.7	....	....	13.4
Work to ultimate load of controls ....in.lb. per $in.^3$	....	....	13.0	....	....	11.0	....	....	13.1	....	....	13.2	....	....	12.6	....	....	13.0
Time to proportional limit ....sec.	60	65	46	11.8	13.6	9.4	4.5	4.3	3.6	2.18	2.15	1.74	0.92	0.94	0.96	0.89	0.66	0.69
Time to proportional limit of controls ....sec.	197	216	196	187	203	184	199	212	187	202	211	200	201	210	202	216	203	199
Stress at proportional limit ....p.s.i.	9,480	9,330	8,380	9,230	9,570	8,490	9,940	9,470	9,200	10,030	10,360	8,620	9,720	9,090	11,140	10,370	9,880	11,370
Stress at proportional limit of controls ....p.s.i.	7,690	8,140	7,810	7,380	7,490	7,290	7,140	7,850	7,470	7,440	8,040	7,580	7,360	7,280	7,620	7,700	7,230	7,350
Percent of control proportional limit	123.5	114.7	107.7	125.6	128.1	117.8	139.5	120.7	124.2	134.8	129.0	113.8	132.2	125.1	146.1	135.0	136.8	155.6
Modulus of elasticity ....p.s.i.	1,868,000	1,651,000	1,978,000	1,832,000	1,669,000	2,018,000	1,694,000	1,709,000	2,013,000	1,744,000	1,863,000	1,850,000	1,791,000	1,628,000	1,835,000	1,688,000	1,742,000	1,784,000
Modulus of elasticity of controls ....p.s.i.	1,864,000	1,738,000	1,882,000	1,903,000	1,696,000	1,880,000	1,751,000	1,736,000	1,897,000	1,742,000	1,860,000	1,744,000	1,775,000	1,688,000	1,714,000	1,678,000	1,707,000	1,664,000
Percent of control modulus of elasticity	100.2	95.2	105.1	96.3	98.3	107.3	96.7	98.3	106.3	100.2	100.2	106.1	100.9	96.4	107.0	100.6	102.0	107.2

[1] Nominal rate of deflection of controls — 0.05 inch per minute.

[2] Based on volume at test and oven-dry weight.

Z M 84957 F

Table 9.--**Effect of rapid loading on the flexural strength properties of maple**

Nominal rate of deformation[1] ... in. per min.	1.0	1.0	1.0	1.0	12.0	12.0	12.0	12.0	80.0	80.0	80.0	80.0
Plank number	M-1	M-2	M-3	M-4	M-1	M-2	M-3	M-4	M-1	M-2	M-3	M-4
Number of tests	5	5	4	5	5	5	4	5	5	5	4	5
Moisture content ... percent	10.4	10.7	10.3	10.9	10.2	10.2	10.3	10.4	10.7	10.2	10.3	10.7
Moisture content of controls ... percent	10.5	10.5	10.3	10.7	10.5	10.5	10.4	10.6	10.5	10.4	10.2	10.7
Specific gravity[2]	0.615	0.640	0.639	0.643	0.607	0.638	0.646	0.653	0.607	0.644	0.638	0.649
Specific gravity of controls[2]	0.615	0.641	0.647	0.648	0.609	0.638	0.645	0.651	0.607	0.641	0.655	0.651
Time to ultimate load ... sec.	29.5	31.4	28.0	30.0	2.19	2.61	2.69	2.33	0.31	0.32	0.33	0.34
Time to ultimate load of controls ... sec.	606	678	724	646	598	708	716	660	649	673	765	651
Modulus of rupture ... p.s.i.	18,620	19,700	17,850	20,670	19,600	21,360	21,380	23,310	22,070	22,290	21,600	23,850
Modulus of rupture of controls ... p.s.i.	16,670	18,210	17,880	19,300	16,460	18,050	17,700	19,300	17,000	17,880	17,770	19,340
Percent of control modulus of rupture	111.8	108.1	99.8	107.1	119.3	118.2	120.9	120.9	130.0	124.6	121.5	123.4
Center deflection at ultimate load ... in.	0.500	0.537	0.461	0.499	0.486	0.550	0.604	0.512	0.523	0.510	0.535	0.529
Center deflection at ultimate load of controls ... in.	0.455	0.516	0.543	0.484	0.452	0.542	0.535	0.489	0.491	0.506	0.578	0.481
Work to ultimate load ... in.lb. per $in.^3$	20.8	24.0	18.3	23.7	20.2	25.5	29.0	27.0	23.9	23.9	24.8	28.7
Work to ultimate load of controls ... in.lb. per $in.^3$	17.5	22.1	22.8	22.2	18.0	23.4	22.1	22.4	19.4	21.0	24.5	22.0
Time to proportional limit ... sec.	10.0	8.5	9.9	9.7	0.80	0.86	0.78	0.70	0.14	0.11	0.12	0.15
Time to proportional limit of controls ... sec.	235	224	209	207	234	220	210	202	223	236	216	211
Stress at proportional limit ... p.s.i.	9,690	8,010	9,460	11,340	10,180	11,420	10,130	10,930	11,640	11,080	11,330	13,850
Stress at proportional limit of controls ... p.s.i.	10,150	10,400	9,110	10,960	10,070	10,080	9,140	10,680	9,910	10,700	9,340	11,040
Percent of control proportional limit	95.6	77.6	96.1	103.7	101.5	113.6	110.8	102.3	117.6	104.0	121.5	125.8
Modulus of elasticity ... p.s.i.	2,067,000	2,168,000	2,054,000	2,454,000	1,961,000	2,011,000	2,004,000	2,505,000	2,032,000	2,154,000	2,047,000	2,571,000
Modulus of elasticity of controls ... p.s.i.	1,972,000	2,100,000	2,053,000	2,477,000	1,936,000	2,067,000	2,030,000	2,454,000	1,987,000	2,052,000	1,990,000	2,462,000
Percent of controls modulus of elasticity	104.7	103.2	100.0	99.1	101.4	97.2	99.0	102.2	102.4	105.0	102.8	104.5

[1] Nominal rate of deflection of controls -- 0.05 inch per minute.

[2] Based on volume at test and oven-dry weight.

Z M 84958 F

Table 10.--Effect of rapid loading on the flexural strength properties of birch

Nominal rate of deflection[1]...in. per min.	1.0	1.0	1.0	1.0	12.0	12.0	12.0	12.0	80.0	80.0	80.0	80.0
Plank number	B-1	B-2	B-3	B-4	B-1	B-2	B-3	B-4	B-1	B-2	B-3	B-4
Number of tests	4	4	4	4	4	4	4	4	4	4	4	4
Moisture content...percent	11.4	11.4	10.8	11.5	11.4	11.2	11.0	11.4	11.7	11.6	11.6	11.3
Moisture content of controls...percent	11.2	11.2	11.1	11.6	11.2	11.3	11.1	11.7	11.3	11.2	11.1	11.7
Specific gravity[2]	0.596	0.595	0.589	0.592	0.608	0.605	0.588	0.593	0.601	0.599	0.590	0.596
Specific gravity of controls[2]	0.600	0.598	0.588	0.592	0.604	0.606	0.588	0.591	0.601	0.600	0.590	0.594
Time to ultimate load...sec.	31.2	30.3	35.9	30.6	2.46	2.37	2.97	2.36	0.37	0.34	0.29	0.27
Time to ultimate load of controls...sec.	678	692	890	690	680	653	896	675	710	673	894	680
Modulus of rupture...p.s.i.	18,900	18,470	17,460	18,650	21,610	21,370	19,280	20,280	22,610	22,330	22,660	21,400
Modulus of rupture of controls...p.s.i.	17,300	17,490	16,580	17,220	17,660	18,120	17,000	17,230	17,280	17,870	16,890	16,970
Percent of control modulus of rupture...p.s.i.	109.3	105.5	105.4	108.1	122.1	118.0	113.4	117.8	132.0	124.9	134.6	125.9
Center deflection at ultimate load...in.	0.515	0.525	0.595	0.503	0.561	0.519	0.643	0.522	0.612	0.532	0.701	0.499
Center deflection at ultimate load of controls...in.	0.512	0.520	0.668	0.524	0.512	0.492	0.679	0.514	0.522	0.497	0.689	0.504
Work to ultimate load...in.lb. per in.[3]	23.2	23.3	23.8	21.8	28.4	25.1	28.1	24.0	32.9	28.4	38.0	25.0
Work to ultimate load of controls...in.lb. per in.[3]	21.8	22.3	27.0	22.2	22.2	21.5	28.3	21.5	22.4	21.4	28.0	23.5
Time to proportional limit...sec.	7.7	8.4	9.8	9.1	0.75	0.77	0.78	0.68	0.10	0.10	0.10	0.10
Time to proportional limit of controls...sec.	220	217	212	214	212	228	205	220	224	224	202	211
Stress at proportional limit...p.s.i.	8,240	9,620	8,170	9,380	10,710	11,080	9,310	9,790	10,480	11,170	9,770	10,350
Stress at proportional limit of controls...p.s.i.	10,310	10,300	8,190	10,020	10,100	11,020	8,150	10,250	10,400	10,710	7,920	9,980
Percent of control proportional limit	80.0	93.9	103.6	94.2	106.8	101.4	121.3	96.6	101.4	105.4	126.9	105.9
Modulus of elasticity...p.s.i.	2,341,000	2,293,000	1,832,000	2,230,000	2,333,000	2,340,000	1,836,000	2,209,000	2,390,000	2,326,000	1,920,000	2,343,000
Modulus of elasticity of controls...p.s.i.	2,232,000	2,234,000	1,779,000	2,177,000	2,266,000	2,305,000	1,838,000	2,170,000	2,256,000	2,267,000	1,811,000	2,184,000
Percent of control modulus of elasticity	105.2	102.8	102.8	102.4	102.9	101.6	99.7	101.8	106.3	102.6	105.9	107.4

[1] Nominal rate of deflection of controls — 0.05 inch per minute.

[2] Based on volume at test and oven-dry weight.

Z M 84959 F

Table 11.--Summary of the rate-of-loading effect on the properties of four species of wood tested in flexure[1]

Nominal rate of deflection	Average time to maximum load	Number of tests	Modulus of rupture		Fiber stress at proportional limit		Modulus of elasticity	
			Average ratio of control modulus[1]	Standard deviation	Average ratio of control proportional limit[1]	Standard deviation	Average ratio of control modulus[1]	Standard deviation
In. per min.	Sec.		Percent	Percent	Percent	Percent	Percent	Percent
			Sitka Spruce					
0.2	130	33	104.8	6.4	111.1	10.3	102.1	4.3
1.0	27.2	31	110.6	5.3	121.1	13.2	102.4	7.9
3.0	8.5	23	113.6	5.1	117.0	6.7	102.5	5.0
6.0	4.40	23	116.6	5.7	122.2	9.8	101.5	4.6
12.0	2.01	25	116.6	4.3	121.6	7.6	100.5	6.0
18.0	1.37	23	118.6	3.9	121.6	4.4	96.2	4.7
			Douglas-fir					
.2	124	14	107.9	6.3	114.2	10.2	100.8	4.5
1.0	25.4	12	113.0	7.6	124.7	11.2	100.1	5.9
3.0	9.8	16	116.6	10.0	126.9	14.0	101.5	6.1
6.0	4.25	16	118.2	5.4	123.8	13.8	102.8	4.4
12.0	1.89	13	119.9	8.5	133.7	11.3	101.0	5.6
18.0	1.28	14	120.1	6.4	143.0	15.0	103.4	3.8
			Maple					
1.0	29.8	19	107.1	6.8	94.8	13.0	102.0	4.0
12.0	2.44	19	119.8	5.4	106.8	10.0	98.4	5.3
80.0	.32	19	125.1	6.8	117.0	11.8	103.7	3.3
			Birch					
1.0	32.0	16	107.1	4.6	92.9	13.6	103.3	4.4
12.0	2.54	16	117.8	7.4	106.5	21.6	101.5	3.6
80.0	.32	16	129.3	12.0	109.9	17.6	105.6	3.9

[1] The properties obtained at rapid rates of loading are compared with those obtained on matched controls tested in flexure at a nominal rate of deflection of 0.05 inch per minute. Average time to maximum load of controls was 550, 530, 670, and 735 seconds for spruce, fir, maple, and birch, respectively.

Z M 84960 F

Table 12.--Summary of the rate of loading effect on the deflection at maximum load and the work to maximum load for four species of wood tested in flexure

Nominal rate of deflection	Average time to maximum load	Number of tests	Average deflection at maximum load	Average work to maximum load
In. per min.	Sec.		Inch	In.-lb. per cu.in.
		Sitka spruce		
0.05	550	127	0.417	10.4
.2	130	33	.395	10.2
1.0	27.2	31	.403	10.9
3.0	8.5	23	.397	10.1
6.0	4.40	23	.426	11.5
12.0	2.01	25	.433	12.1
18.0	1.37	23	.412	11.6
		Douglas-fir		
.05	530	111	.391	12.6
.2	124	14	.374	11.8
1.0	25.4	12	.388	15.0
3.0	9.8	16	.412	16.5
6.0	4.25	16	.411	13.5
12.0	1.89	13	.396	14.7
18.0	1.28	14	.385	13.4
		Maple		
.05	670	88	.504	21.4
1.0	29.8	19	.501	21.9
12.0	2.44	19	.534	25.1
80.0	.32	19	.524	25.4
		Birch		
.05	735	76	.553	23.3
1.0	32.0	16	.535	23.0
12.0	2.54	16	.561	26.4
80.0	.32	16	.586	31.2

Figure 1.--Method of testing small clear specimens in compression parallel to grain at rapid rates of loading. The upper end of the calibrated loading tube and deformation and time measuring equipment are shown.

(ZM58764F)

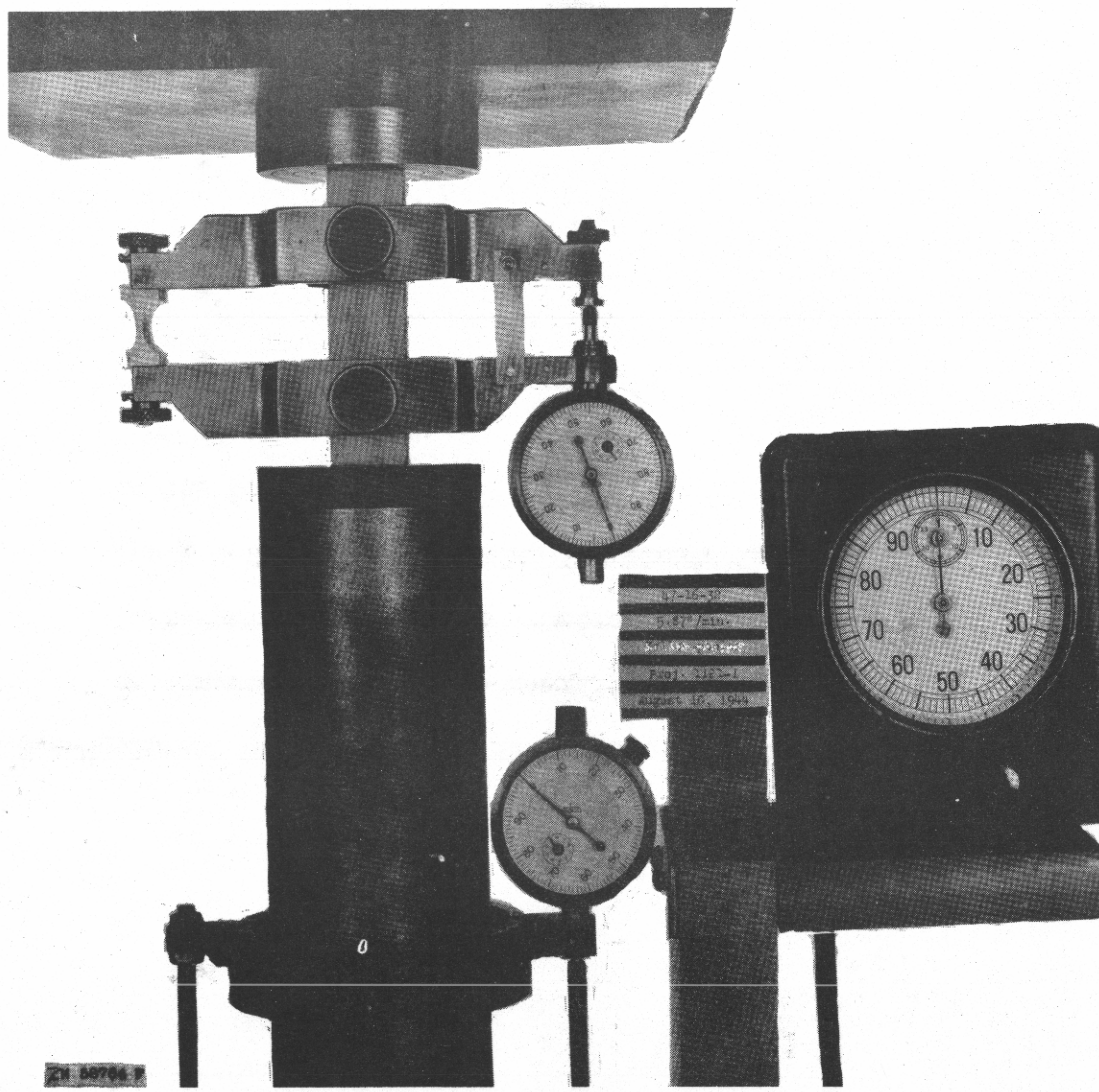

Figure 2.--Equipment used to measure the effect of rapid loading on compression-parallel-to-grain properties. High-speed motion-picture camera used to record load, deformation, and time increments is shown in the foreground.

(ZM57093F)

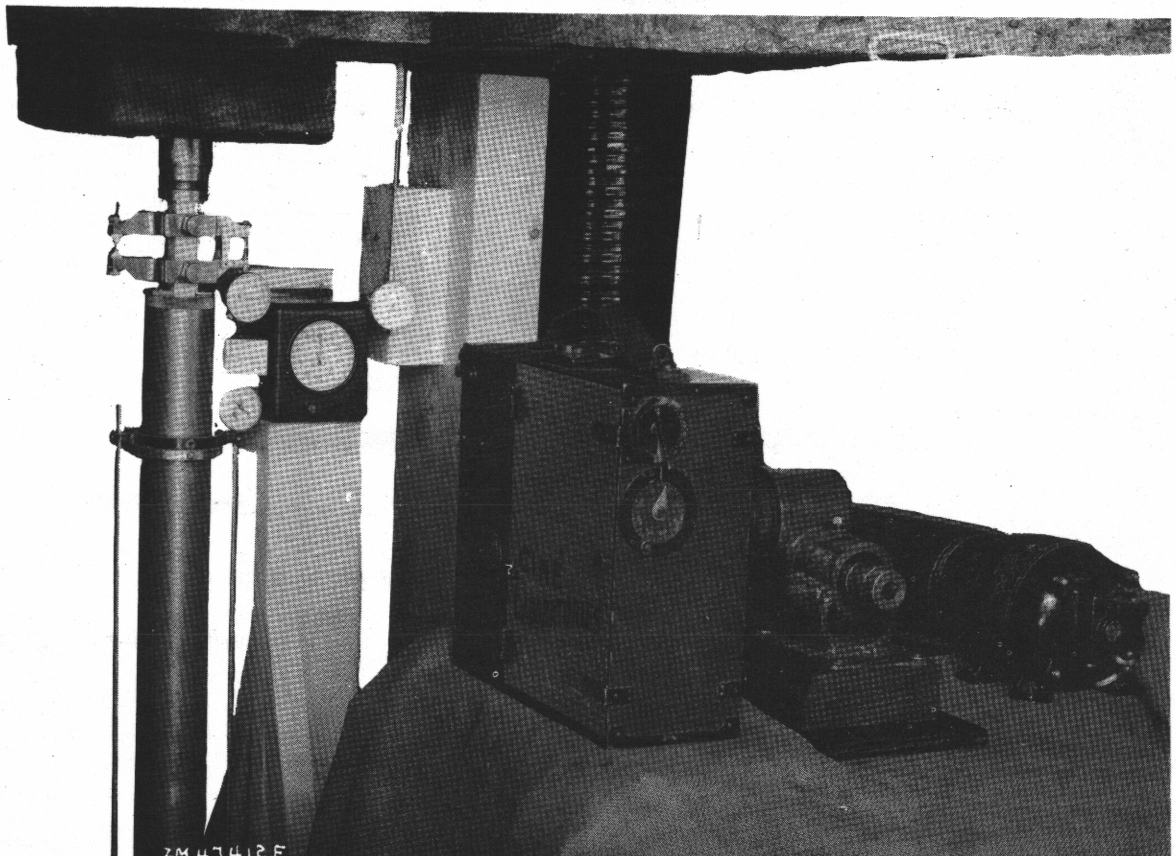
ZM47412F

Figure 3.--View of 2-inch gage length compressometer developed for rapid loading tests.

(ZM47886F)

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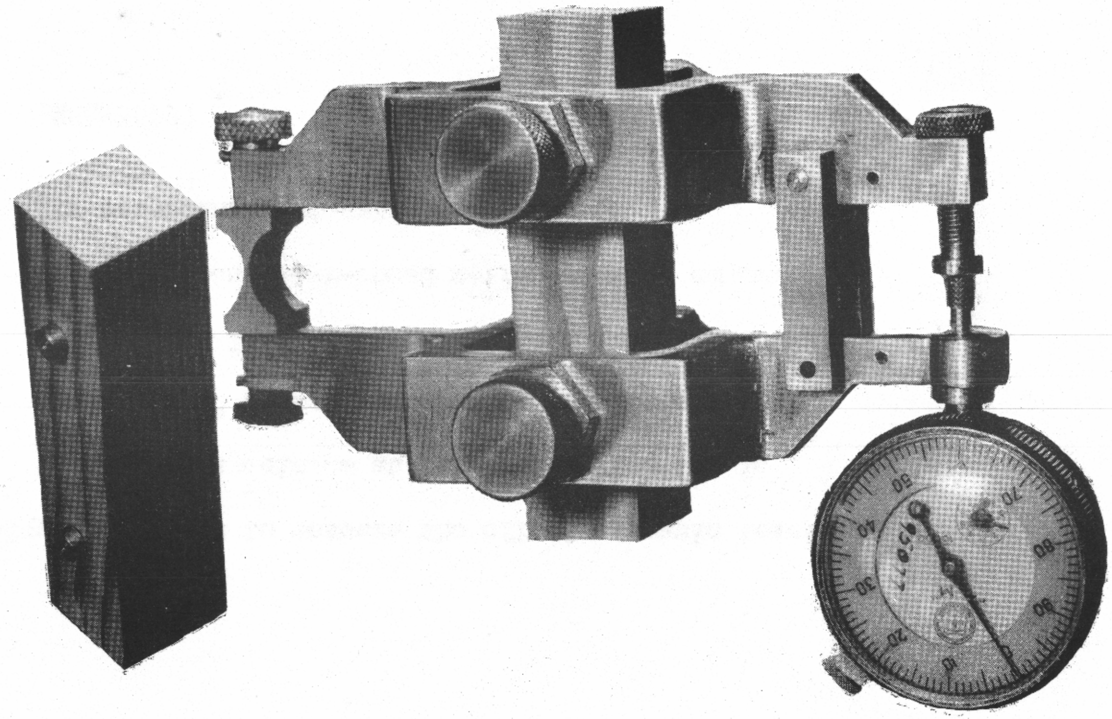

ZM 47886 F

Figure 4.--Equipment used to measure the effect of rapid loading on flexure specimens at rates of deflection in excess of 18 inches per minute. Bellows with surge tank; load, deformation, and time measuring apparatus; and high-speed motion-picture camera for recording test data are shown.

(ZM49862F)

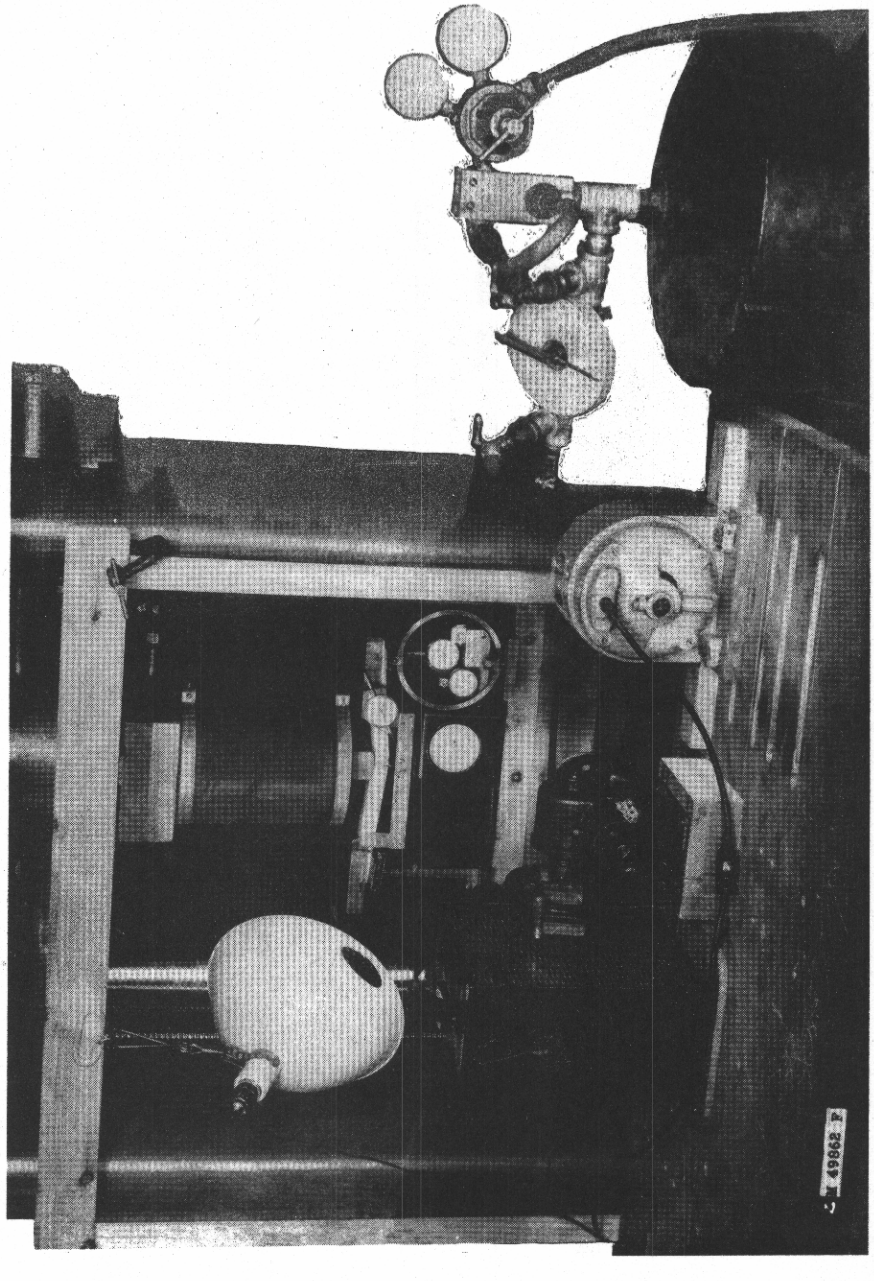
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Figure 5.—Method of testing small, clear flexure specimens at rates of deformation up to 18 inches per minute. The calibrated loading ring, deflection and time measuring apparatus are shown.

(ZM46937F)

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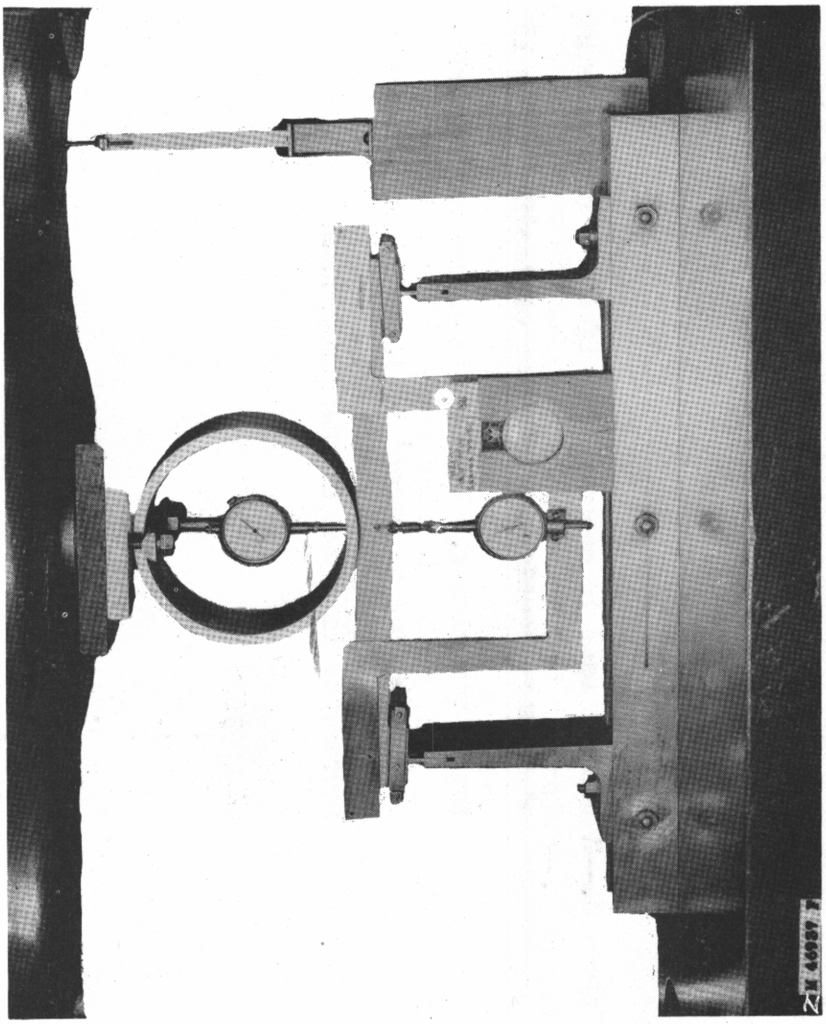

Figure 6.--Equipment used to measure the effect of rapid loading on flexure specimens for rates of loading up to 18 inches per minute. High-speed camera with driving mechanism used to record load, deflection, and time increments is shown in the foreground.

(ZM46936F)

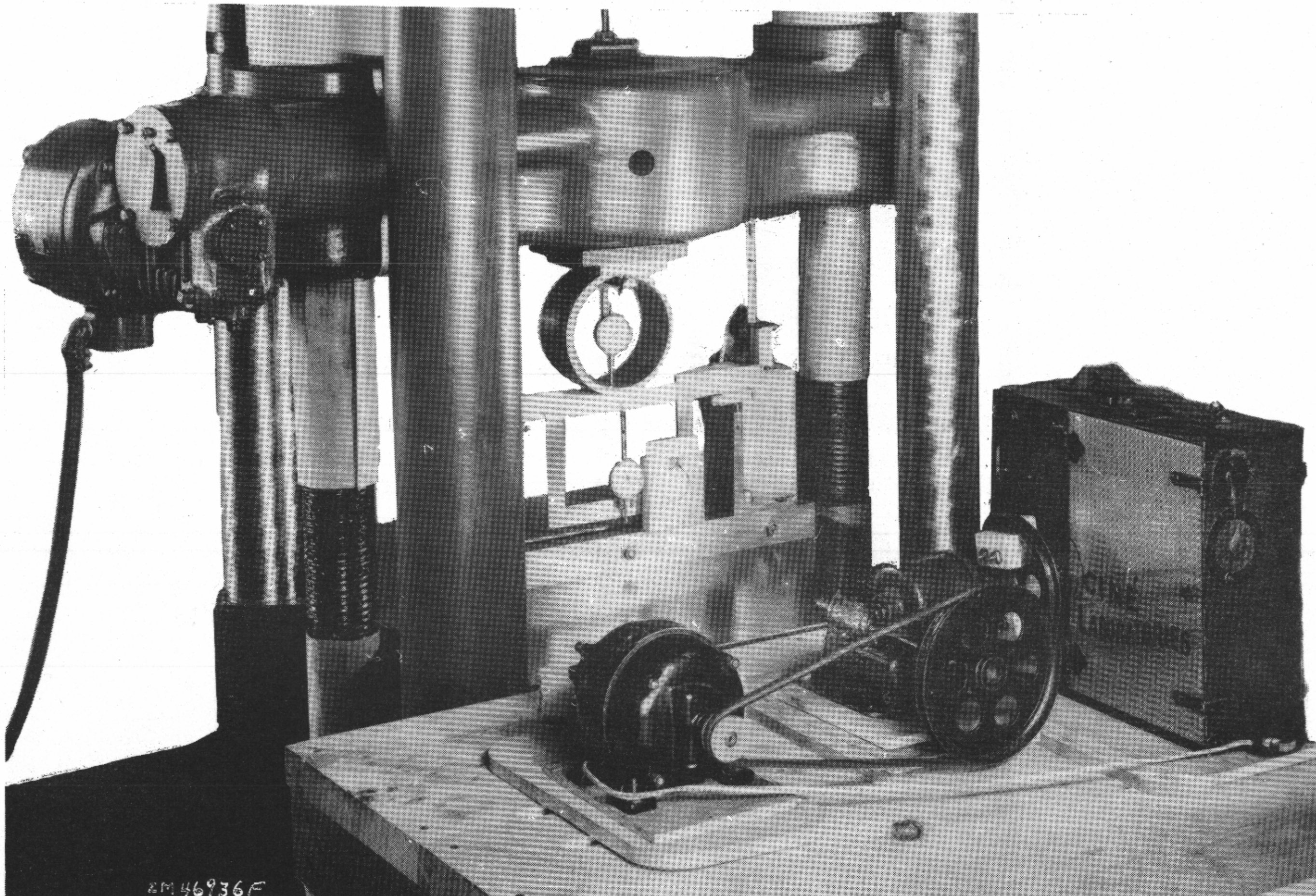
EM 46936 F

Figure 7.--Method of testing small clear flexure specimens at rates of deformation in excess of 18 inches per minute by means of loading bellows. Calibrated ring for measuring load used as one reaction and the deflection and time measuring equipment are shown.

(ZM49860) . . . .

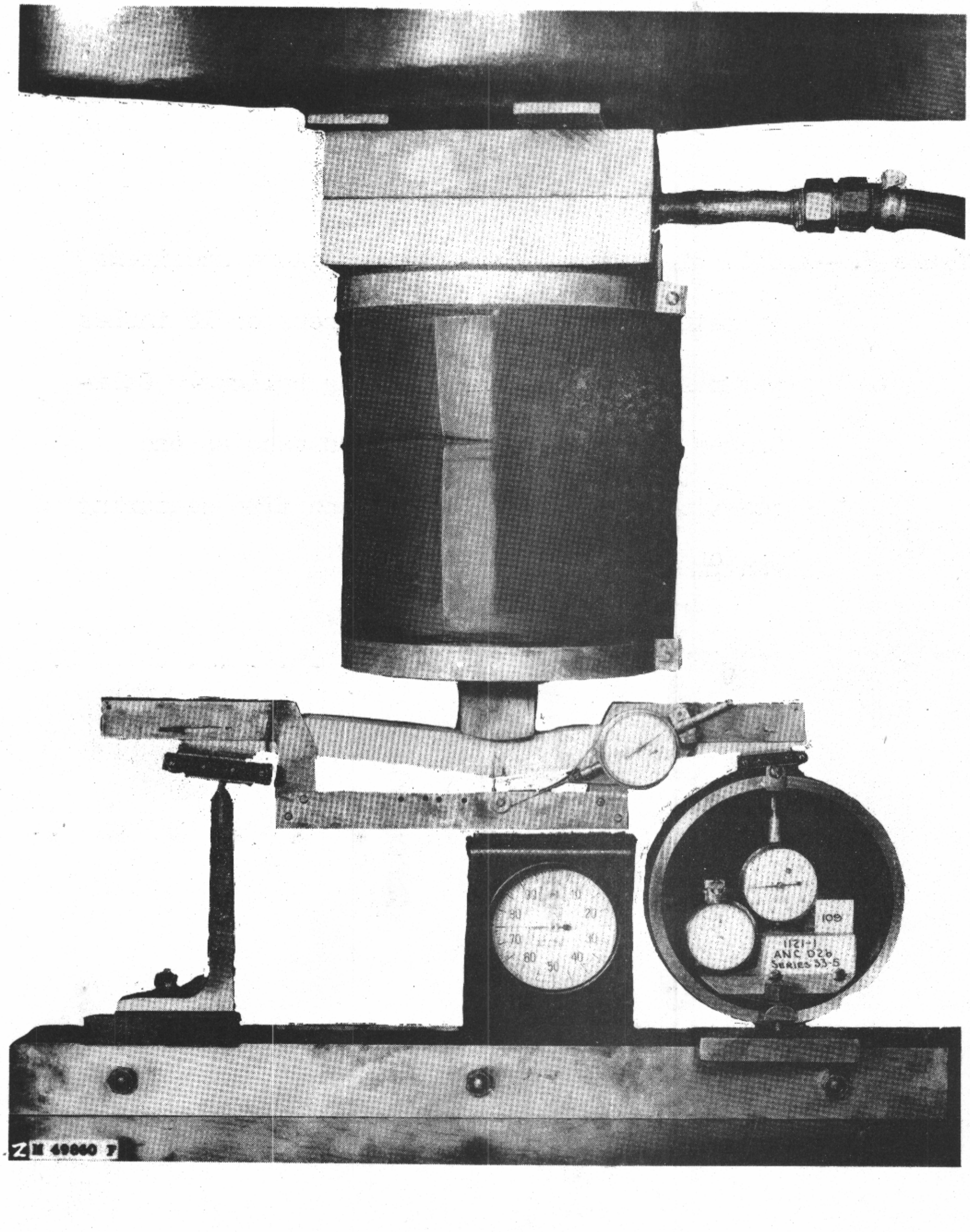
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Figure 8.--The effect of rate of load application on the ultimate compressive strength of small clear Sitka spruce compression-parallel-to-grain specimens.

(ZM85136F)

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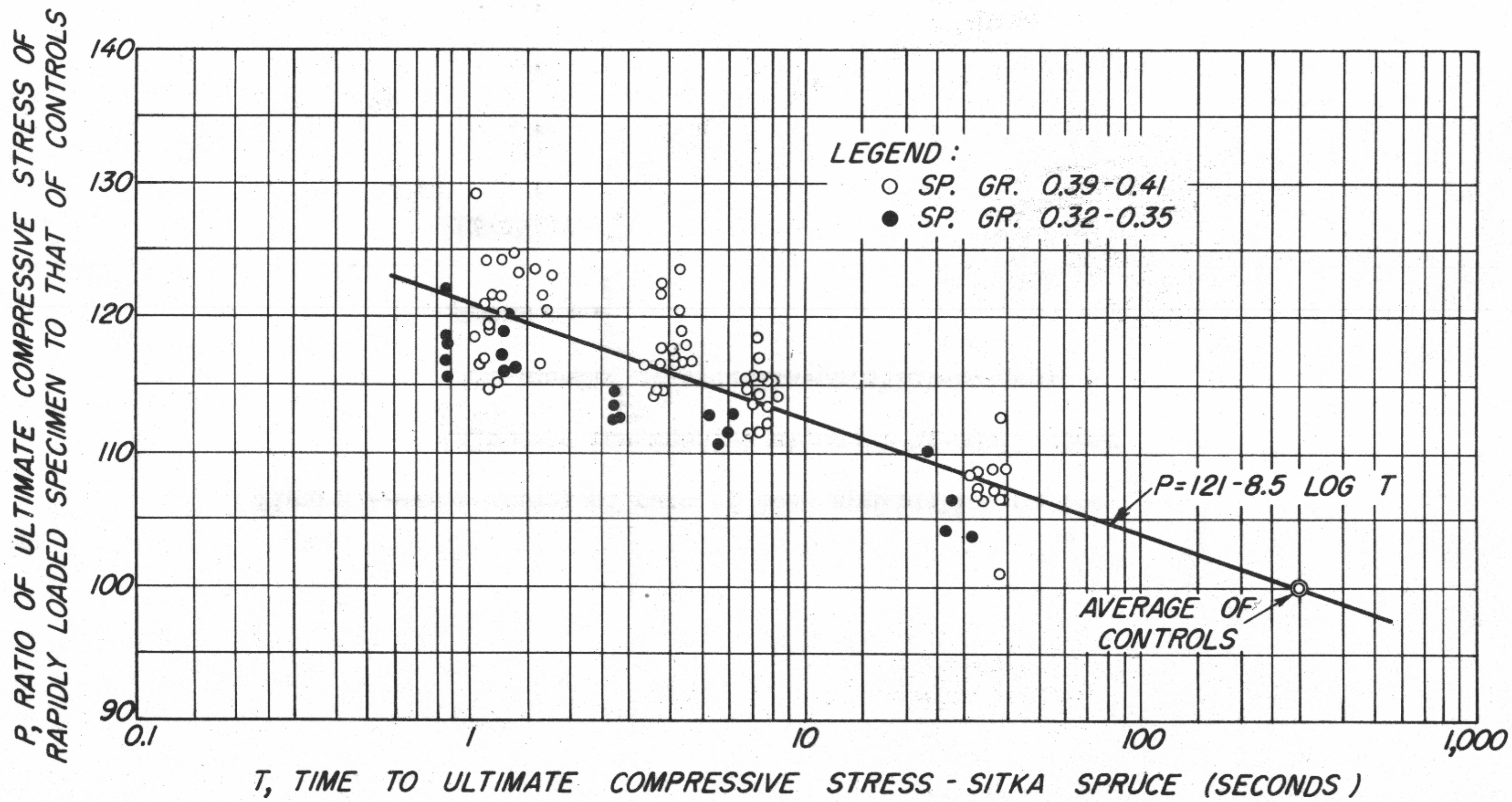
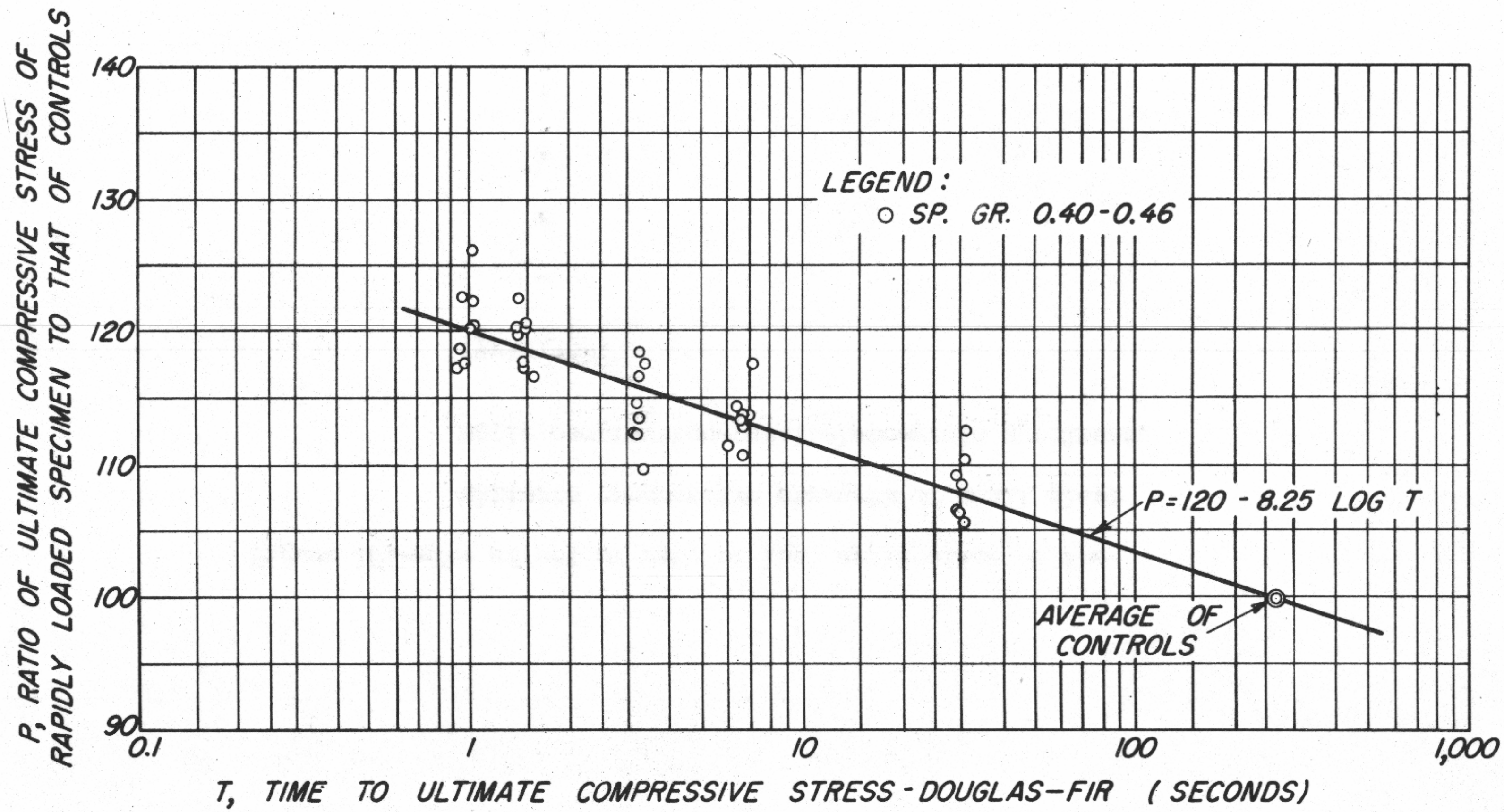

P, RATIO OF ULTIMATE COMPRESSIVE STRESS OF RAPIDLY LOADED SPECIMEN TO THAT OF CONTROLS
140
130
120
110
100
90
0.1
1
10
100
1,000
T, TIME TO ULTIMATE COMPRESSIVE STRESS - SITKA SPRUCE (SECONDS)
LEGEND:
SP. GR. 0.39-0.41
SP. GR. 0.32-0.35
P=121-8.5 LOG T
AVERAGE OF CONTROLS

Z M 85136 F

Figure 9.--The effect of rate of load application on the ultimate compressive strength of small clear Douglas-fir compression-parallel-to-grain specimens.

(ZM85137F)

Rept. No. R1767

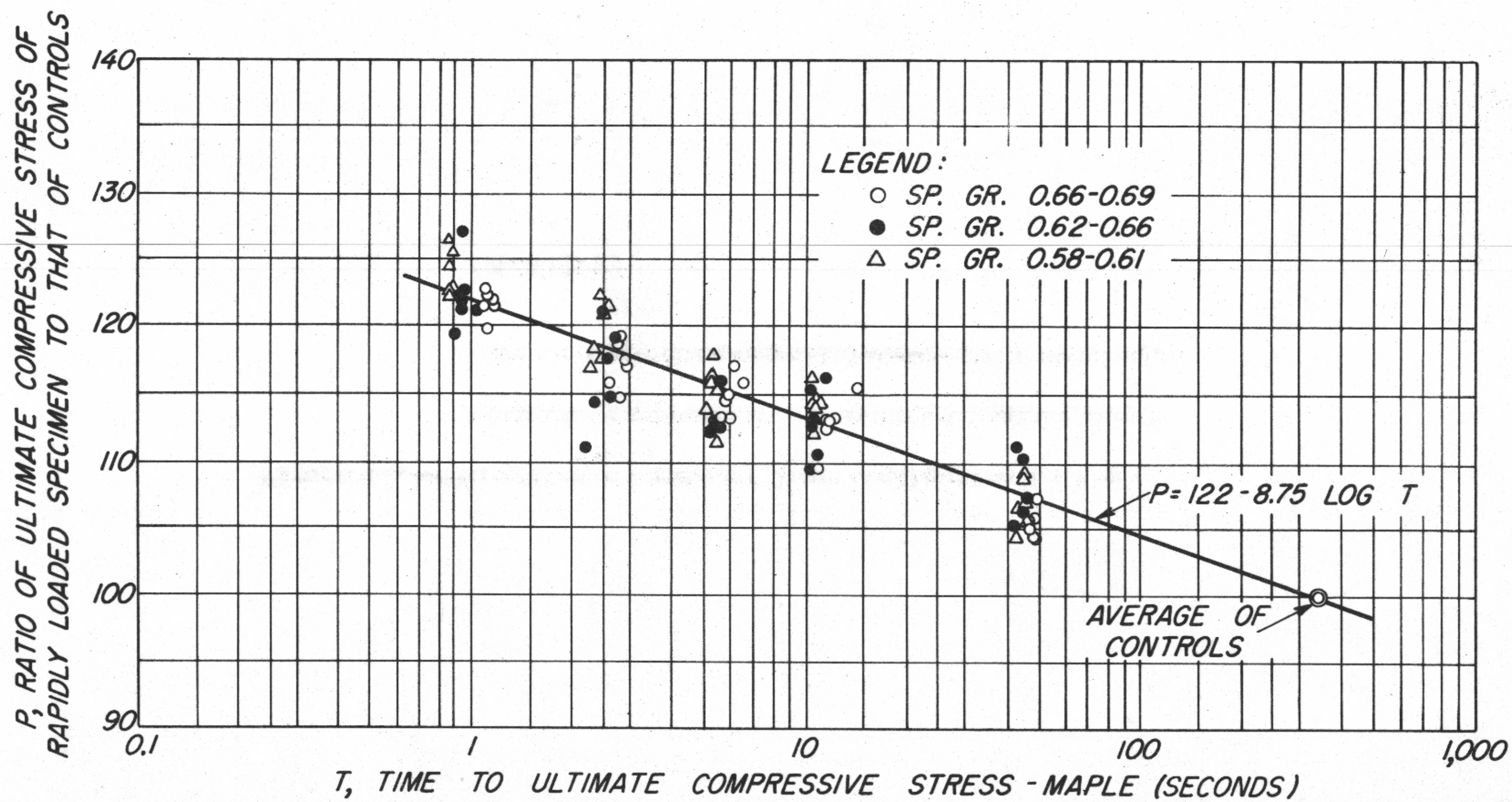


P, RATIO OF ULTIMATE COMPRESSIVE STRESS OF RAPIDLY LOADED SPECIMEN TO THAT OF CONTROLS
140
130
120
110
100
90
0.1
1
10
100
1,000
T, TIME TO ULTIMATE COMPRESSIVE STRESS - DOUGLAS-FIR (SECONDS)
LEGEND:
○ SP. GR. 0.40-0.46
P=120 - 8.25 LOG T
AVERAGE OF CONTROLS

Z M 85137 F

Figure 10.--The effect of rate of load application on the ultimate compressive strength of small clear maple compression-parallel-to-grain specimens.

(ZM85138F)

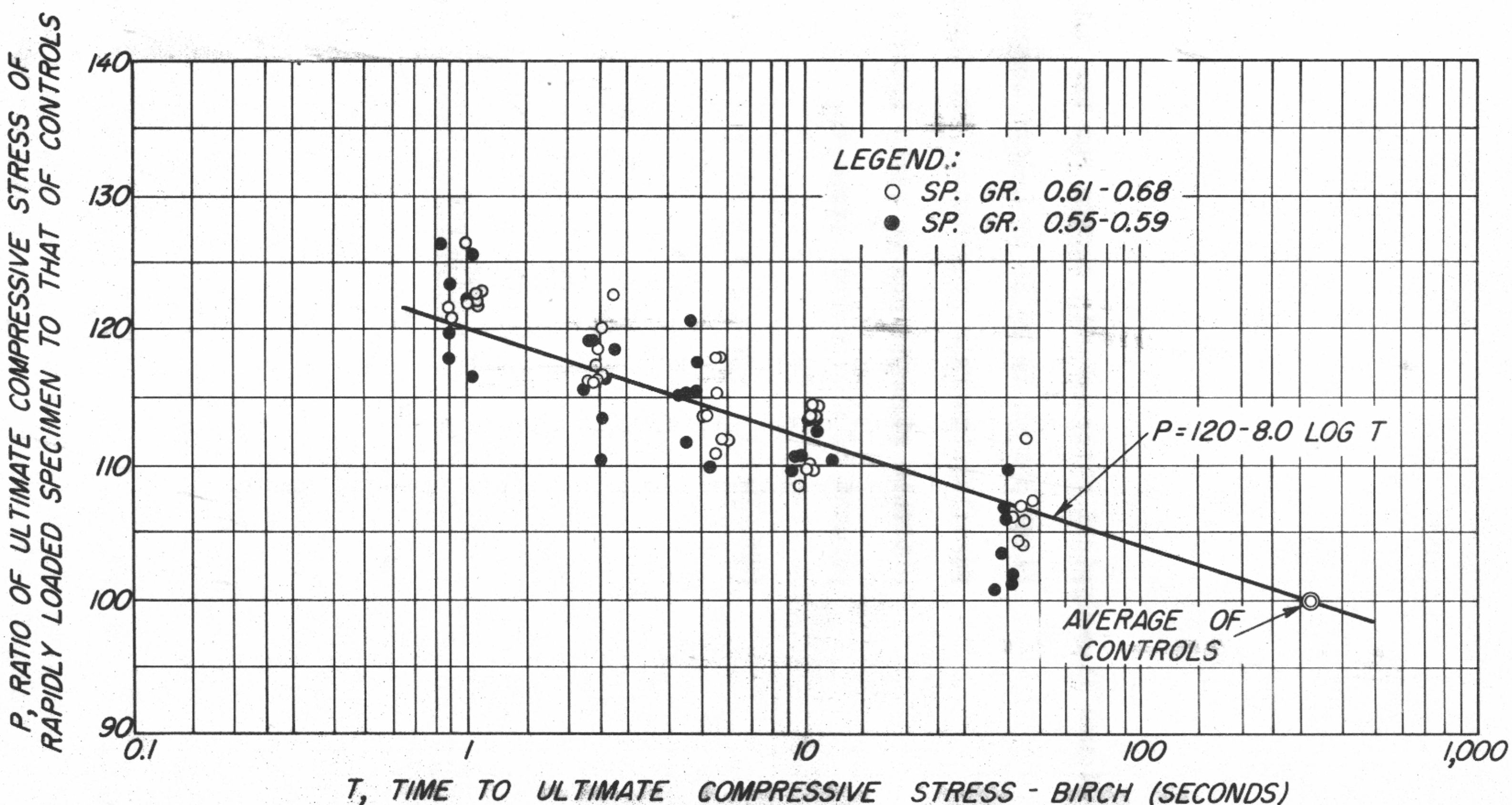

P, RATIO OF ULTIMATE COMPRESSIVE STRESS OF RAPIDLY LOADED SPECIMEN TO THAT OF CONTROLS
140
130
120
110
100
90
0.1
1
10
100
1,000
T, TIME TO ULTIMATE COMPRESSIVE STRESS - MAPLE (SECONDS)
LEGEND:
○ SP. GR. 0.66-0.69
● SP. GR. 0.62-0.66
△ SP. GR. 0.58-0.61
P= 122 - 8.75 LOG T
AVERAGE OF CONTROLS

Z M 85138 F

Figure 11.--The effect of rate of load application on the ultimate compressive strength of small clear birch compression-parallel-to-grain specimens.

(ZM85139F)

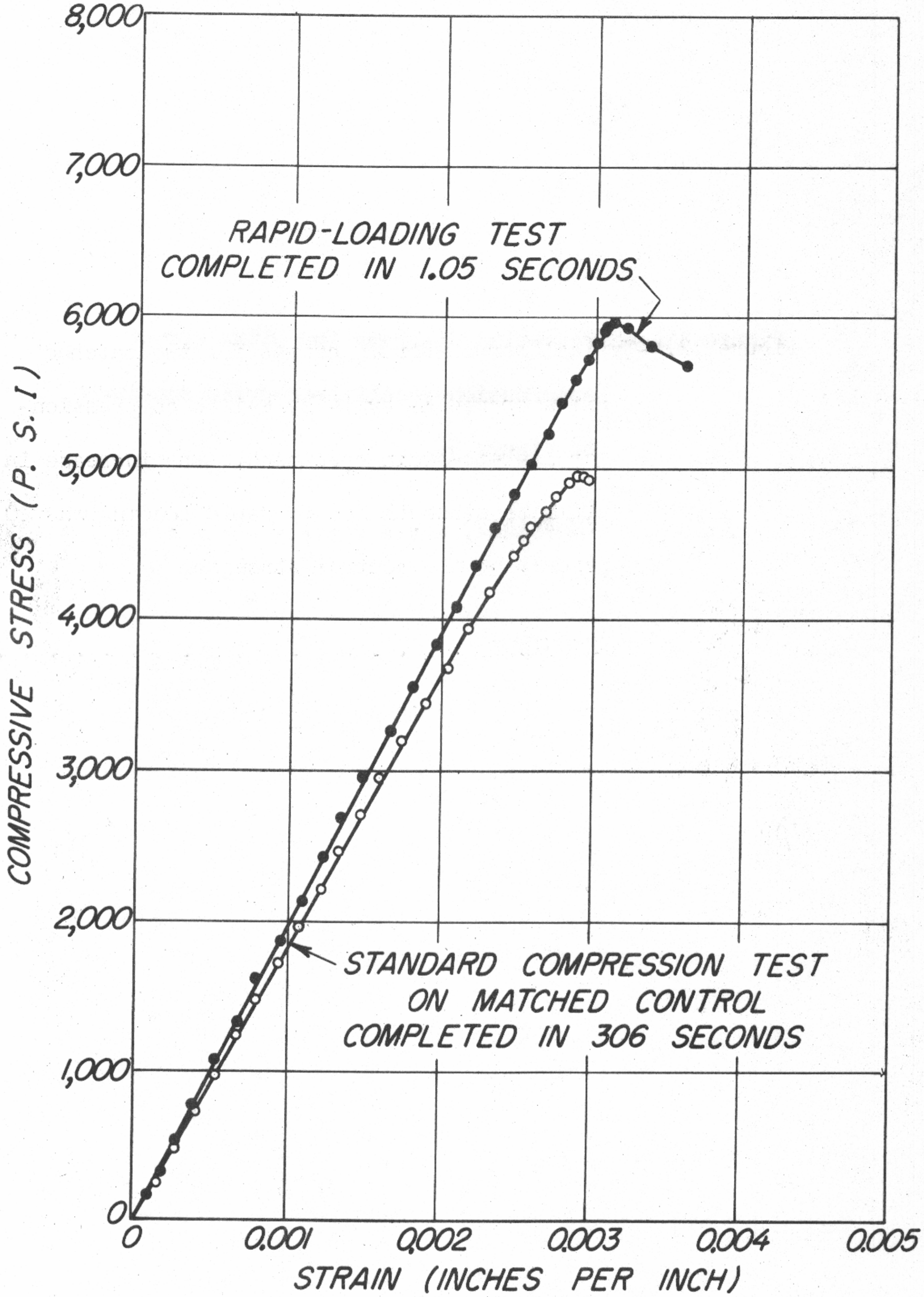
Rept. No. R1767


LEGEND:
SP. GR. 0.61-0.68
SP. GR. 0.55-0.59
P=120-8.0 LOG T
AVERAGE OF CONTROLS
140
130
120
110
100
90
0.1
1
10
100
1,000
P, RATIO OF ULTIMATE COMPRESSIVE STRESS OF RAPIDLY LOADED SPECIMEN TO THAT OF CONTROLS
T, TIME TO ULTIMATE COMPRESSIVE STRESS - BIRCH (SECONDS)

Z M 85139 F

Figure 12.--Typical stress-strain curves for two matched Sitka spruce 1- by 1- by 4-inch compression-parallel-to-grain specimens. The increase in ultimate strength due to rapid loading was 20 percent of the control strength.

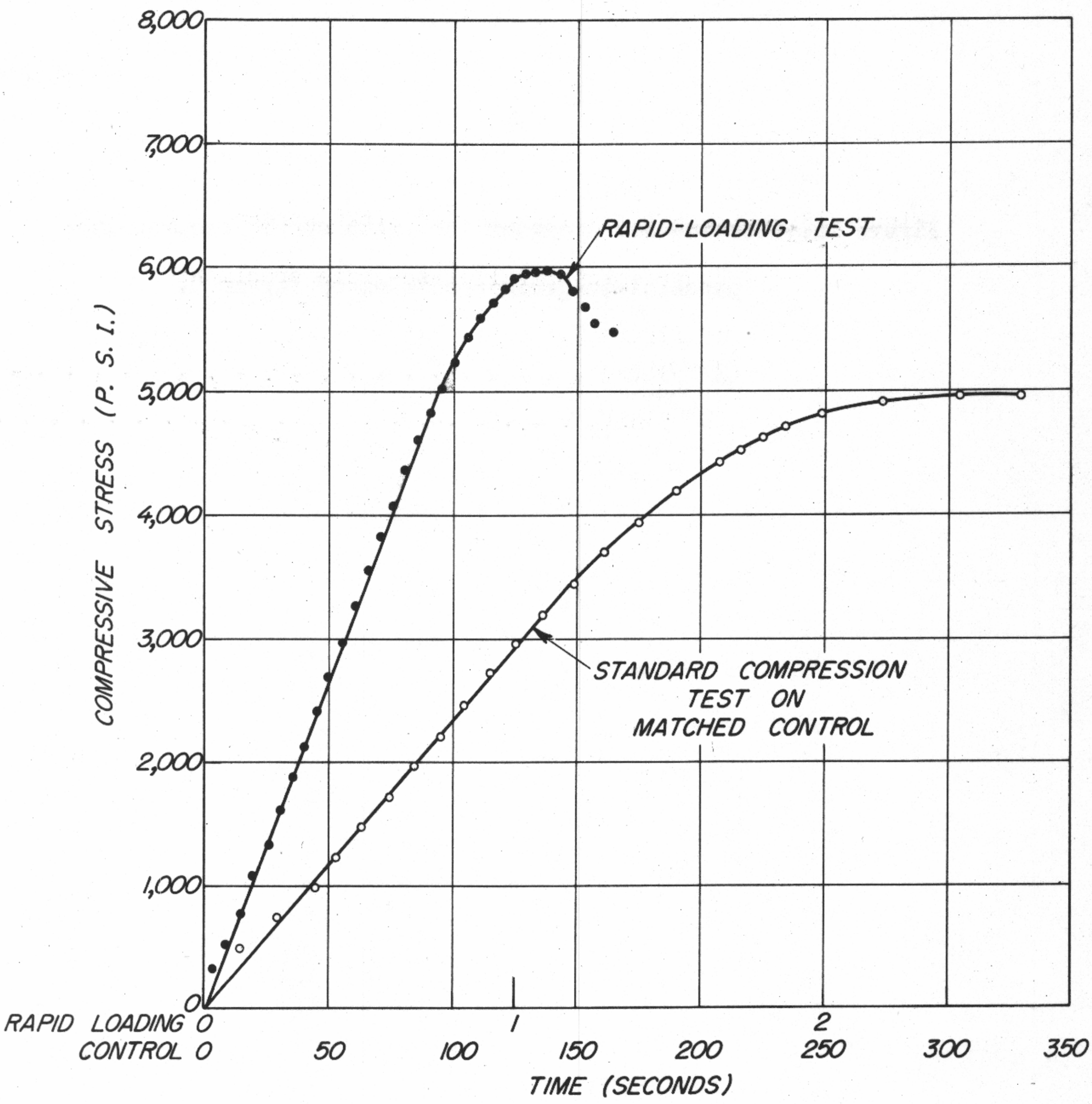
(ZM85140F) . . . .


8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
COMPRESSIVE STRESS (P. S. I)
0
0.001
0.002
0.003
0.004
0.005
STRAIN (INCHES PER INCH)
RAPID-LOADING TEST
COMPLETED IN 1.05 SECONDS
STANDARD COMPRESSION TEST
ON MATCHED CONTROL
COMPLETED IN 306 SECONDS

Z M 85140 F

Figure 13.--Stress-time diagrams for Sitka spruce compression-parallel-to-grain specimens of figure 5.

(ZM85141F) . . . .

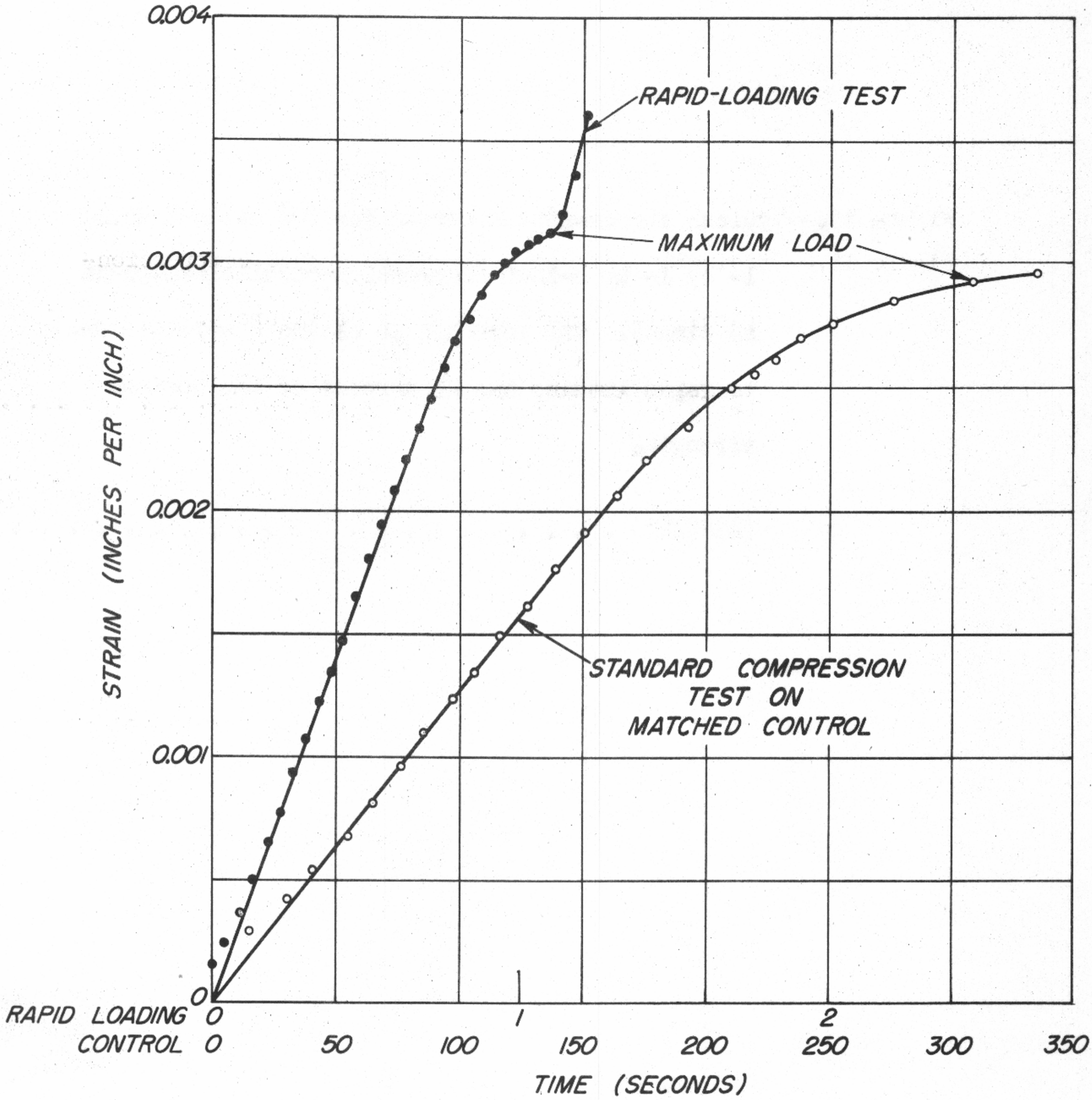


8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
COMPRESSIVE STRESS (P. S. I.)
RAPID-LOADING TEST
STANDARD COMPRESSION TEST ON MATCHED CONTROL
RAPID LOADING 0
1
2
CONTROL 0
50
100
150
200
250
300
350
TIME (SECONDS)

Z M 85141 F

Figure 14.--Strain-time diagrams for Sitka spruce compression-parallel-to-grain specimens of figure 5.

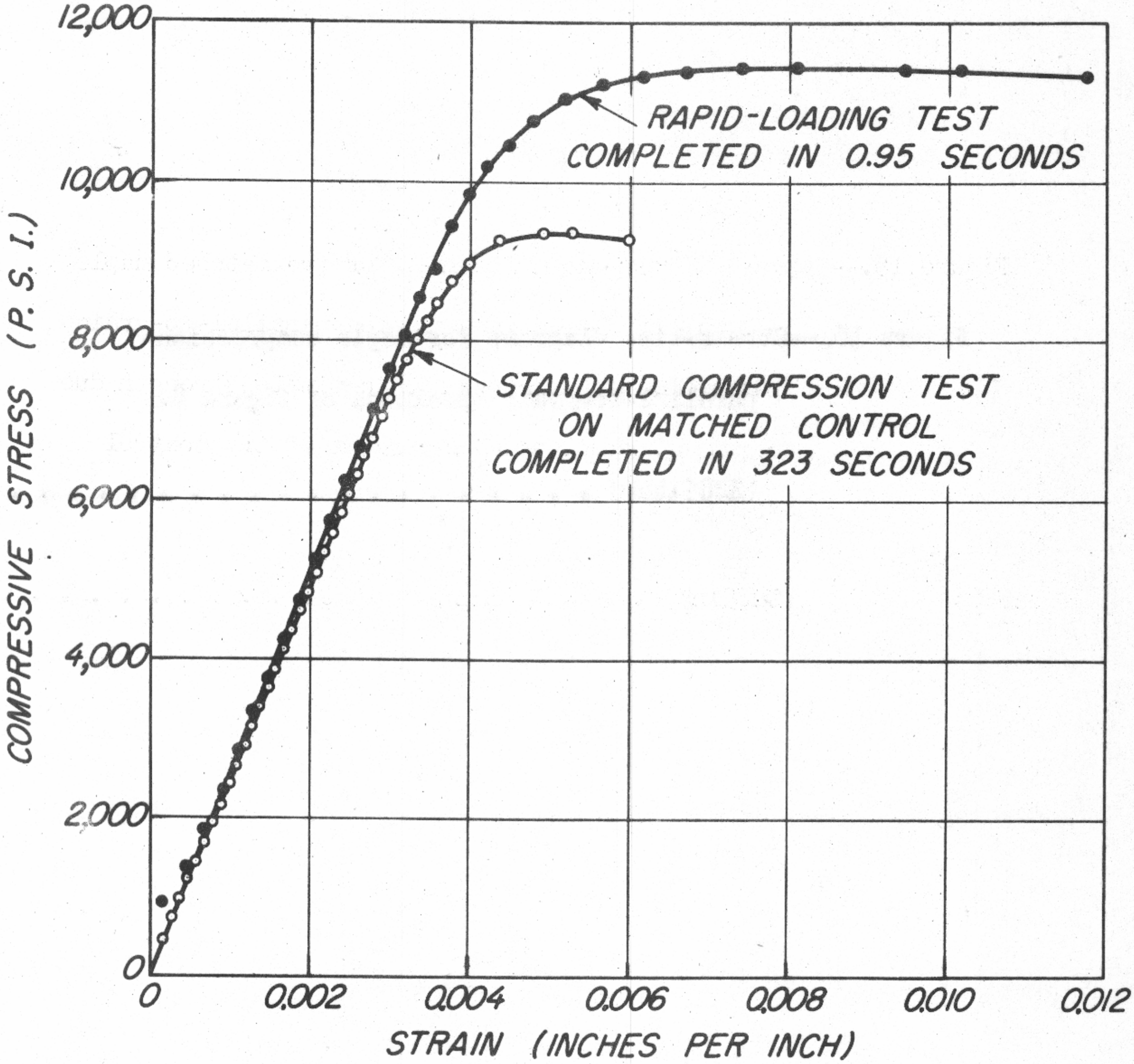
(ZM85142F) . . . .


0.004
0.003
0.002
0.001
0
STRAIN (INCHES PER INCH)
RAPID-LOADING TEST
MAXIMUM LOAD
STANDARD COMPRESSION TEST ON MATCHED CONTROL
RAPID LOADING 0 1 2
CONTROL 0 50 100 150 200 250 300 350
TIME (SECONDS)

Z M 85142 F

Figure 15.--Typical stress-strain curves for two matched maple 1- by 1- by 4-inch compression-parallel-to-grain specimens. The increase in ultimate strength due to rapid loading was 22 percent of the control strength.

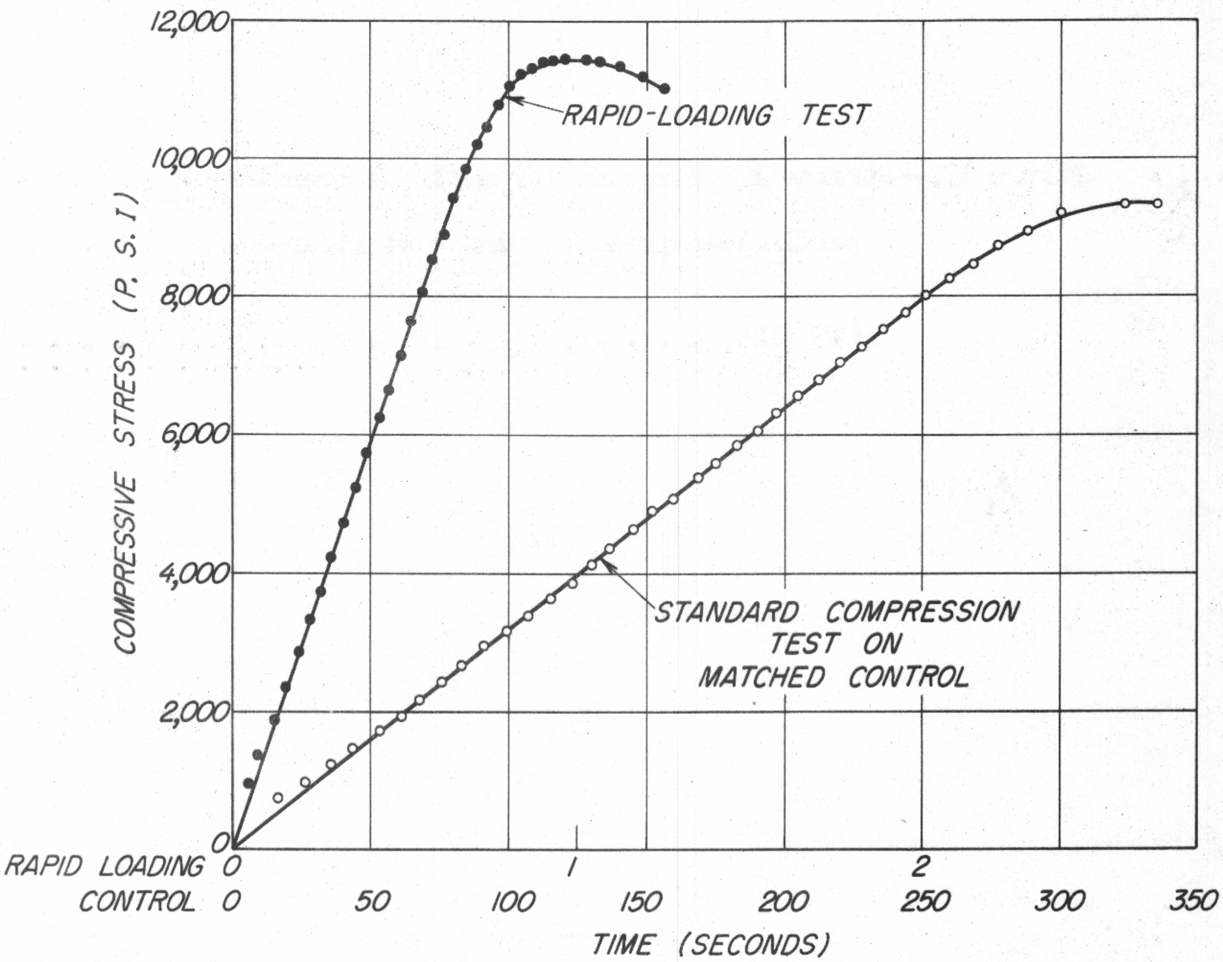
(ZM85143) . . . .


12,000
10,000
8,000
6,000
4,000
2,000
0
COMPRESSIVE STRESS (P. S. I.)
RAPID-LOADING TEST
COMPLETED IN 0.95 SECONDS
STANDARD COMPRESSION TEST
ON MATCHED CONTROL
COMPLETED IN 323 SECONDS
0
0.002
0.004
0.006
0.008
0.010
0.012
STRAIN (INCHES PER INCH)

Z M 85143 F

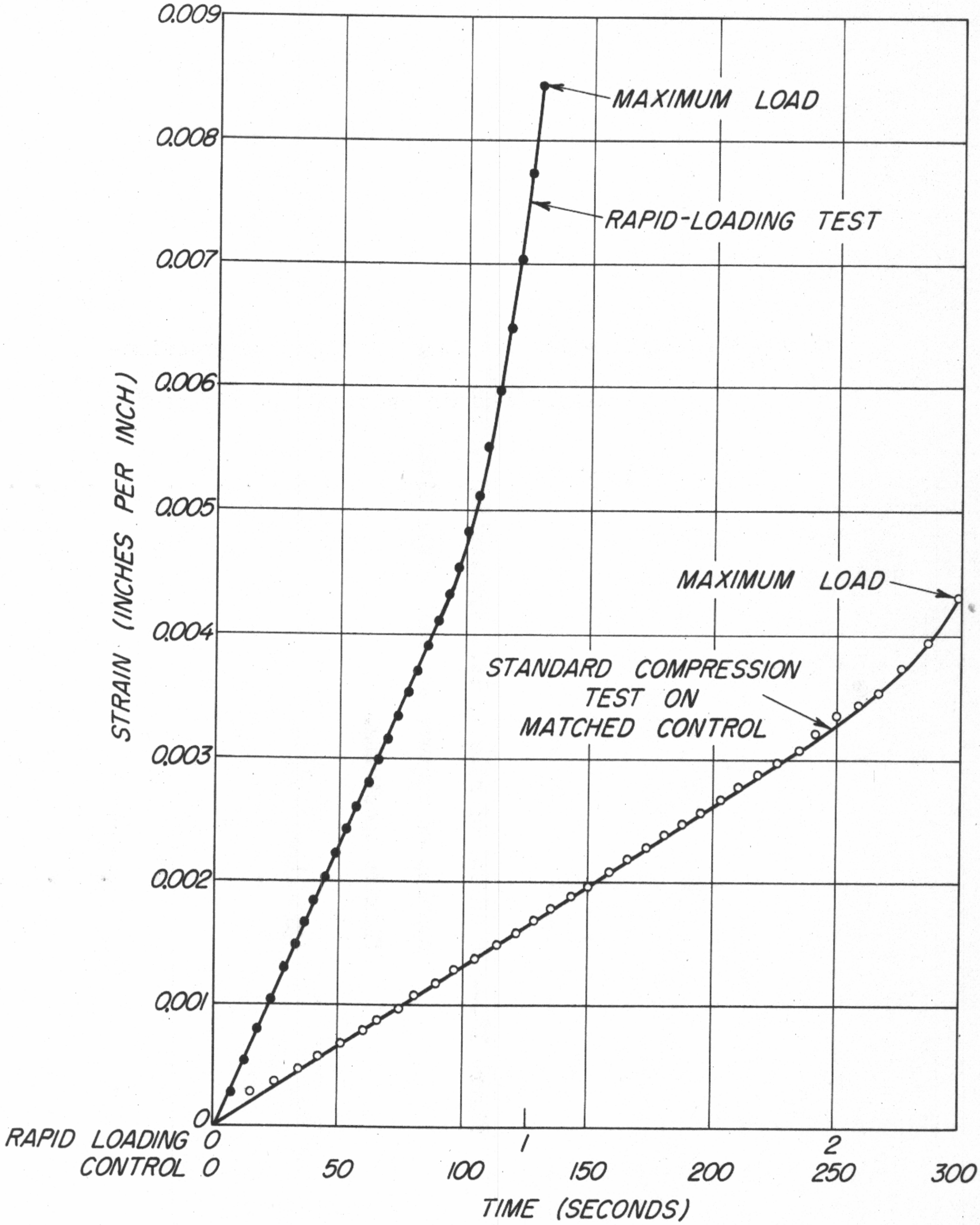
Figure 16.--Stress-time diagrams for maple compression-parallel-to-grain specimens of figure 8.

(ZM85144F) . . . .


RAPID-LOADING TEST
STANDARD COMPRESSION TEST ON MATCHED CONTROL
COMPRESSIVE STRESS (P. S. I)
12,000
10,000
8,000
6,000
4,000
2,000
0
RAPID LOADING 0
1
2
CONTROL 0
50
100
150
200
250
300
350
TIME (SECONDS)

Z M 85144 F

Figure 17.--Strain-time diagrams for maple compression-parallel-to-grain specimens of figure 8. (ZM85145) . . . .

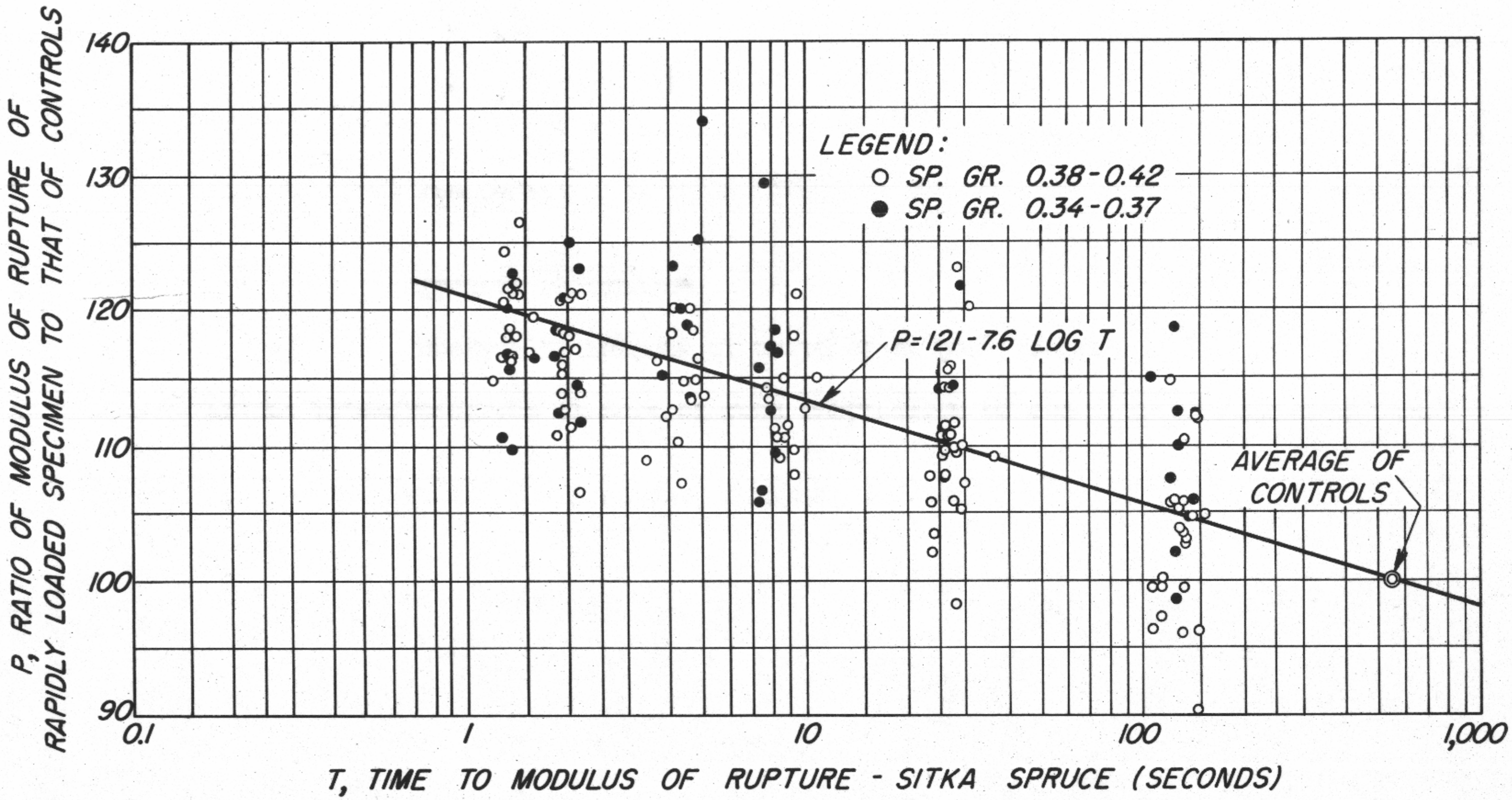


0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
STRAIN (INCHES PER INCH)
MAXIMUM LOAD
RAPID-LOADING TEST
MAXIMUM LOAD
STANDARD COMPRESSION TEST ON MATCHED CONTROL
RAPID LOADING 0
1
2
CONTROL 0
50
100
150
200
250
300
TIME (SECONDS)

Z M 85145 F

Figure 18.--The effect of rate of load application on the modulus of rupture of small clear Sitka spruce flexure specimens.

(ZM85146F)

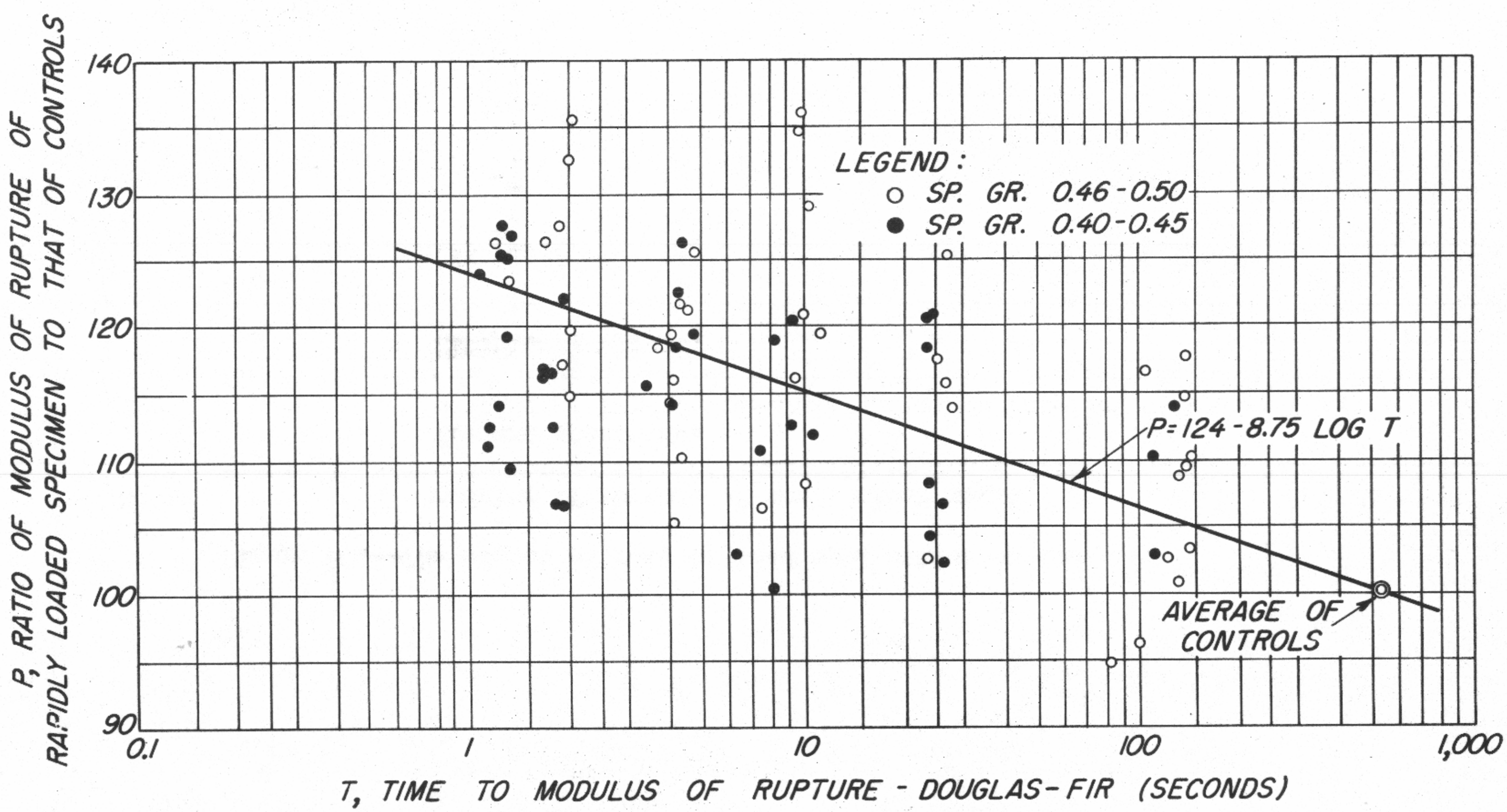


LEGEND:
○ SP. GR. 0.38-0.42
● SP. GR. 0.34-0.37
P=121-7.6 LOG T
AVERAGE OF CONTROLS
140
130
120
110
100
90
0.1
1
10
100
1,000
P, RATIO OF MODULUS OF RUPTURE OF RAPIDLY LOADED SPECIMEN TO THAT OF CONTROLS
T, TIME TO MODULUS OF RUPTURE - SITKA SPRUCE (SECONDS)

Z M 85146 F

Figure 19.--The effect of rate of load application on the modulus of rupture of small clear Douglas-fir flexure specimens.

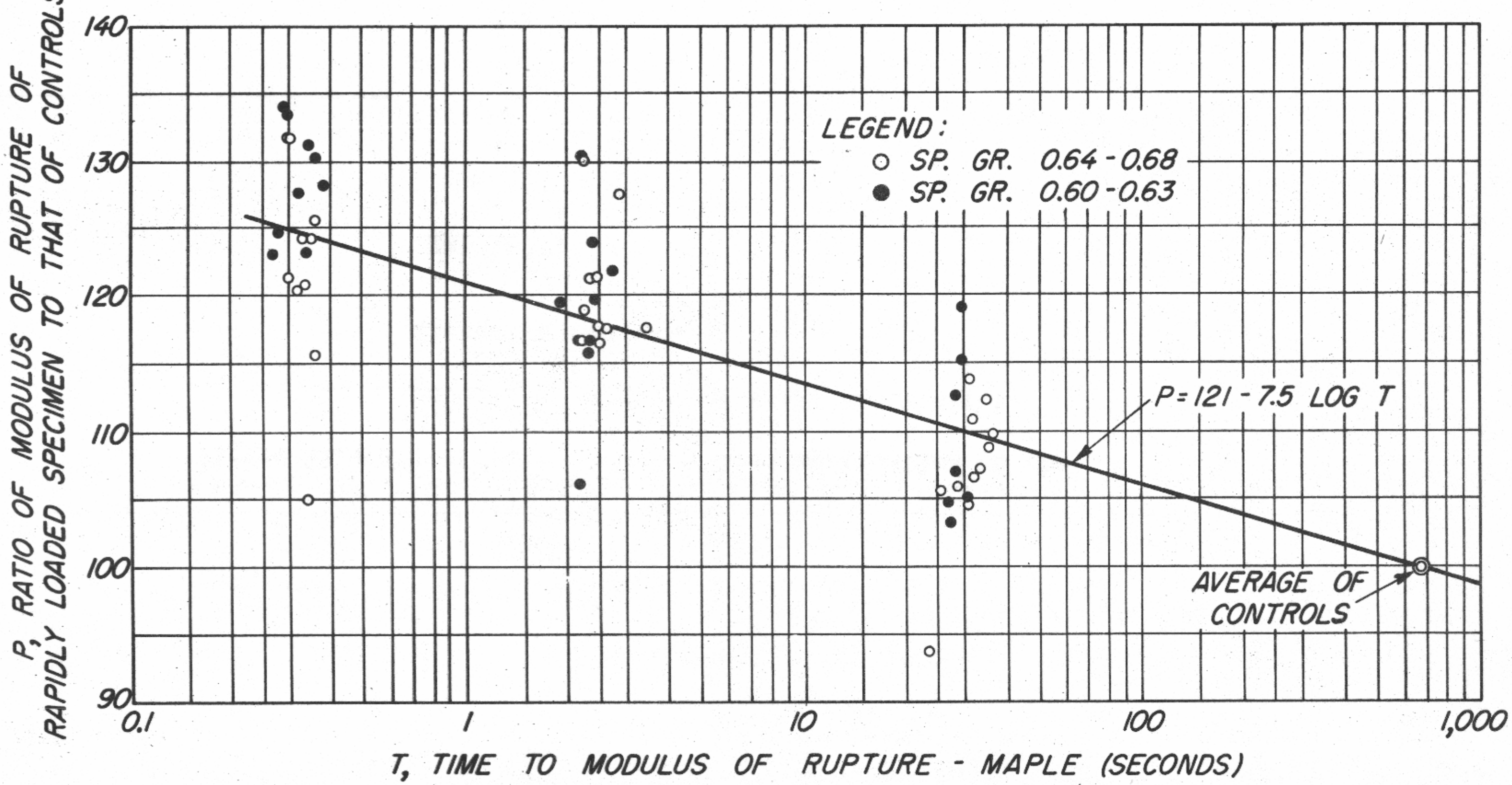
(ZM85147F)


LEGEND :
SP. GR. 0.46-0.50
SP. GR. 0.40-0.45
P=124-8.75 LOG T
AVERAGE OF CONTROLS
P, RATIO OF MODULUS OF RUPTURE OF RAPIDLY LOADED SPECIMEN TO THAT OF CONTROLS
140
130
120
110
100
90
0.1
1
10
100
1,000
T, TIME TO MODULUS OF RUPTURE - DOUGLAS-FIR (SECONDS)

Z M 85147 F

Figure 20.--The effect of rate of load application on the modulus of rupture of small clear maple flexure specimens.

(ZM85148F)

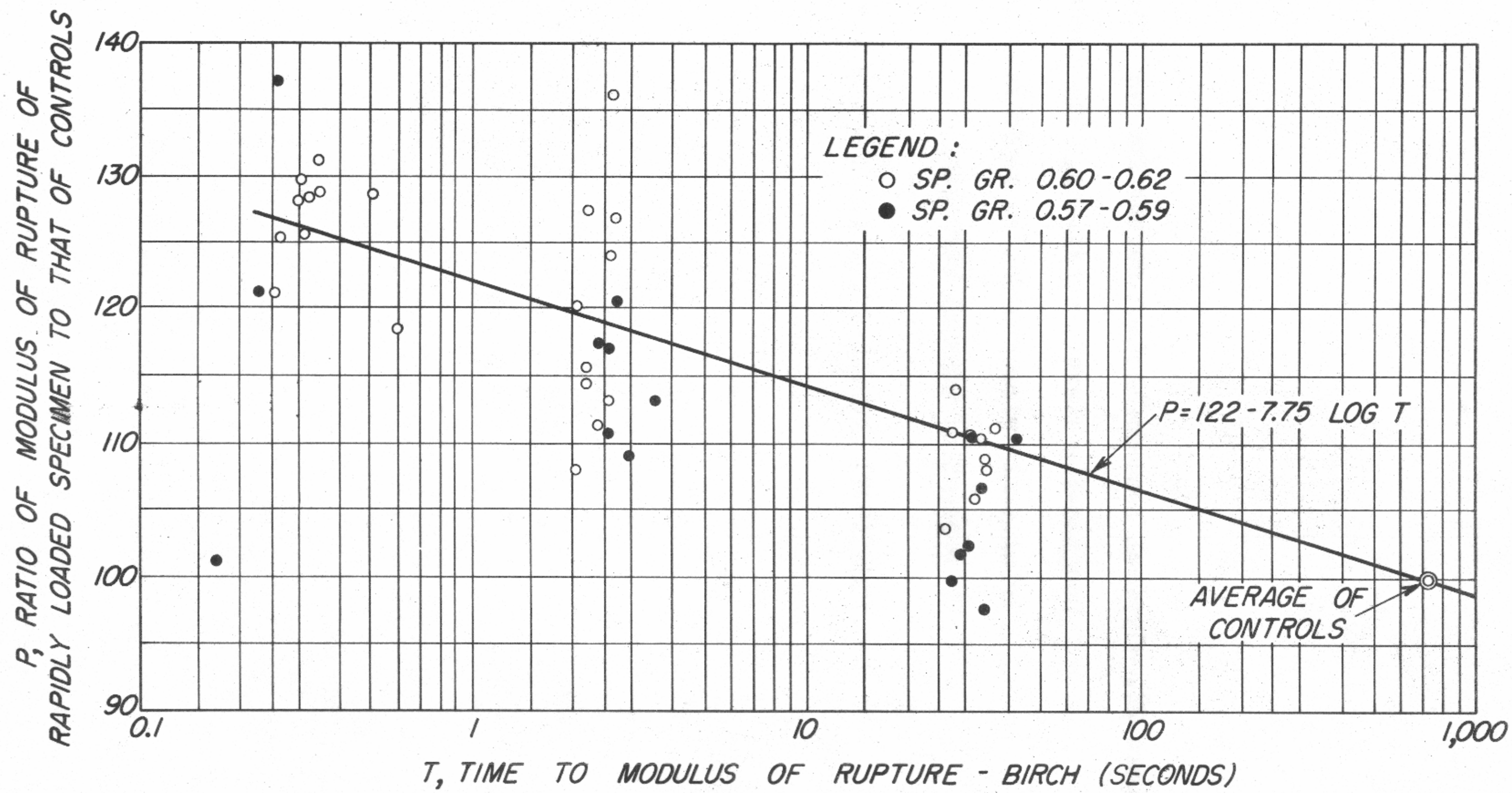

LEGEND:
SP. GR. 0.64 - 0.68
SP. GR. 0.60 - 0.63
P = 121 - 7.5 LOG T
AVERAGE OF CONTROLS
P, RATIO OF MODULUS OF RUPTURE OF RAPIDLY LOADED SPECIMEN TO THAT OF CONTROLS
T, TIME TO MODULUS OF RUPTURE - MAPLE (SECONDS)
140
130
120
110
100
90
0.1
1
10
100
1,000

Z M 85148 F

Figure 21.--The effect of rate of load application on the modulus of rupture of small clear birch flexure specimens.

(ZM85149F)

Rept. No.
R1767

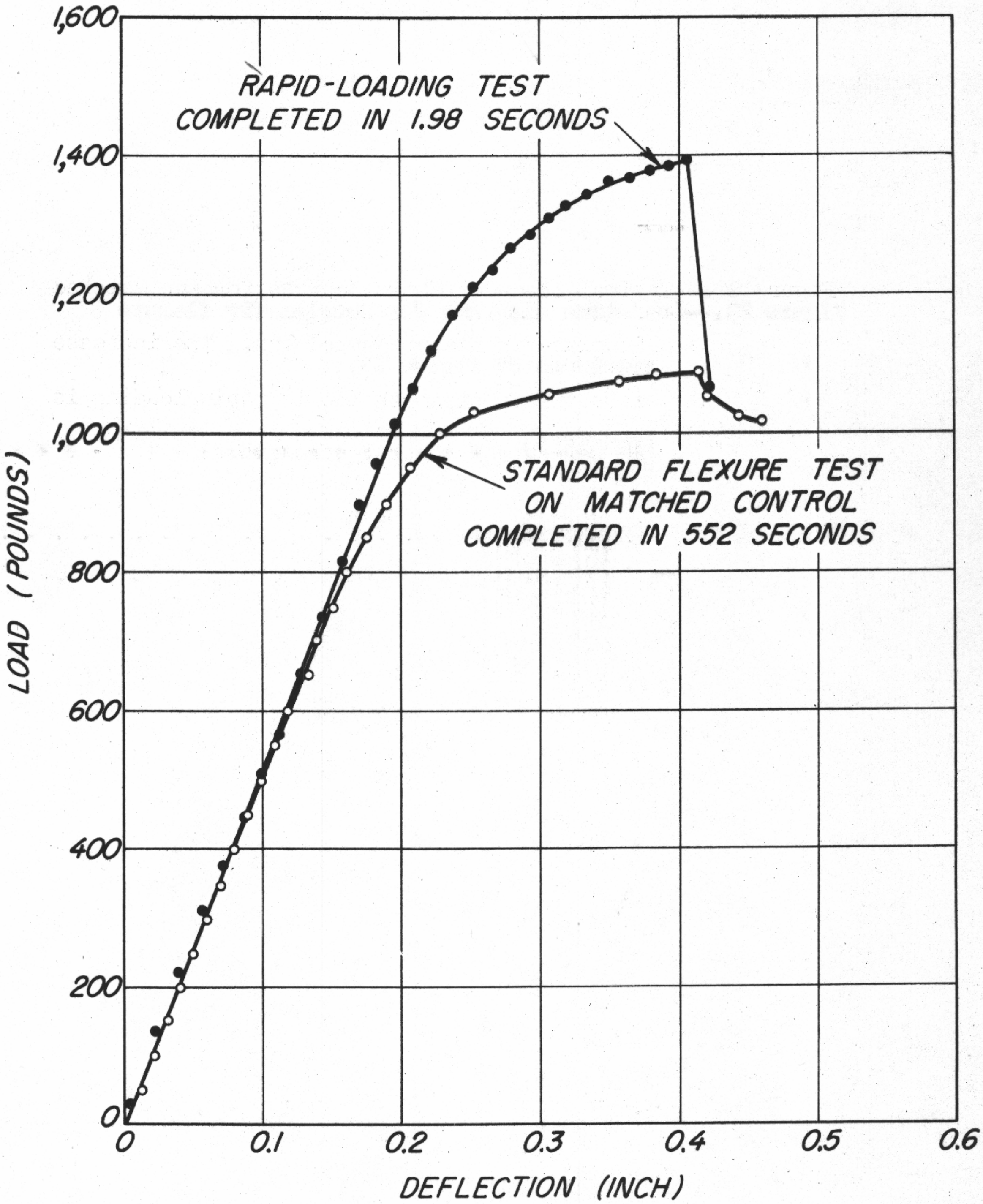


LEGEND :
SP. GR. 0.60-0.62
SP. GR. 0.57-0.59
P=122-7.75 LOG T
AVERAGE OF CONTROLS
140
130
120
110
100
90
0.1
1
10
100
1,000
P, RATIO OF MODULUS OF RUPTURE OF RAPIDLY LOADED SPECIMEN TO THAT OF CONTROLS
T, TIME TO MODULUS OF RUPTURE - BIRCH (SECONDS)

Z M 85149 F

Figure 22.--Typical load-deflection curves for two matched Douglas-fir flexure specimens. The increase in ultimate strength due to rapid loading is 28 percent of control strength.

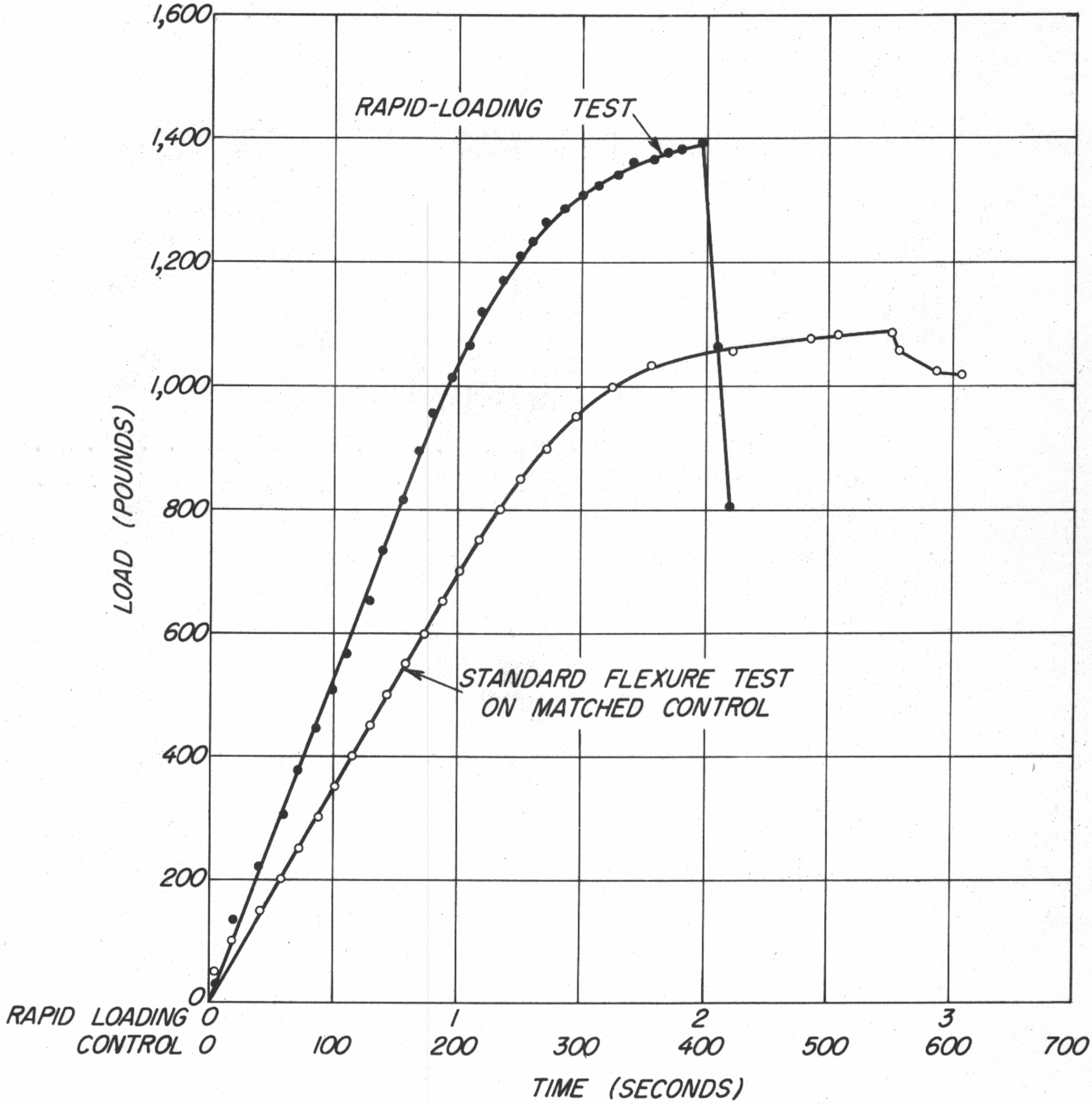
(ZM85150F) . . . .


RAPID-LOADING TEST
COMPLETED IN 1.98 SECONDS
STANDARD FLEXURE TEST
ON MATCHED CONTROL
COMPLETED IN 552 SECONDS
LOAD (POUNDS)
DEFLECTION (INCH)
1,600
1,400
1,200
1,000
800
600
400
200
0
0
0.1
0.2
0.3
0.4
0.5
0.6

Z M 85150 F

Figure 23.--Load-time diagrams for Douglas-fir flexure specimens of figure 15.

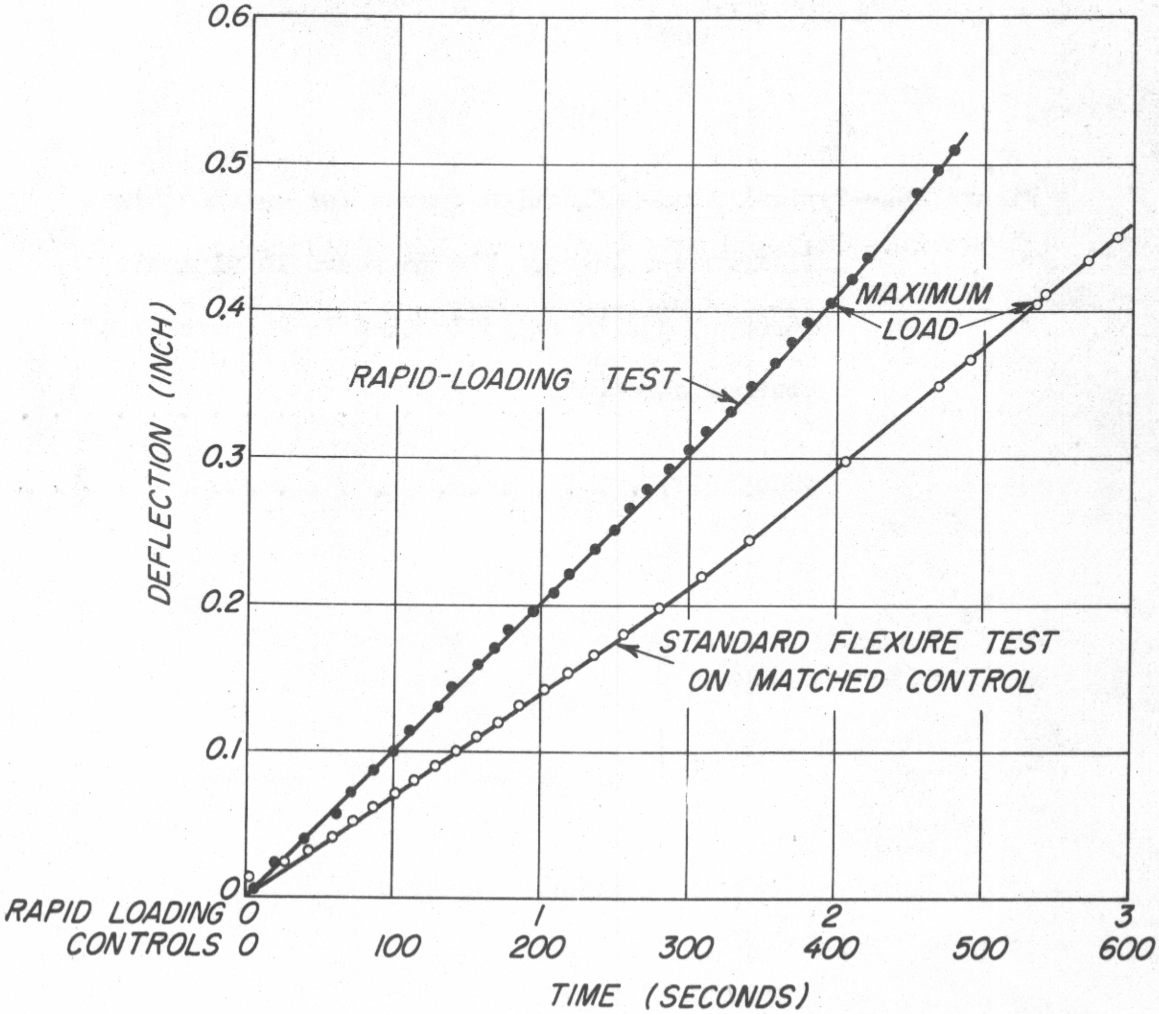
(ZM85151F) . . . .



RAPID-LOADING TEST
STANDARD FLEXURE TEST
ON MATCHED CONTROL
LOAD (POUNDS)
0
200
400
600
800
1,000
1,200
1,400
1,600
RAPID LOADING 0
1
2
3
CONTROL 0
100
200
300
400
500
600
700
TIME (SECONDS)

Z M 85151 F

Figure 24.--Deflection-time diagrams for Douglas-fir flexure specimens of figure 15.

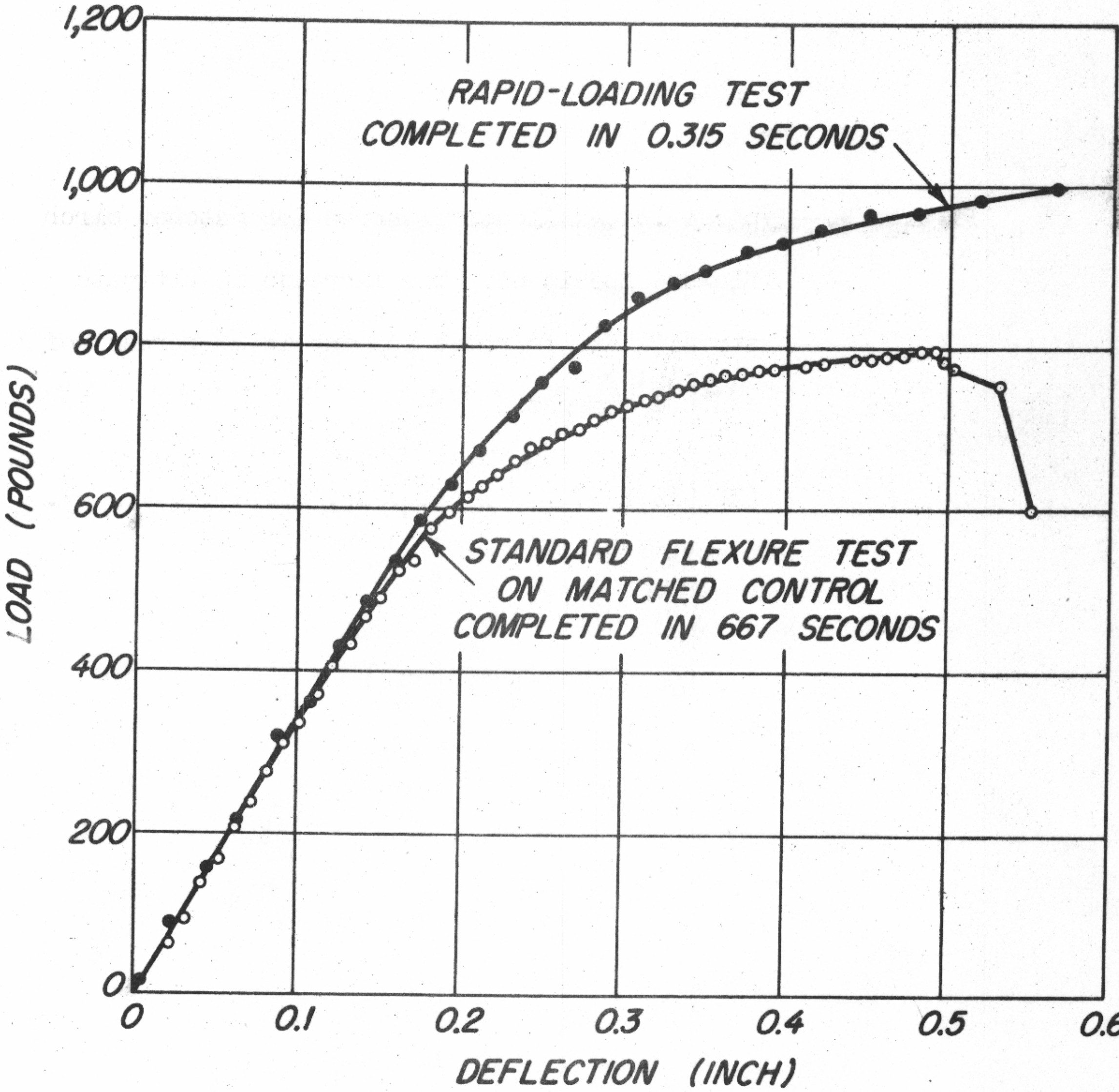


0.6
0.5
0.4
0.3
0.2
0.1
0
DEFLECTION (INCH)
RAPID-LOADING TEST
MAXIMUM
LOAD
STANDARD FLEXURE TEST
ON MATCHED CONTROL
RAPID LOADING 0
CONTROLS 0
1
2
3
100
200
300
400
500
600
TIME (SECONDS)

Z M 85152 F

Figure 25.--Typical load-deflection curves for matched birch flexure specimens. The increase in ultimate strength due to rapid loading is 26 percent of control strength.

(ZM85153F) . . . .

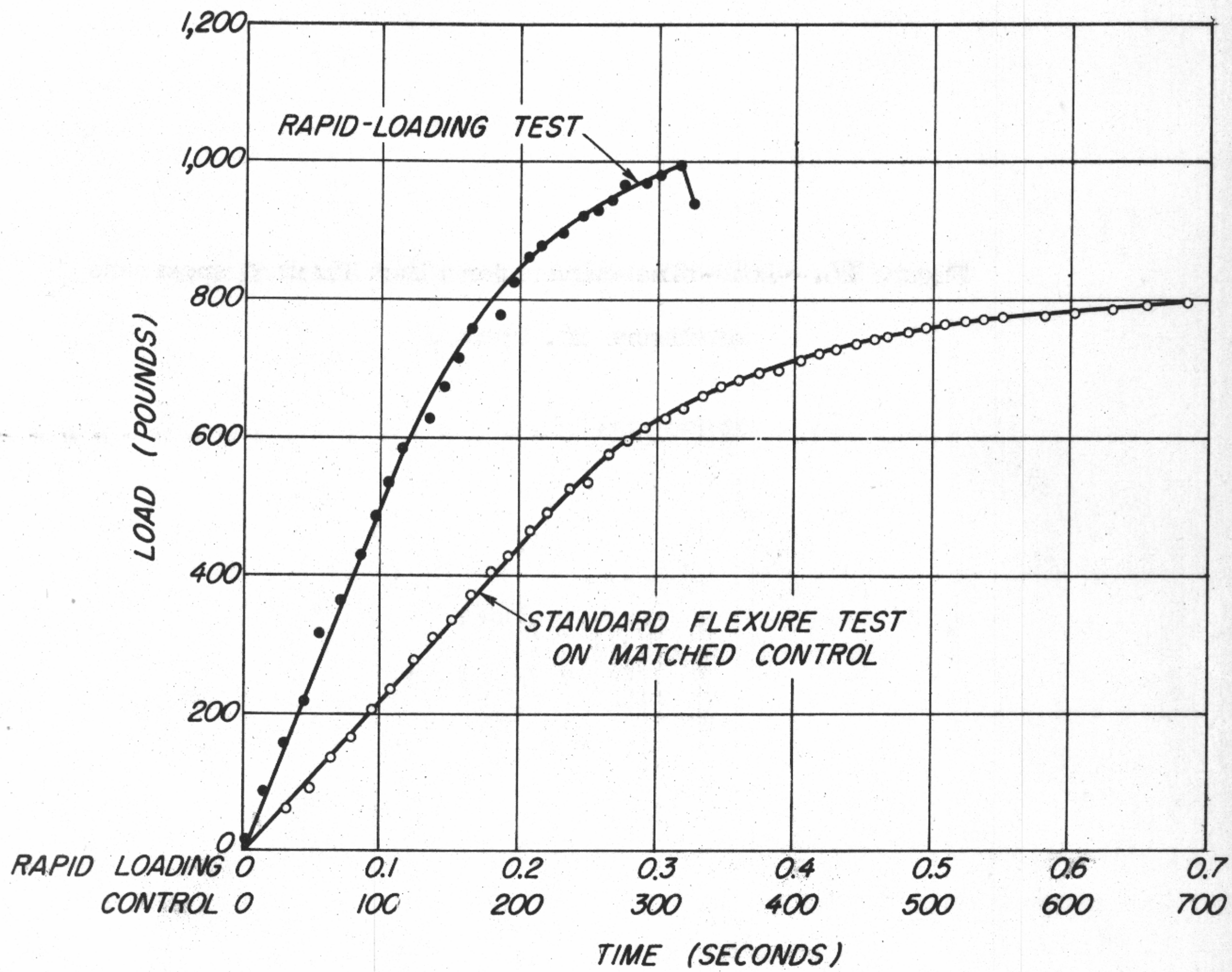

RAPID-LOADING TEST
COMPLETED IN 0.315 SECONDS
STANDARD FLEXURE TEST
ON MATCHED CONTROL
COMPLETED IN 667 SECONDS
LOAD (POUNDS)
1,200
1,000
800
600
400
200
0
0
0.1
0.2
0.3
0.4
0.5
0.6
DEFLECTION (INCH)

Z M 85153 F

Figure 26.--Load-time curves for birch flexure specimens

of figure 18.

(ZM85154F) . . . .

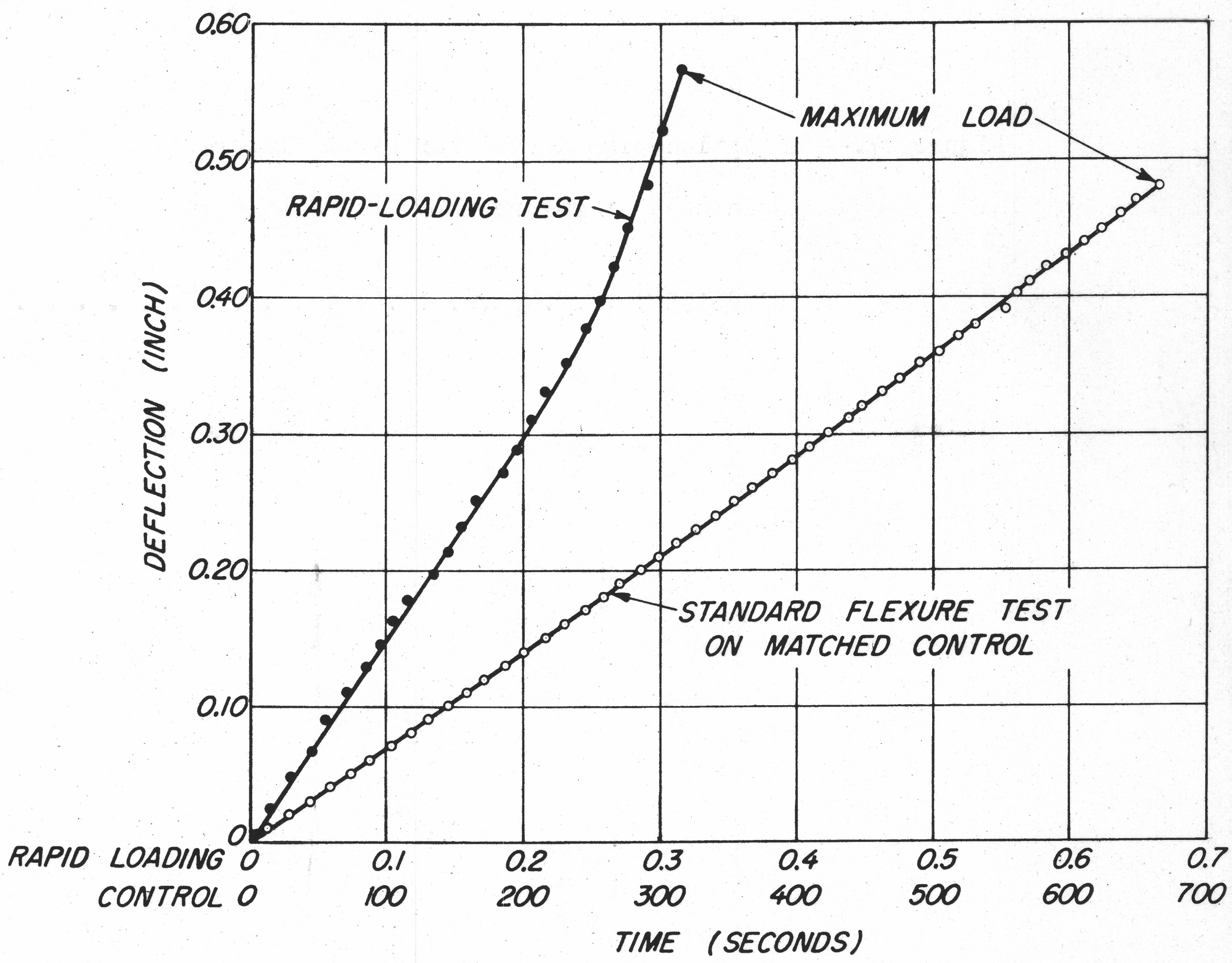


RAPID-LOADING TEST
STANDARD FLEXURE TEST ON MATCHED CONTROL
LOAD (POUNDS)
0
200
400
600
800
1,000
1,200
RAPID LOADING 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7
CONTROL 0 100 200 300 400 500 600 700
TIME (SECONDS)

Z M 85154 F

Figure 27.--Deflection-time curves for birch flexure specimens of figure 18.

(ZM85155F) . . . .



DEFLECTION (INCH)
0.60
0.50
0.40
0.30
0.20
0.10
0
RAPID-LOADING TEST
MAXIMUM LOAD
STANDARD FLEXURE TEST ON MATCHED CONTROL
RAPID LOADING 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7
CONTROL 0 100 200 300 400 500 600 700
TIME (SECONDS)

Z M 85155 F