EFFECT OF TIME OF LOADING
ON SHEAR STRENGTH
OF AIR DRIED DOUGLAS FIR

Thesis by

Richard A. Boettcher

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CONTENTS

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INTRODUCTION

Object of Test

The purpose of this project was the experimental determination of the effect of long-continued shear stress upon the strength of structural timber. By means of a careful test of a limited number of selected timber specimens experimental verification of the commonly assumed relationship between strength and time of loading was sought. Similar verification has been made for the effect of long-continued compressive stress[1] and is indicated for long-continued flexural stress[2]. It was believed that if such a relationship existed for shearing stresses the results of only a comparatively few tests would be sufficient to reveal its presence.

Many codes contain provisions for increasing the allowable stresses on timber structures for loads that will remain on the structure for a short time only. Wind, earthquake and impact loads are specific examples. Ordinarily in designing for wind loads the working stresses may be increased 50 percent provided the resulting structural members are not smaller than those designed for dead and live load alone; and impact stresses may be neglected unless the impact stress exceeds the allowable live load stress. Regarding duration of stress, the "Wood Handbook" of the Forest Products Laboratory of the U. S. Department of Agriculture states:

> "Duration of stress is an important factor in determining the load a timber can safely carry. A beam

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1. "Johnston's Materials of Construction", Chapter VI
2. "Some Results of Dead Load Bending Tests of Timber by Means of a Recording Deflectometer" Harry D. Tiemann; Proc. ASTM, Vol. 9

loaded continuously for several years will break under a force about nine-sixteenths of that necessary to cause failure in a few minutes. If a beam is loaded quickly and the load released immediately, the beam will sustain a proportionately higher load; the increase is approximately 10 percent when the time of carrying the load is reduced to one-tenth of the previous time.

"In compression parallel to the grain failure under long-time loading would be expected to occur at approximately the proportional limit stress as found in a test of short duration. The relation of proportional-limit strength to ultimate crushing strength parallel to the grain as obtained in a standard test of only a few minutes duration is 0.80 for the softwoods and 0.75 for the hardwoods."

In general, a 25% increase in stress is allowable for loads remaining on the structure for 24 hours or less, 50% increase for loads of 5 minutes duration or less, and 100% increase for loads such as impact loads of a duration less than 0.2 seconds.

Another factor which focuses increasing attention on the effect of time of loading on the shearing strength of timber is the growing use of timber connectors. Many wood roof structures using timber connectors were erected during the war due to the shortage of steel for industrial consumption. Since the dead load on a roof is a much higher percentage of the total load than for any other common type of structure more attention must be paid to the time effect when designing such structures. Timber connectors lend themselves admirably to the construction of roof trusses; multiple-piece, divided chords can be used and vertical and diagonal members brought into them and developed fully by means of connectors placed in the faces of the chord and web members at the joint. However, in many cases it is not convenient to bring both the vertical and diagonal into the chord at one point because too wide a joint would result. In this case they are usually brought in at two points along the chord which, depending upon the sizes of the members, may be separated by twelve inches or more. This practice results in excessively high shearing stresses in the chord member. As mentioned before, resulting principally from dead load, these stresses are long-continued, and their effect is aggravated by the common practice of permitting a 50% increase in the allowable unit shear for the design of joint details. Several recent failures of large, timber-connector joined wood trusses have been attributed directly to this cause.

Thus the importance of determining definitely the correlation, if any, between the time of loading and the shearing stress is evident. If there is no reduction in strength due to long-time loading, higher design stresses may safely be allowed. If a definite relationship can be proved to exist, it can be compared with that for compression and flexure upon which the present allowance for the time effect in shear has been based, and the allowance, and consequently the allowable unit shearing stresses, revised accordingly.

Outline of Tests

This test in essential respects was patterned after the tests in compression previously referred to made by Professor J. B. Johnston and reported in his book, "Johnston's Materials of Construction". From each stick of wood used representative specimens amounting to from 15% to 25% of the total were selected and tested in the usual manner to determine the ultimate shearing stress of the material. In this series of tests the specimens and method of applying load were identical with that used later for long-time loading. From the ultimate shearing stresses so determined the dimensions of the long-time test specimens were calculated to give unit stresses of 90%, 80%, 75%, 70%, 60% and 50% of the ultimate with a load of 3000 pounds. An attempt was made to select an equal number of specimens for each load group from each of the four different sticks from which the specimens were obtained. An equal division was not fully realized because the length required for specimens with the lower stresses exceeded the lengths of certain of the pre-cut pieces. Also, after the beginning of the series of long-time tests it was decided to reduce the load to approximately 2500 pounds because of the failure of a number of the specimens upon application of load; this reduced the unit loads to percentages of the ultimate ranging from 40 to 75 percent.

TEST SPECIMENS

Materials

The wood used for this test was air-dried, structural grade Douglas Fir, three pieces of which were obtained from a single source, the fourth piece being obtained from stock on hand in the Materials Testing Laboratory. All four sticks were nominal 2" x 4", surfaced four sides. All pieces were substantially free from knots, checks or shakes; all were reasonably dense and fairly straight grained.

Photographs showing the top, side and end grain of representative specimens of each stick were taken as recommended in the A. S. T. M. Standard Method of Test and are included on the following page.

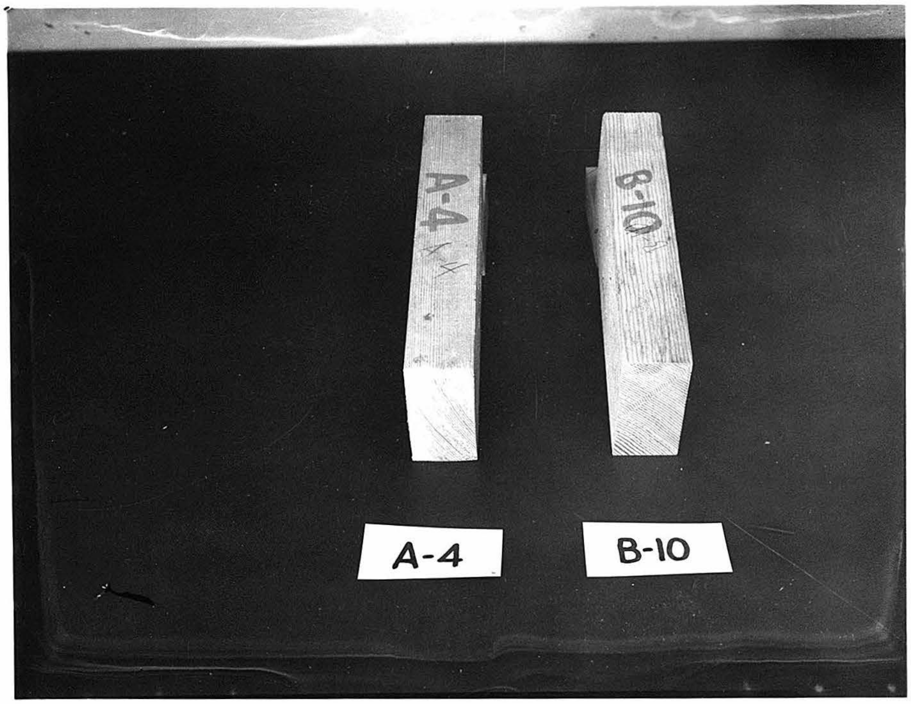
A detailed description of the individual sticks is given in Table III of the Appendix.

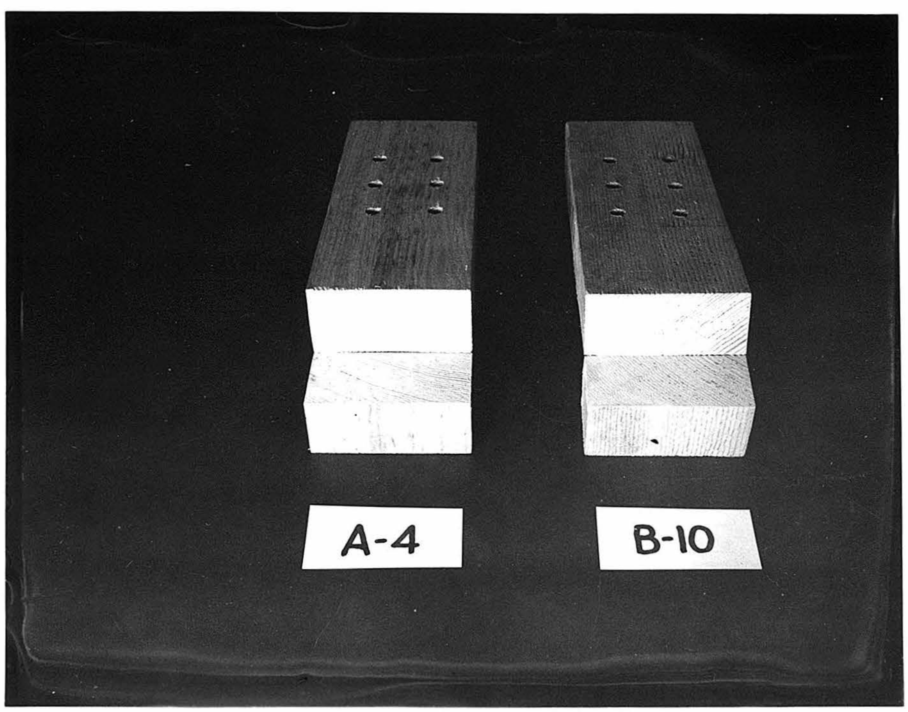
Fabrication

Each specimen, which was identical with every other specimen excepting for the distance below the shear key, consisted of four separate pieces -- the wood specimen itself, two steel side plates which were attached to the specimen by means of six 3/8" bolts, and one 3/4" x 1-1/2" steel shear key. The side plates were drilled with 5/8" holes and the shear keys were fabricated with 5/8" round projections on each side so the specimens could be connected together chain fashion and the same load applied through the chain to each one.

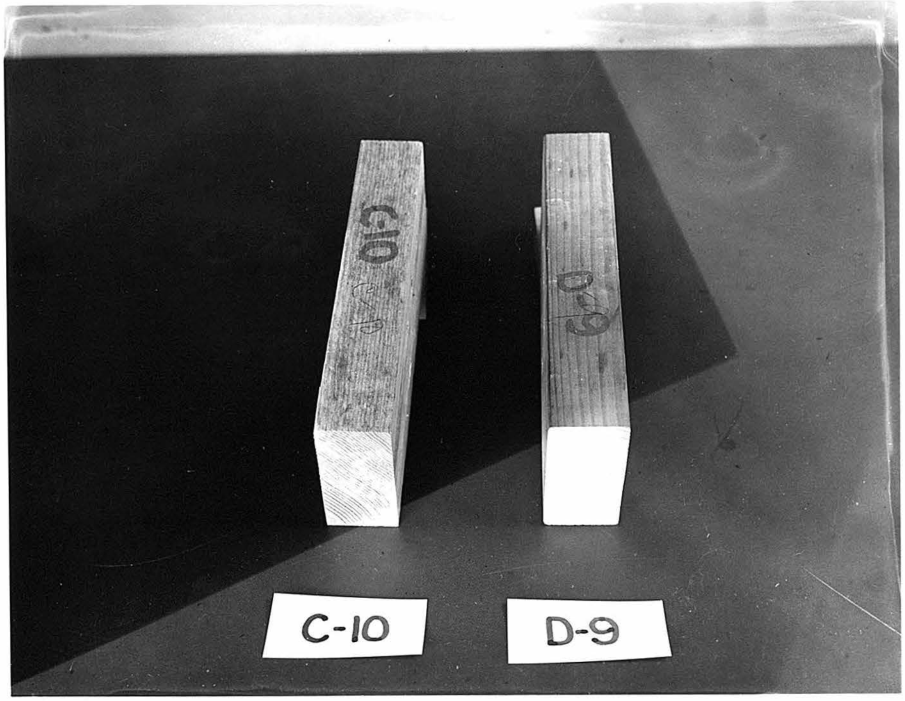
An assembly of a complete specimen is shown in the photograph

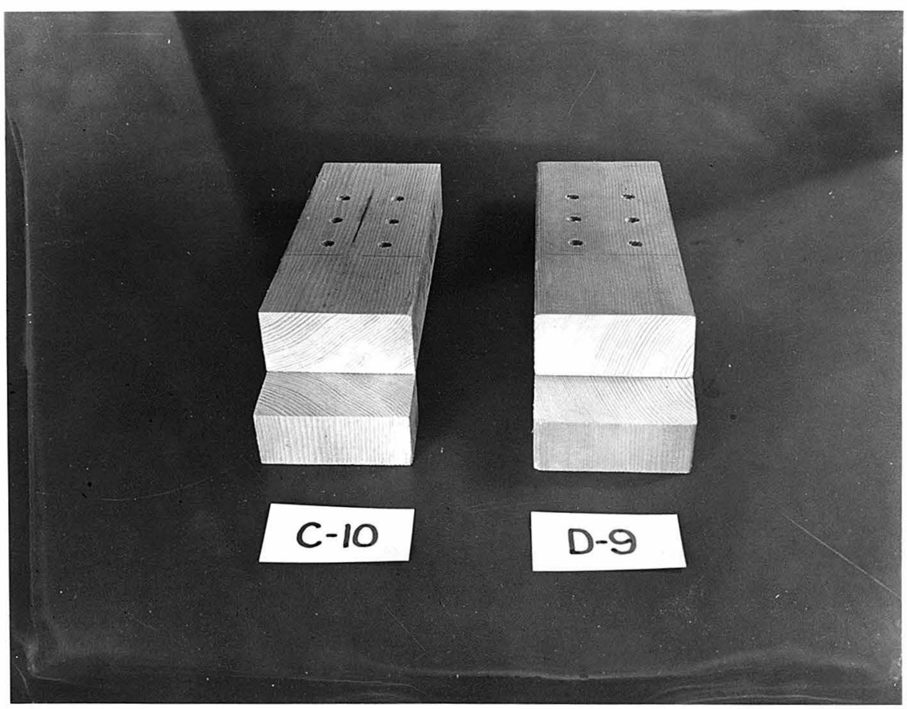
GRAIN PHOTOGRAPHS --- STICKS A & B



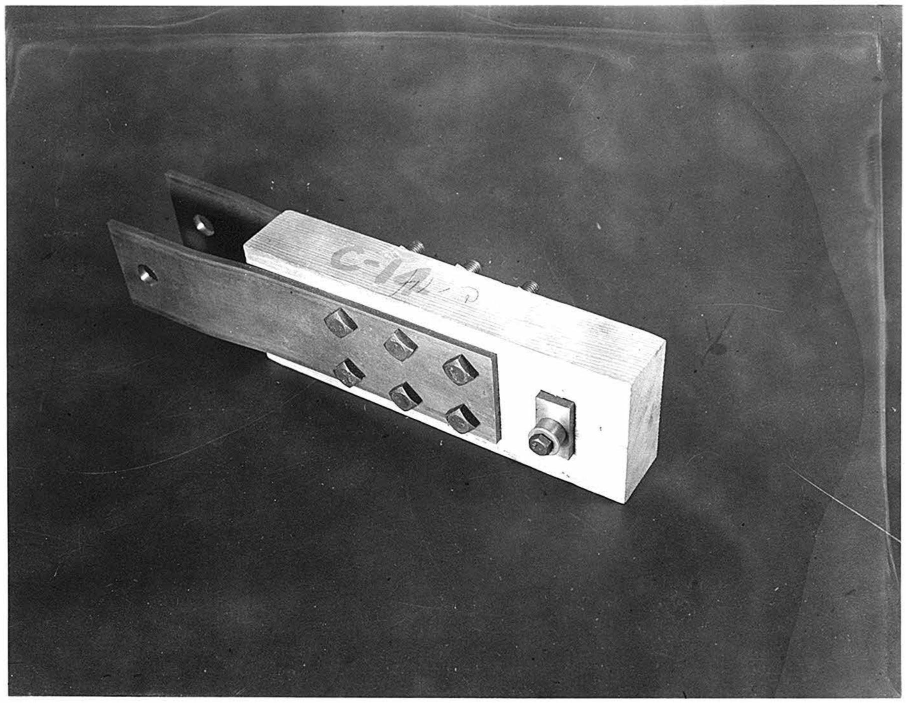


GRAIN PHOTOGRAPHS --- STICKS C & D





below. Details of the parts are shown on Sketch III of the



ASSEMBLED TEST SPECIMEN

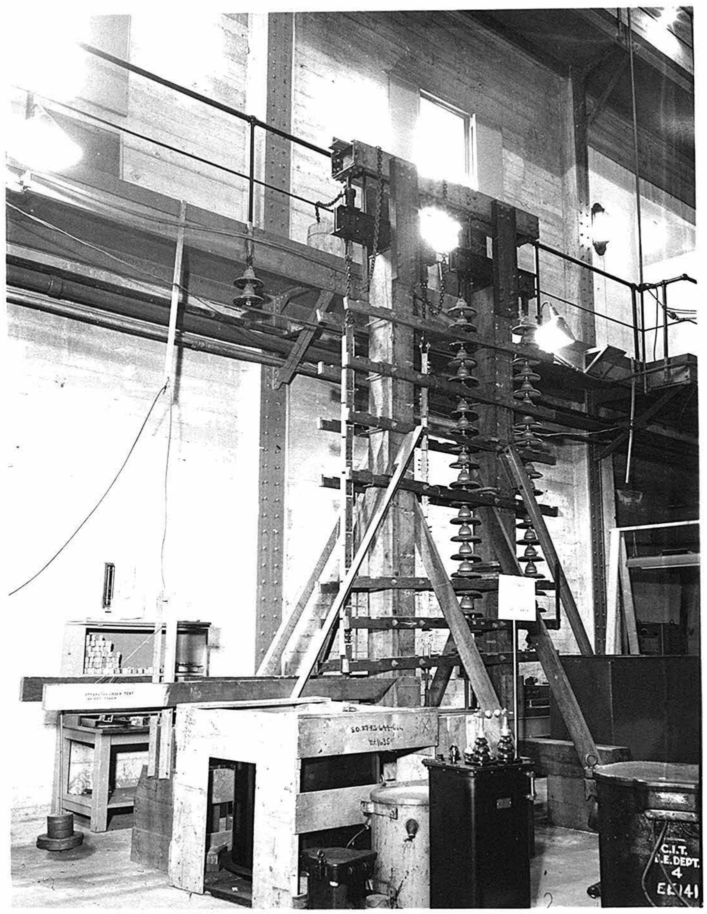
Appendix.

The side plates were accurately laid out and drilled together, twelve or thirteen at a time. The offsets in the side plates were made separately by striking the plate with a heavy hammer while it was clamped in a vise. This gave rise to the possibility of a difference between plates in the distance from the bolt holes to the holes by means of which the specimen was connected to the next specimen in the string. It is probable that the slight eccentricity of loading which resulted from this difference in the length of the straps may explain partially certain inconsistencies in the results obtained

The bolt holes in the specimen were drilled using the side plate as a template. A drill press was used so that the holes would be atright angles to the surface of the specimen, allowing the bolts to be inserted through the specimen and both side plates without difficulty. The 3/4" x 1-1/2" hole for the shear key was a machine-made mortise, using a 3/8" square mortiser. Particular care was taken to obtain a bearing surface for the shear key that was at right angles to the surface of the specimen.

DESCRIPTION OF APPARATUS

The apparatus used to apply long-time load is shown in the photograph below and diagrammatically by Sketches I and II of the Appendix. The latter show the arrangement of specimens in the testing machine and a detail of the testing machine loading beam and weights.



APPARATUS FOR LONG-TIME TEST

This machine was originally designed to test strings of high-voltage, suspension insulators to a maximum dead load of 15,000 pounds. It was equipped with two separate loading beams, one approximately eight and the other about twelve feet in length, by means of which two independent loading tests could be carried on simultaneously. The shorter of the two was used for this test as the loads planned were only in the neighborhood of 2500 to 3000 pounds. This is the left half of the machine in the photograph, which can be seen to be filled with the long-time shear specimens under test. The other half contains a string of insulators which were not removed.

As can be clearly seen in the photograph, the machine consists of two 12" x 12" timber uprights approximately eighteen feet long surmounted by a top-work of structural steel which serves the purpose of tying the two columns together as well as supporting the balancing beams by means of which the load is transferred from one string to the other. The device attached to the top flange of each balancing beam on either end is a dash-pot which acted to prevent the balancing beam from leaving its seat upon failure of the test string. Loose tie rods between the balancing beam and the top-work structure also aided in this respect.

The balancing beam rested on knife edges and all connections between both the balancing beam and the loading beam and the test string were through knife edge connections. Adjusting nuts were provided at the bottom of each string so that the balancing beam and the loading beam could be adjusted to a horizontal position.

Referring again to the photograph, the connection between the balancing beam and the top of the string of specimens can be seen to have been made with a length of 3/8" hoisting chain. This was done to provide flexibility and to allow for continuing the load as specimens failed and were removed from the string. The chain weighed somewhat less than the specimens for a given length, but this was compensated for and the load on the remaining specimens kept constant by increasing the length of the loop of loose chain until the weights of the two strings were equal and the balancing beam in balance under no load.

The electric clock and the knife switch which disconnected the power supply when the beam dropped upon failure of a specimen in the test string can be seen mounted at the top of the loading beam guides in the lower, left-hand corner of the picture. A short piece of light wire rope, adjustable in length connects the loading beam and the knife switch.

The author devised what he considers to be a clever arrangement for indicating whether the time of failure shown by the stopping of the clock was A. M. or P. M. This made it necessary to inspect the test only once a day. The clock glass was removed and through the hole in the face which shows a red tag upon failure of the current supply a small hook of soft copper wire was inserted. The hook projected far enough to engage only the hour hand, the minute hand clearing the end and not disturbing the hook as it passed. Use of the device was as follows: Upon inspecting the test in the evening the hook was pushed to the left of center. When inspecting the test the next day if the clock indicated failure at say 6:30, if the little hook had been pushed to the right the time of failure was 6:30 A. M.; if the hook remained at the left where it had been set the previous evening the time of failure was 6:30 P. M. The device worked dependably and very well.

TEST PROCEDURE

Short-Time Test

The short-time tests were performed to determine the ultimate shearing stress of the material. These tests are summarized in Table IV of the Appendix.

A small Riehle Universal testing machine was used which gave readings to ten pounds. The speed of testing was 0.025 inches per minute which gave a rate of unit deformation of about 0.020 inches per inch per minute, the shear area being roughly 1.25 inches in length. This is in excess of the rate used in the A. S. T. M. Standard Method of Test which is 0.0075 inches per inch per minute, and slightly greater than that recommended as maximum by the Forest Products Laboratory, i. e. 0.150 inches per inch per minute. However, it is also stated that a variation in speed of ± 50% does not affect results more than 2%, so this was not considered a significant factor. Rates of loading were 350-400 pounds per minute between 500 and 1000 pounds and 700-750 pounds per minute between 1500 and 2000 pounds.

The short-time test specimens were tested completely assembled and were identical with the specimens tested under long-time load. Special adapters to the testing machine grips were fabricated to connect onto the ends of the specimens.

All specimens from Sticks A, B and C failed in double shear, except Specimen C-9 which failed in single shear accompanied by secondary splitting of the body of the specimen through the bolt holes. All specimens from Stick D also failed by the latter method. In certain of the double shear failures the planes of failure were not parallel and the wedging action of the sheared section caused slight cracking in the body of the specimen. In others, namely A-6, C-4 and D-4, bending stresses of sufficient magnitude to produce small cracks in the bottom face of the sheared section between the shear planes apparently accompanied the shearing stresses. This also occurred in the long-time test specimens where the distance "d" was small as can be seen from the photographs of Specimens A-1 and B-16 where the sheared section is in two pieces. No evidence of even localized bearing failure under the key was apparent. A bearing test run on the body of failed Specimen C-4 indicated that bearing stresses of almost 7000 psi could be withstood without failure.

In all cases the ultimate shearing stress was calculated using the double shear area. This appears to be logical since both areas are loaded equally up to the point of failure, failure of one resulting before before the other because of slightly lower strength. It was noticed that in the "D" specimens the grain varied across the end of the specimen from 17 rings per inch and 35-40% summerwood at one shear area to about 10 rings per inch and 30-35% summerwood at the other shear area. Failure invariably occurred at the section of lowest percent summerwood.

The shearing strengths obtained by this method were slightly lower than the ultimate shearing strength for air-dried Douglas Fir as given in the "Wood Handbook".

Moisture contents were determined for the sheared wedge as required by the A. S. T. M. Standard Method of Test.

Long-Time Test

The specimens for the long-time test were assembled in two strings of ten specimens each and placed in the testing machine. The load was applied slowly by hooking the weights over the pin in the end of the loading beam and transferring the load gradually to the beam over a period of approximately one minute. The time of loading was recorded. Upon failure, the time of failure, the designation of the specimen failing and its position in the string were recorded. As soon as possible the failed specimen was removed and replaced in the same position in the string by a new specimen, using the bolts, shear key and side plates from the failed specimen. Upon reloading, the time of reloading, the designation of the new specimen and its position in the string were recorded. The total time under load since the previous failure and the time unloaded were then computed. When sufficient failures had occurred so that new specimens were no longer available for replacement, all specimens above the failed specimen were lowered one position by lengthening the chain connecting the top specimen to the balancing beam and the resulting string reloaded. The strings were balanced by increasing the length of the loop of loose chain until the weights of the two strings were equal and the balancing beam in balance under no load.

Prior to applying load to the string each time, the balancing beam was checked to be sure that it was resting properly in its knife edges; the shear keys were centered in each specimen; and the lengths of the strings were adjusted by means of the adjusting nuts at the bottom of each string so that both the balancing beam and the loading beam would be horizontal after the load was applied.

Once each day readings of the wet and dry bulb thermometers and the barometer were taken and the temperature, humidity and atmospheric pressure recorded. As for the short-time specimens moisture content determinations were made on the sheared wedge of the failed specimens.

Specimens were placed in the machine in the following order: First, 90% ultimate stress group -- second, 80% ultimate stress group-- third, 75% ultimate stress group -- fourth, 50% ultimate stress group-- fifth, 60% ultimate stress group -- and last, 70% ultimate stress group. This order was decided upon as a compromise between the desire to obtain results as quickly as possible so as to have some data upon which to base a preliminary report in case failures were greatly prolonged, and the desire to load those specimens whose times of failure were expected to be greatest as soon as possible.

RESULTS AND DISCUSSION

The results of this test were at first quite disconcerting in that a number of failures occurred as the load was being applied, and at a stress much lower than the short-time ultimate. After eight such failures, on April 16, 1947 it was decided to reduce the load to approximately 2500 pounds so that the time effect, if one existed, would have an opportunity of manifesting itself. This reduced load was retained throughout the balance of the test.

Results obtained to date are plotted on Curve I of the Appendix entitled "Effect of Time of Loading on Shear Strength of Air Dried Douglas Fir". The curve for compressive stress obtained by Professor J. B. Johnston is also included on this sheet as an example of the type of correlation originally expected. Obviously, the results of this test show no such definite correlation. However, suppose a curve is drawn as indicated, similar in shape to the compression curve except somewhat lower -- asymptotic to the 50% stress line. In this case two point will fall definitely below the curve. Failure of these two specimens at lower stresses and in shorter lengths of time than anticipated and failure of the thirteen specimens which failed upon application of load might be explained by the supposition of a factor which acted to prevent the equal distribution of load between the two shear areas, possibility eccentricity in the application of the load. However, there are other specimens which required for failure that the load be maintained much longer than would have been anticipated if they followed a curve similar to the compression curve. Three specimens required approximately ten times as long and five others between five and ten times the length of time which could have been predicted for them. No eccentric loading hypothesis will explain this behavior. It might be explained by the variability of the wood specimens themselves or by the variation of the strength of the wood due to changes in its moisture content.

Another factor whose effect must be evaluated, in that it may have an important bearing on the results obtained, is the intermittent loading factor. Chart I of the Appendix entitled "Time Chart of Test" shows clearly the intermittent nature of the load which was unavoidable because of the method of test selected. This was considered carefully before making the decision to proceed with the test, and it was decided that the effect of the intermittent loading on final failure would be negligible. This seems to be borne out by the results of Mr. Harry D. Tiemann's tests in flexure[1] from which he concludes in part:

> "Deflections or recoveries produced by immediate addition or removal of loads up to the elastic limit and probably to the point of first failure are independent of any deflection or recovery due to time effect of dead loads."

However, recovery due to release of load may in some way be responsible for the long lives of the specimens requiring a load duration of many times any predictable value, because, of necessity, the load was removed and reapplied to these specimens oftener than to the others.

Summarizing the results obtained then, in the light of an almost complete lack of correlation between stress and the time required

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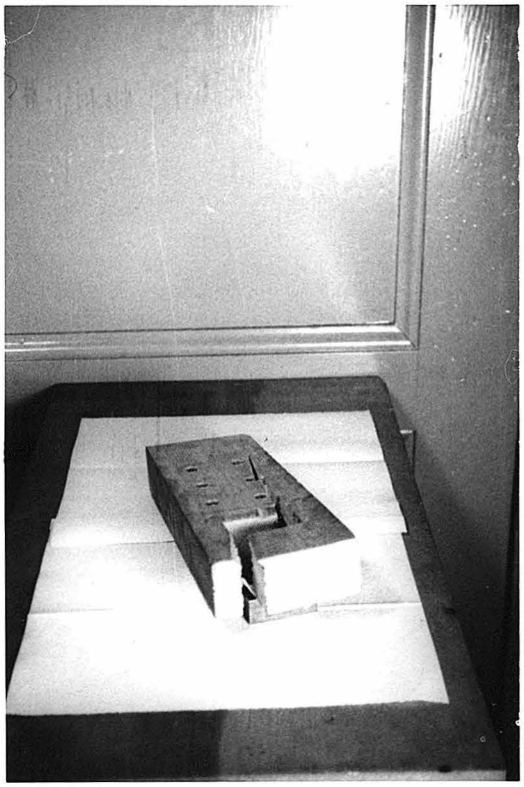
1. Op. cit. 2, intro.

to produce failure, we can say that the time effect, if one exists for shearing stresses, was for all practical purposes obscured by the relatively greater effects of (a) variability of the material, (b) recovery due to intermittent loading, (c) eccentricities of loading or other stress-increasing factors and (d) variation of strength due to variation of moisture content. These factors do not enter as prominently into a compressive test because of the high compressive strength of the material. Variability could be responsible for either an increase or a decrease in the predictable time. The existence of variability in the strength of wood is well recognized and is allowed for in the determination of working stresses by reducing by one-fourth the average ultimate strength values as found from tests of clear wood before applying the factor of safety. However, it is doubted that variability alone could account for the spread in results that was obtained. Recovery due to load removal could be responsible only for an increase in the predictable time. Eccentricities of loading and other stress-increasing factors could be responsible only for a decrease in the predictable time. Every attempt was made in the fabrication of the specimens to avoid introducing stress-increasing factors, and it is known that a much greater degree of care was taken than the designer can ordinarily rely on being taken in the fabrication of an actual structure from his design; but it is entirely probable that these factors entered to a certain extent. The effect of eccentricity introduced by the side plates conceivably might be evaluated by correlating premature failures with their position in the test string. No such correlation could be obtained. Variation in strength due to variation in moisture content could be responsible for either an increase or a decrease in the predictable time. The atmospheric conditions of the test were recorded to enable an evaluation of this factor to be made and are plotted on Chart III entitled "Chart of Atmospheric Conditions of Test" in the Appendix. While the humidity shows considerable variation its effect on the moisture content of the specimens is small, and the effect of the moisture content variation which results is negligible. In general, the moisture contents decreased 1 - 2 % between the short-time test and the completion of the long-time test. Conversion to the standard air-dried moisture content of 12% by the method recommended in the "Wood Handbook", page 62, gave only a 1 - 2% decrease in strength. It is believed that conversion of stresses to a constant moisture content would be inconsistent with the nature of the test and the degree of accuracy obtainable in measurements from which stresses are calculated.

At the time of writing this report twelve specimens are still under load -- C-11, stressed to somewhat over 60% of the short-time ultimate for almost 550 hours; C-16, stressed to just under 60% of its short-time ultimate for over 500 hours; five specimens from Sticks C and D stressed to about 50% of their short-time ultimate for between 530 and 550 hours; and five specimens from Stick B stressed to over 40% of their short-time ultimate for about 540 hours. A dial indicator attached to the loading beam shows that no further deflection is taking place which suggests that the load may be sustained indefinitely, if the specimens do not increase in moisture content.

PHOTOGRAPHS OF TYPICAL FAILURES

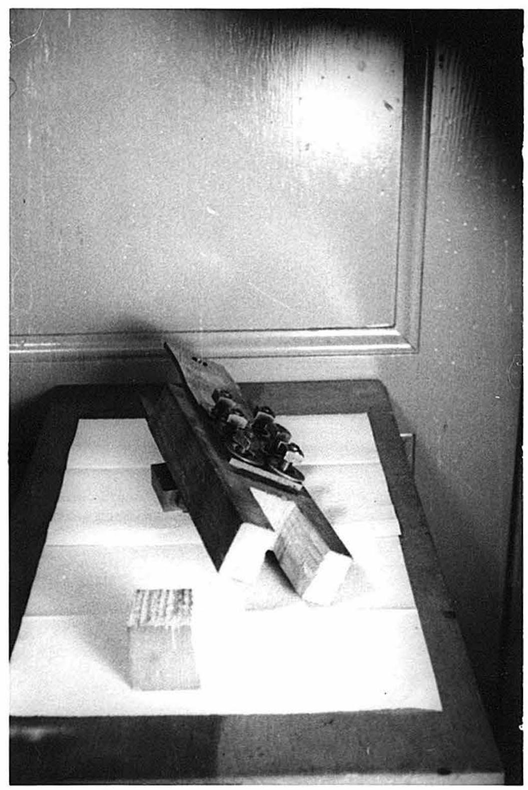


Left -- SPECIMEN C-5

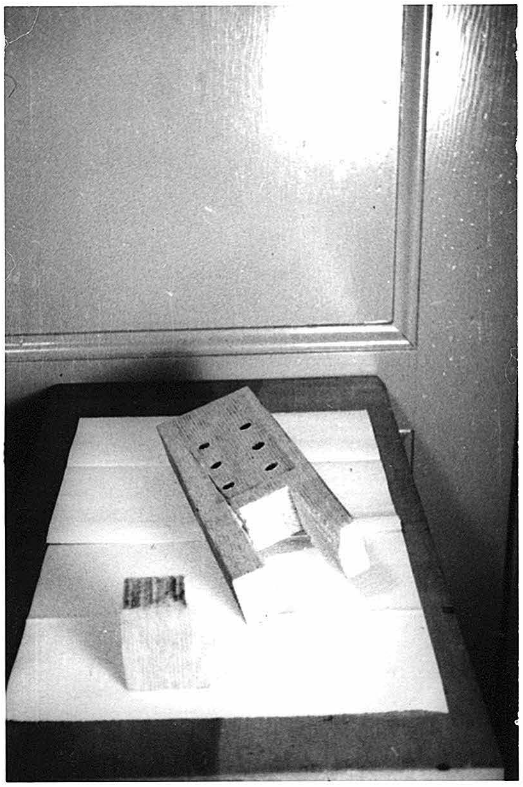
Accidental failure; similar to single shear failure with secondary cracking thru bolt holes.

Right -- SPECIMEN D-3

Typical double shear failure.

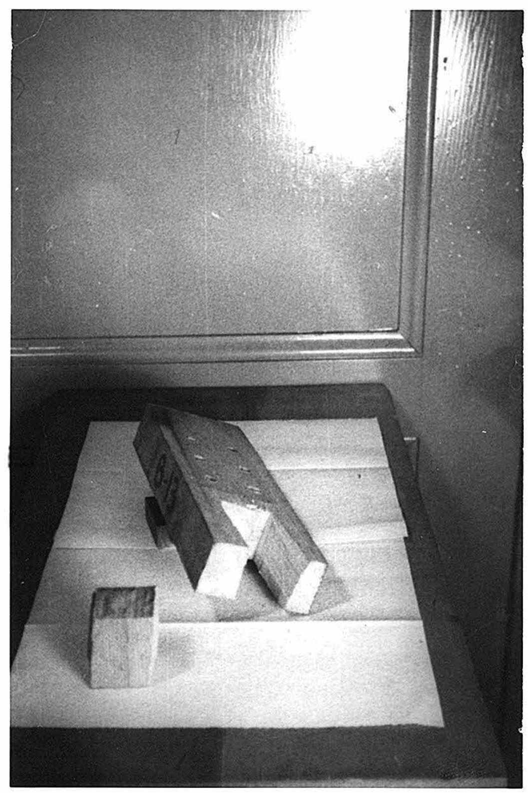


PHOTOGRAPHS OF TYPICAL FAILURES



Left -- SPECIMEN B-7

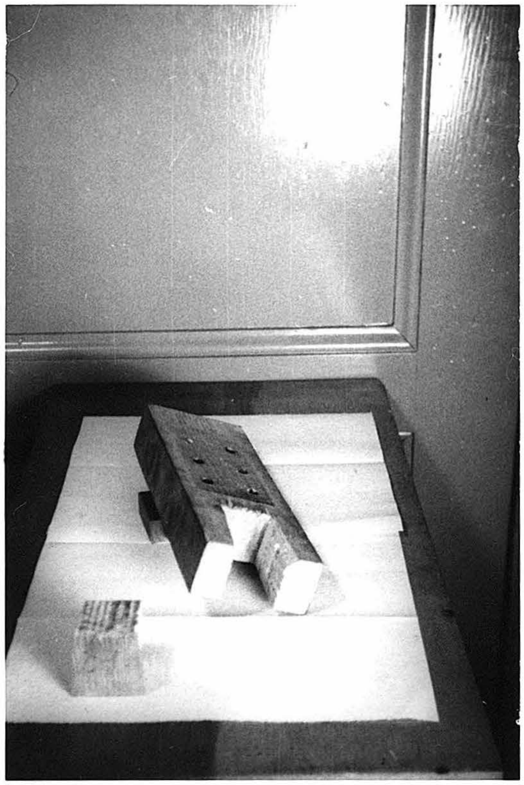
Double shear failure with secondary cracking of body of specimen due to wedging of sheared key.



Right -- SPECIMEN B-13

Typical double shear failure.

PHOTOGRAPHS OF TYPICAL FAILURES

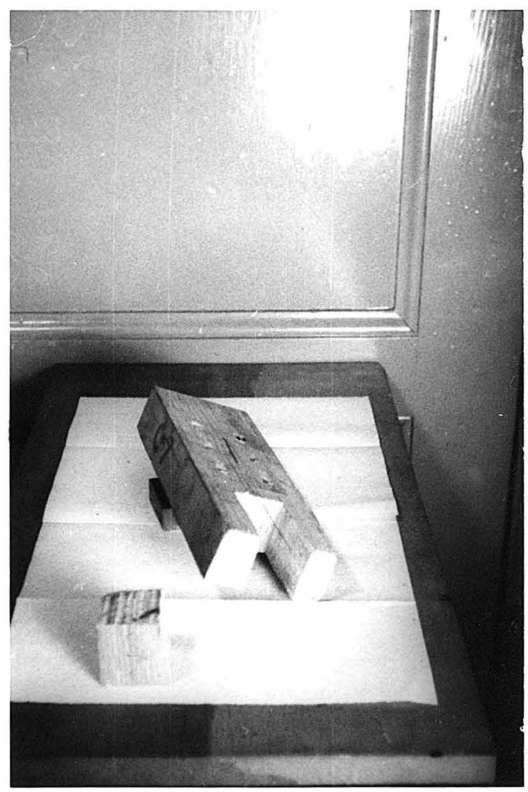


Left -- SPECIMEN C-1

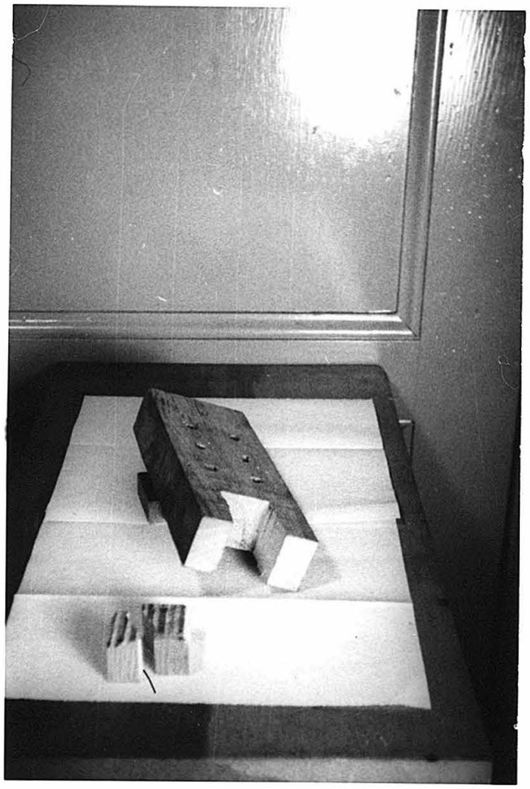
Typical double shear failure. Roughening of right shear plane due to wedging of steel shear key.

Right -- SPECIMEN C-7

Typical double shear failure.

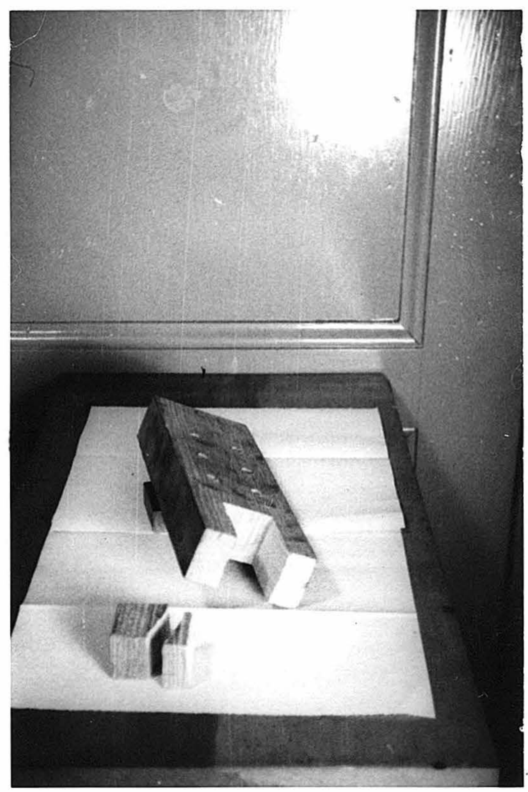


PHOTOGRAPHS OF TYPICAL FAILURES



Left -- SPECIMEN A-1

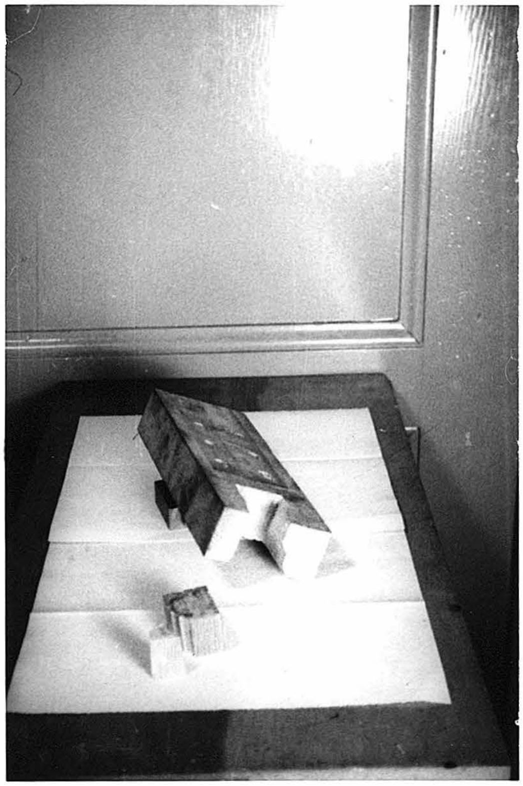
Typical double shear failure with splitting of sheared wedge.



Right -- SPECIMEN A-4

Typical double shear failure with splitting of sheared wedge.

PHOTOGRAPHS OF TYPICAL FAILURES

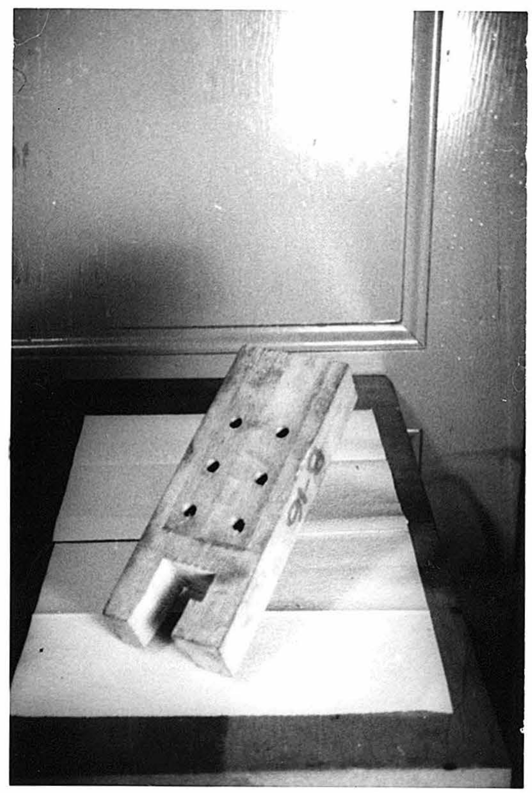


Left -- SPECIMEN B-16

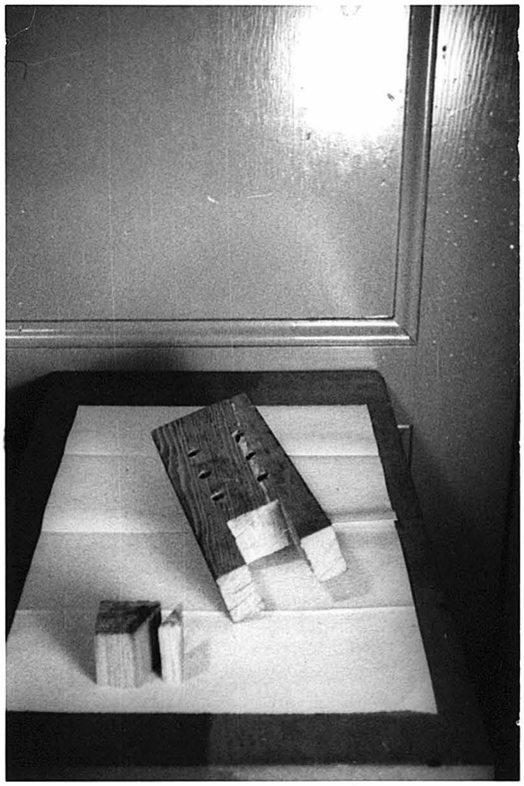
Unusual double shear failure with cracking of sheared wedge.

Right -- SPECIMEN B-16

Note that right shear plane is not continuous with edge of mortised hole.



PHOTOGRAPHS OF TYPICAL FAILURES

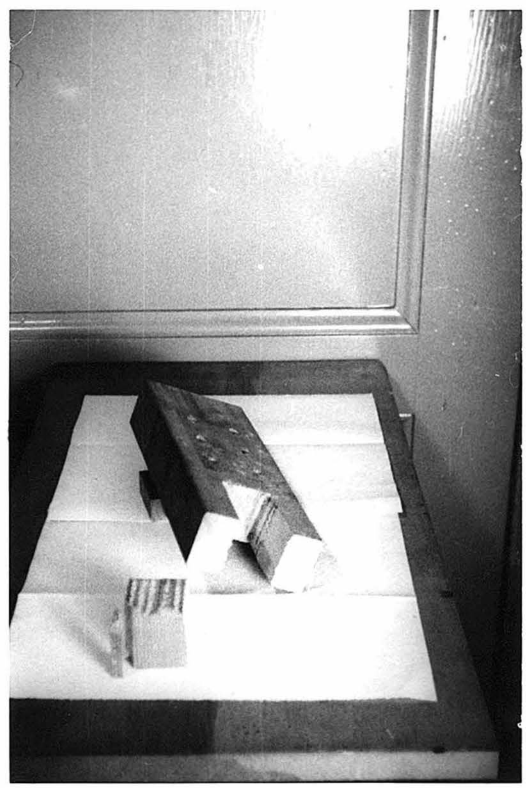


Left -- SPECIMEN A-7

Typical double shear failure with splitting of sheared wedge. Note pitch pocket; splitting of wedge occurred thru pitch pocket.

Right -- SPECIMEN D-9

Typical double shear failure.



CONCLUSIONS

1. The results of this test neither proved conclusively nor disproved the existence of a relationship between shear strength and time of loading comparable to that for compressive strength.

2. Because of the relatively, very low strength of wood in shear, other factors assumed greater importance and combined to obscure the effect of time of loading.

3. Variability appears to be of greater importance than any other factor in the shear strength of wood. Any increase in allowable shear strength values, such as the 50% increase sometimes recommended in the design of joint details, should be made only when the analysis is rigorous and with due consideration for the effect of variability in causing a failure which would result in personal injury or large property damage.

SUGGESTIONS FOR FURTHER STUDY

Further study will be required if the relationship between strength and time of loading is to be verified for shearing stresses. From the accumulated experience to date the following avenues of procedure and investigation can be suggested as offering the most promising possibilities of results.

1. Effect of Variability -- A possible experiment to determine the effect of variability on the strength of the actual specimens used in the tests for which these results are reported is as follows: All of the failed specimens have been retained. These could be turned end-for-end and a 3/4" x 1-1/2" slot for the steel shear key mortised in the opposite end, as the closest bolt holes are 2-5/8" from the end. The side plates could be attached using only four bolts and a string of specimens built up similar to the original string. This string could be tested to failure in the dead load tester, applying increasing load to the end of the loading beam by means of a spring balance or some similar arrangement.

2. Variation of Stress Under Shear Key -- Time did not permit an analysis of the deflections of the specimen under the shear key to determine the relative magnitudes of the deflections due to shear and those due to flexure. (There should be little distortion due to bending of the key itself as it was selected with a section modulus equivalent to that of a bolt of such a diameter that no load reduction would be required because of the low L/d ratio.) Such an

analysis would give a picture of the distribution of load under the shear key and might be helpful in evaluating stress concentrations.

3. Future Long-Time Tests -- If another series of long-time tests is to be made, it is suggested that the steel side plates be stencilled so that they can be kept in pairs, and that each pair be aligned by bolting together and reaming through the 5/8" holes slightly oversize. Particular attention should be paid to the fabrication of the wood specimens -- the bolt holes should be drilled in the drill press with a side plate clamped to the specimen as a template; the mortised hole should be made with the utmost care to insure uniform bearing for the shear key.

SUMMARY OF TIME SPENT

	Hours
Preliminary study and discussion	9
Investigation of shop and laboratory facilities	4
Design of specimen and apparatus	6
Shop work	
Machine Shop	22
Wood Shop	12
Testing	
Short-time Test	9
Long-time Test	
Set up equipment	16
Testing	30
Photography	10
Analysis and discussion of results	8
Write-up	25
Total	151

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Johnston's Materials of Construction, Chapter VI

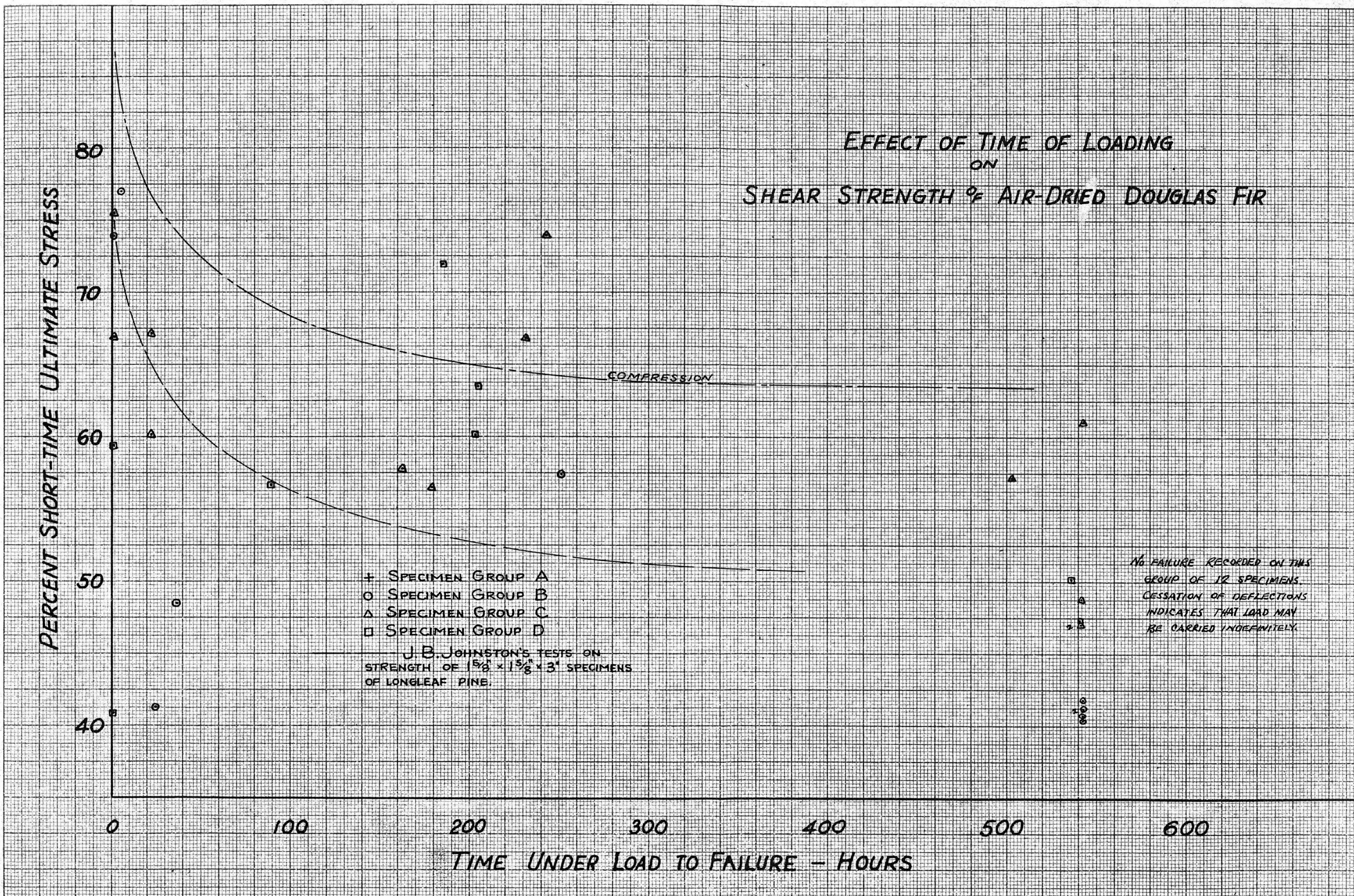
Wood Handbook -- Forest Products Laboratory of U. S. Department of Agriculture

Forest Service Tests to Determine the Influence of Different Methods and Rate of Loading on the Strength and Stiffness of Timbers -- McGarvey Cline; Proc. A.S.T.M., Vol. 8, p.535

The Effect of the Speed of Testing Upon the Strength of Wood and the Standardization of Tests for Speed -- Harry D. Tiemann; Proc. A.S.T.M., Vol. 8, p.541

Standard Methods of Testing Small, Clear Specimens of Timber. A.S.T.M., D-143 27

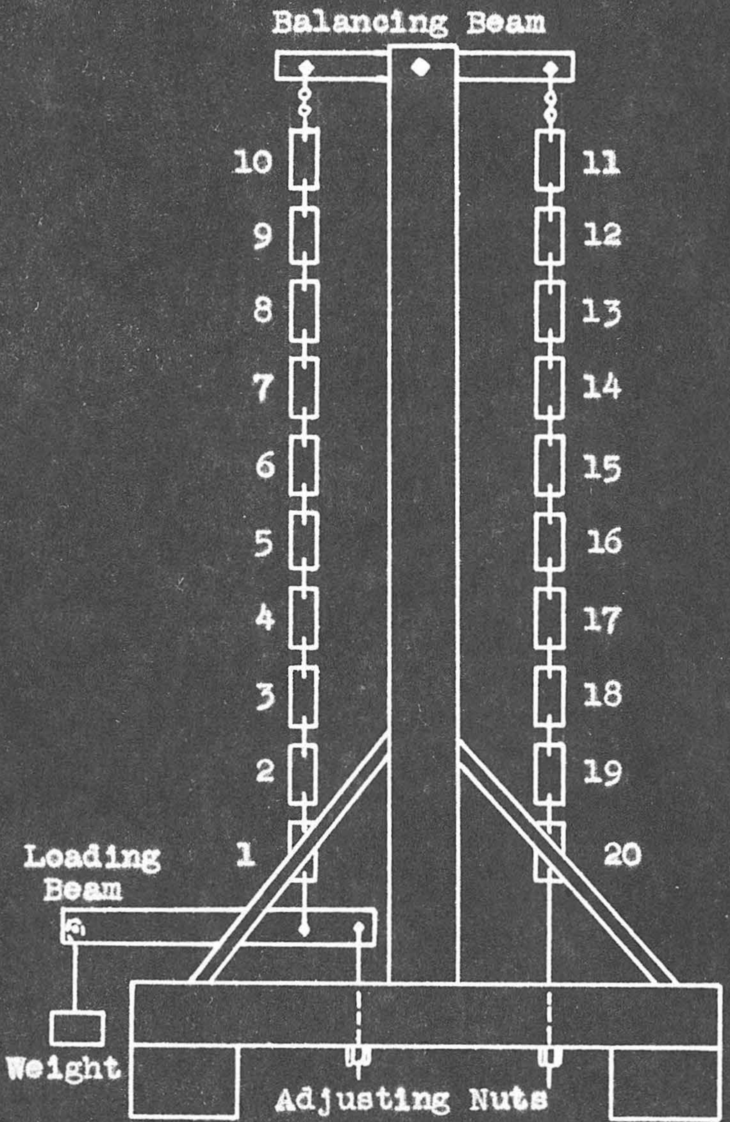
Some Results of Dead Load Bending Tests of Timber by Means of a Recording Deflectometer -- Harry D. Tiemann; Proc. A.S.T.M., Vol. 9, p. 534



EFFECT OF TIME OF LOADING
ON
SHEAR STRENGTH OF AIR-DRIED DOUGLAS FIR
PERCENT SHORT-TIME ULTIMATE STRESS
80
70
60
50
40
0
100
200
300
400
500
600
TIME UNDER LOAD TO FAILURE - HOURS
COMPRESSION
+ SPECIMEN GROUP A
o SPECIMEN GROUP B
△ SPECIMEN GROUP C
□ SPECIMEN GROUP D
J. B. JOHNSTON'S TESTS ON STRENGTH OF 1 5/8" × 1 5/8" × 3" SPECIMENS OF LONGLEAF PINE.
NO FAILURE RECORDED ON THIS GROUP OF 12 SPECIMENS. CESSATION OF DEFLECTIONS INDICATES THAT LOAD MAY BE CARRIED INDEFINITELY.

SKETCH I

ARRANGEMENT OF SPECIMENS IN TESTING MACHINE
SHOWING POSITION DESIGNATIONS



Load on String -- 2409#
Ave. Wt. of Specimen -- 5#

Location In String	Load - Lbs.
1-20	2409
2-19	2414
3-18	2419
4-17	2424
5-16	2429
6-15	2434
7-14	2439
8-13	2444
9-12	2449
10-11	2454

NOTES:

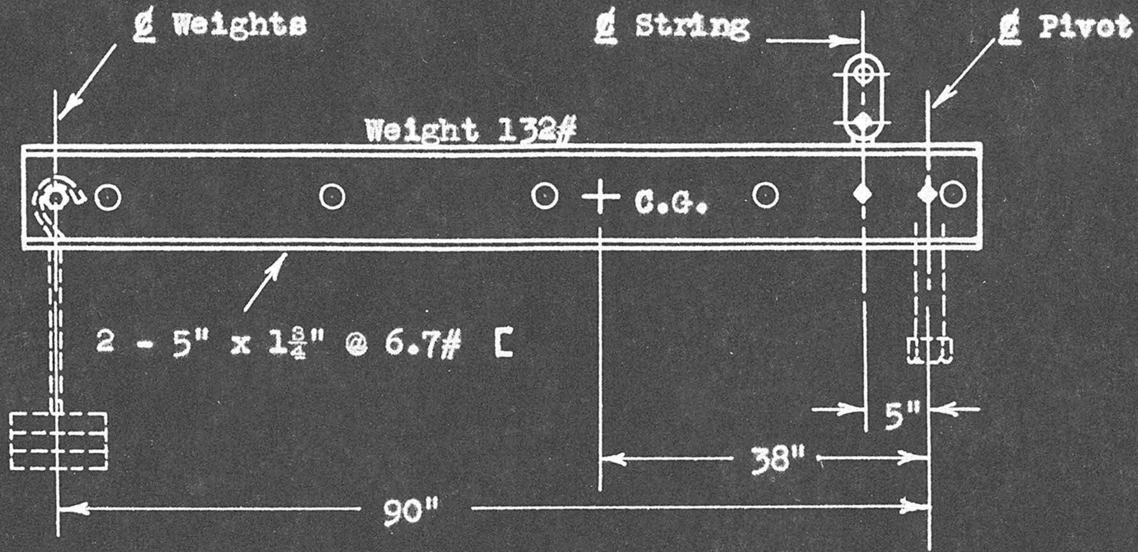
1. Where specimen is moved from its initial position because of failure of intermediate specimens, the average of the loads corresponding to its initial position and its position at time of failure is taken as the load for stress computation purposes.

2. Chain weight approx. 3 #/ft. When string lowered, length of chain loop adjusted to balance string and maintain equal loads. (See photograph of apparatus.)

SKETCH II

DETAIL OF TESTING MACHINE LOADING BEAM & WEIGHTS

LOADING BEAM:



Notes: 1. C.G. determined by balancing.
2. Weight of 132# includes beam, 2 square knife edges with cotter pins, three links and bolt.
3. All dimensions to closest 1/16".

WEIGHTS:

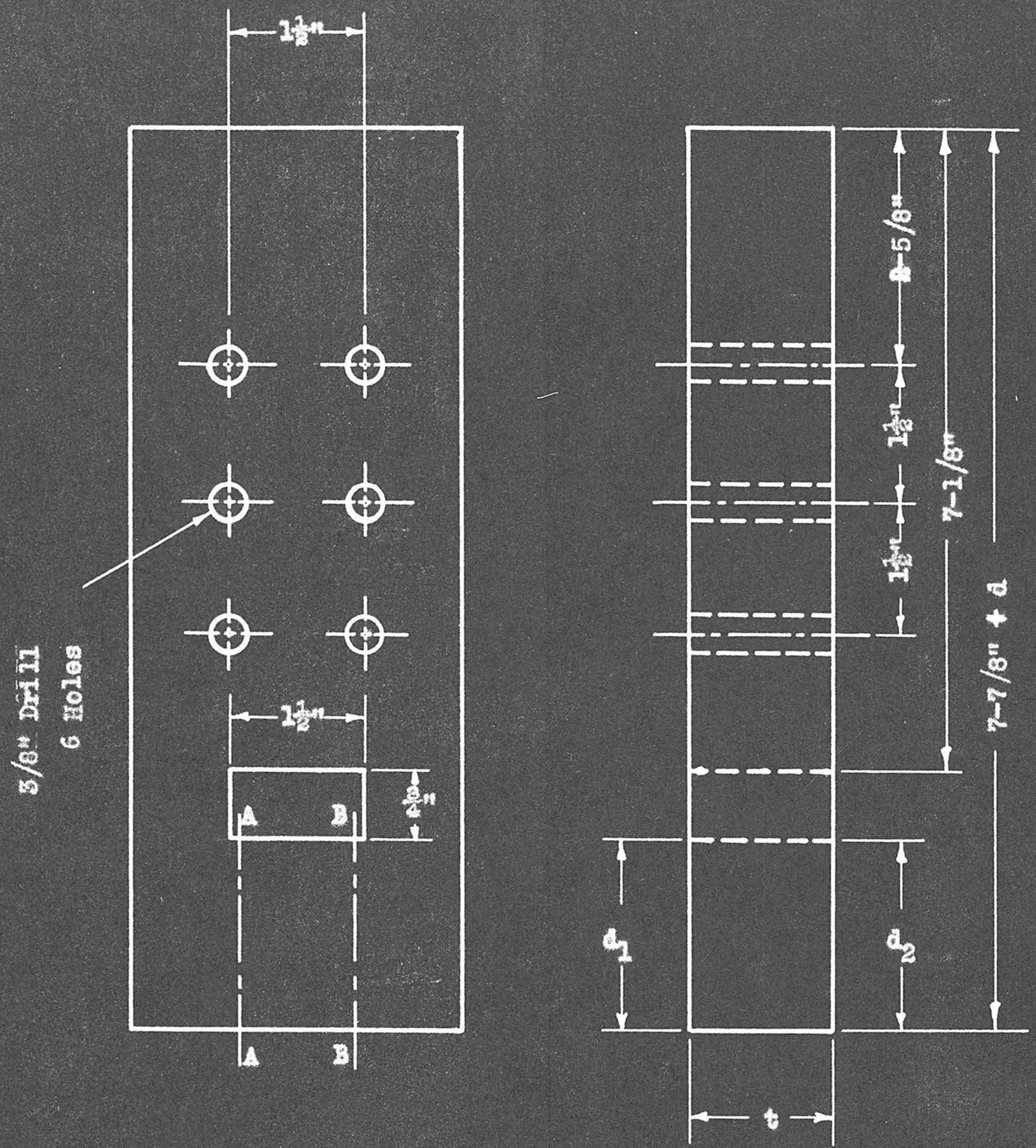
Hook and Platform for Weights	6.72 #
Large Disc #1	22.08
Large Disc #2	22.30
Large Weight #1	9.60
Large Weight #2	9.86
Small Weight #1	3.78
Small Weight #2	3.76
Total	78.10 #

Note: Weights in pounds and hundredths stenciled on weight.

LOAD ON STRING:

Effect of Beam Weight -- $P_{Beam} = \frac{132 \times 38}{5} = 1003\#$

Total Load -- $P_{Total} = 1003 + 78.1 \times 90/5 = 2409\#$



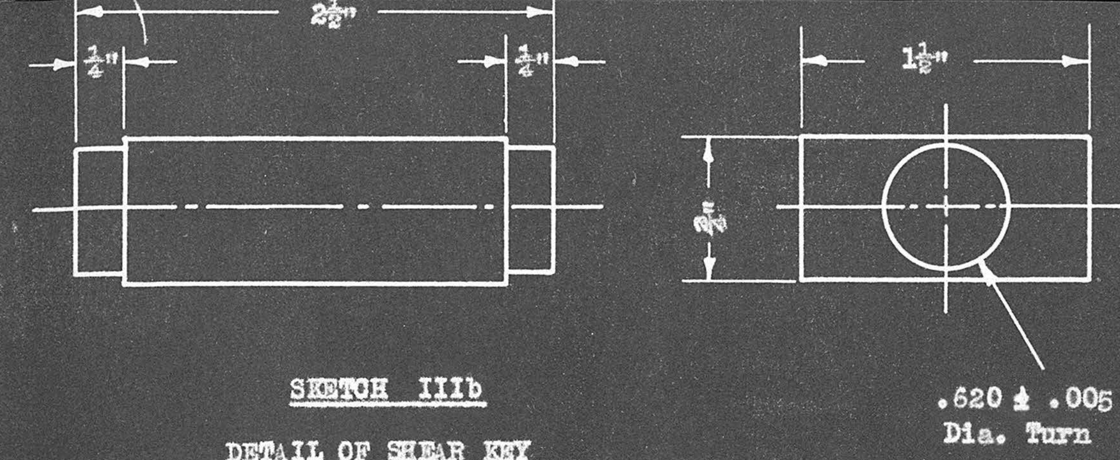
NOTES: 1. Dimensions d_1 and d_2 are approximately equal. This dimension is, however, variable between specimens so that different stresses will result with a given load on the test string.

2. Dimensions d_1, d_2 and t measured to closest 0.01" at Sections AA and BB for computation of double shear area.

SKETCH IIIa

DETAIL OF SPECIMEN

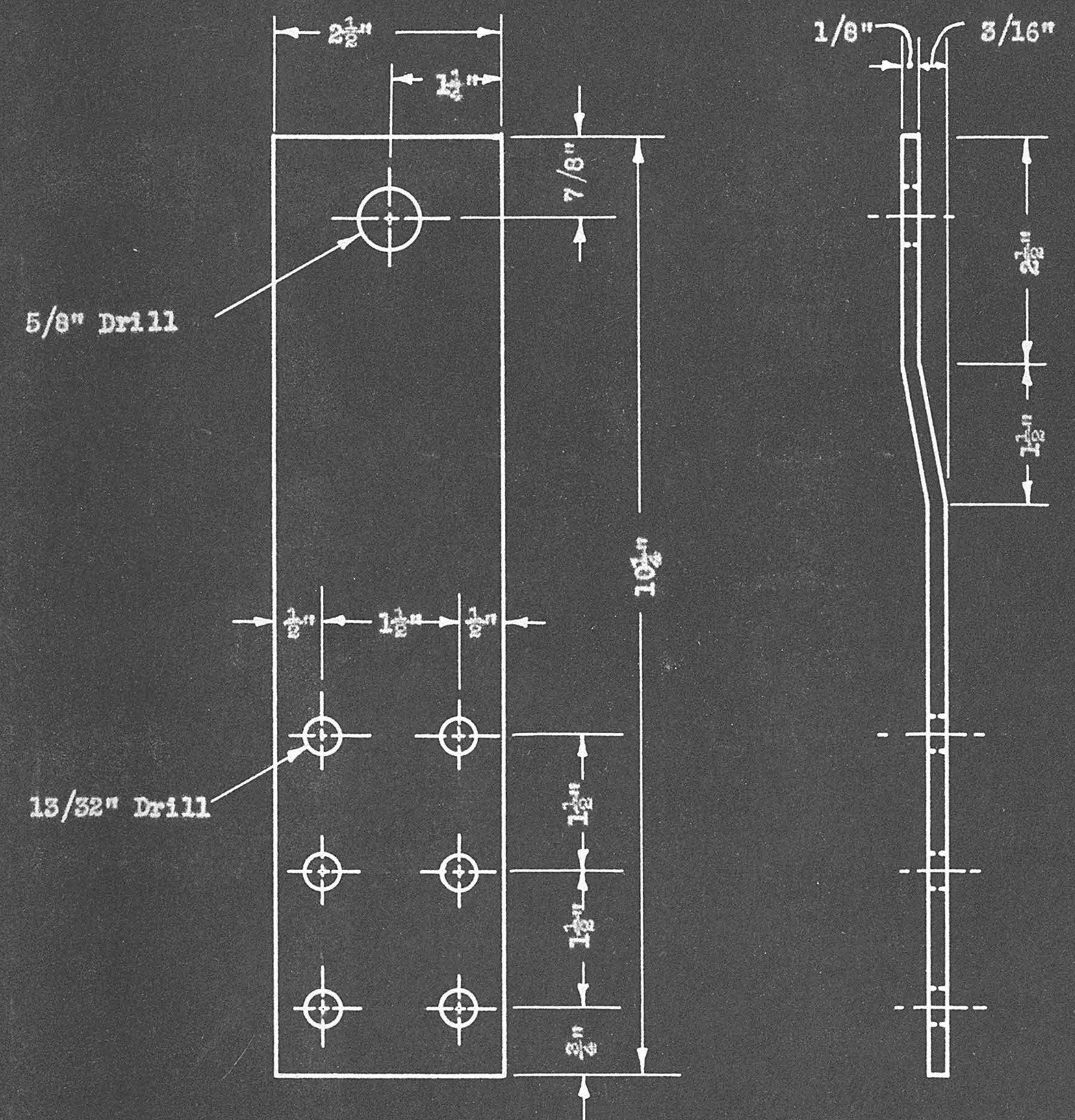
Material: 2" x 4" S4S Structural Douglas Fir (Air Dried)
No. Required: 56



SKETCH IIIb

DETAIL OF SHEAR KEY

Material: ¾" x 1½" Steel Bar Stock
No. Required: 20



SKETCH IIIc

DETAIL OF SIDE PLATES

Material: 1/8" x 2½" Steel Strap No. Required: 40

<u>CHART I</u>

<u>TIME CHART OF TEST</u>

Sheet 1 of 7

This chart provides a continuous record of the time-loading test.

Time scale — 1/8" = 1 hour

Shaded portion indicates time under load; unloaded time denoted by unshaded portion. These times are given in hours and minutes.

At the beginning and end of each period of loading actual times are indicated.

Corresponding to each failure the number of the specimen failing and the number of the specimen replacing it in the test string are given.

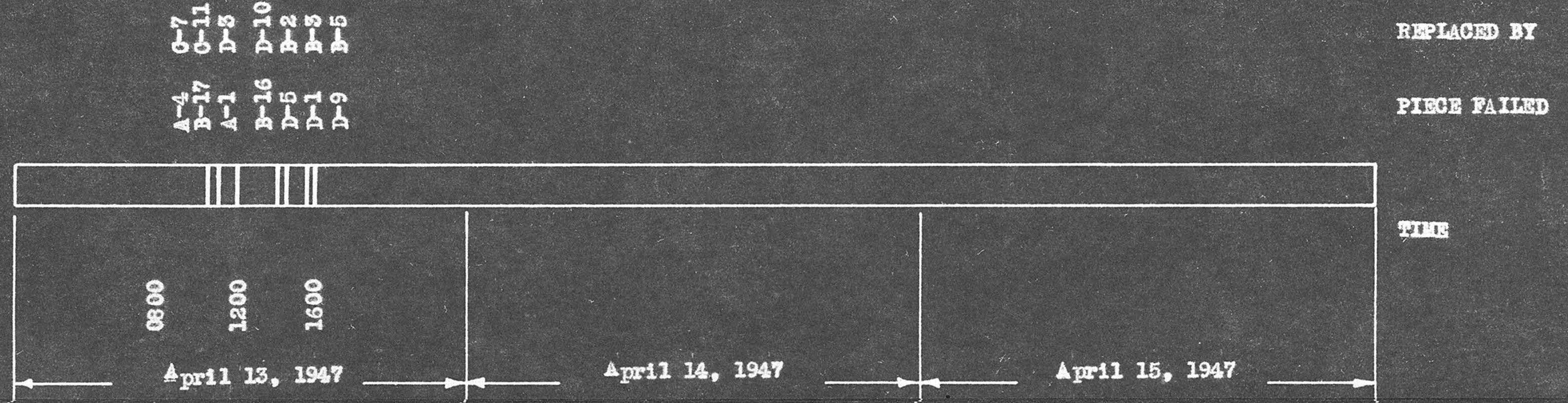


CHART I

TIME CHART OF TEST

Sheet 2 of 7

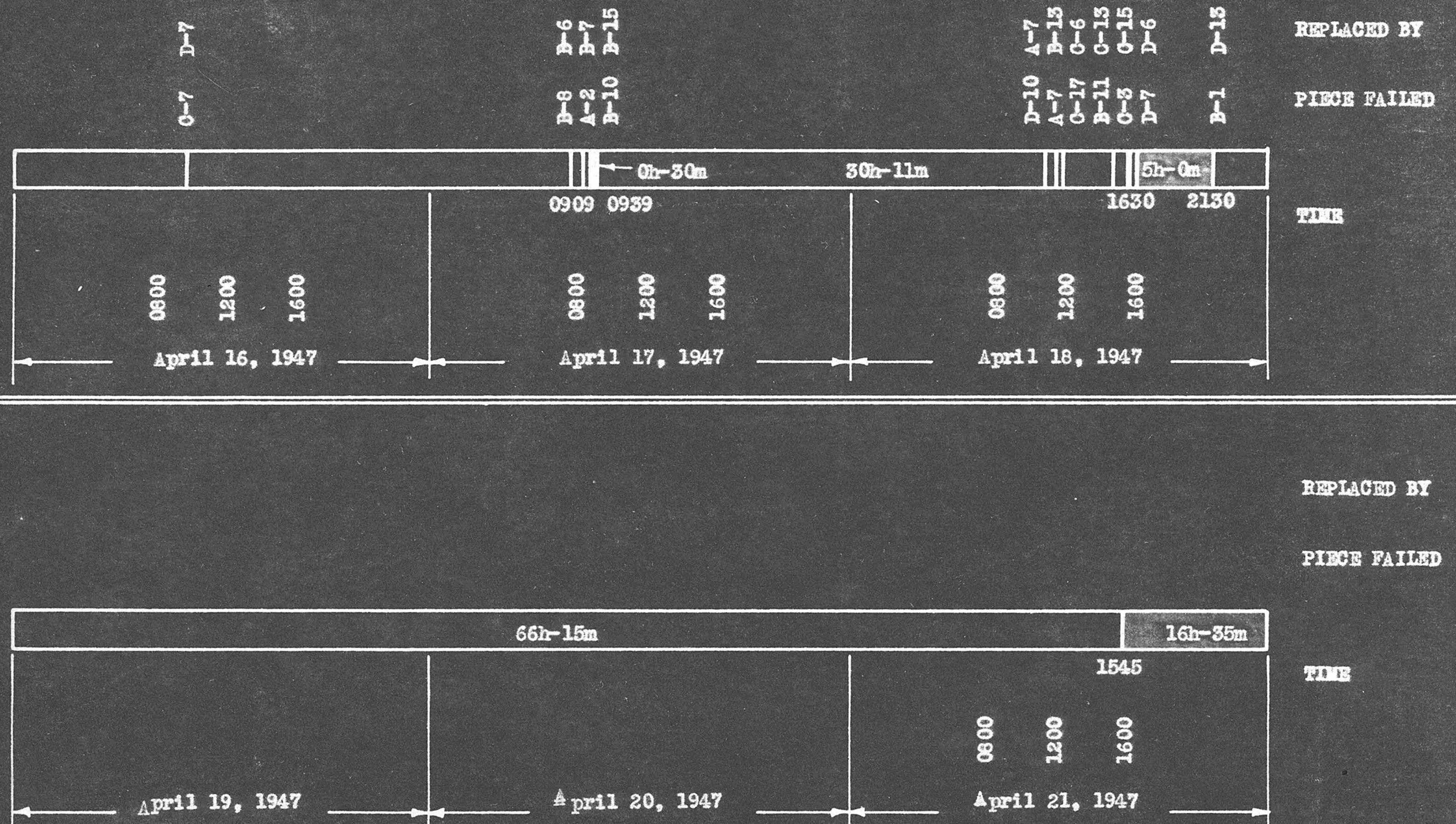


CHART I

TIME CHART OF TEST

Sheet 3 of 7

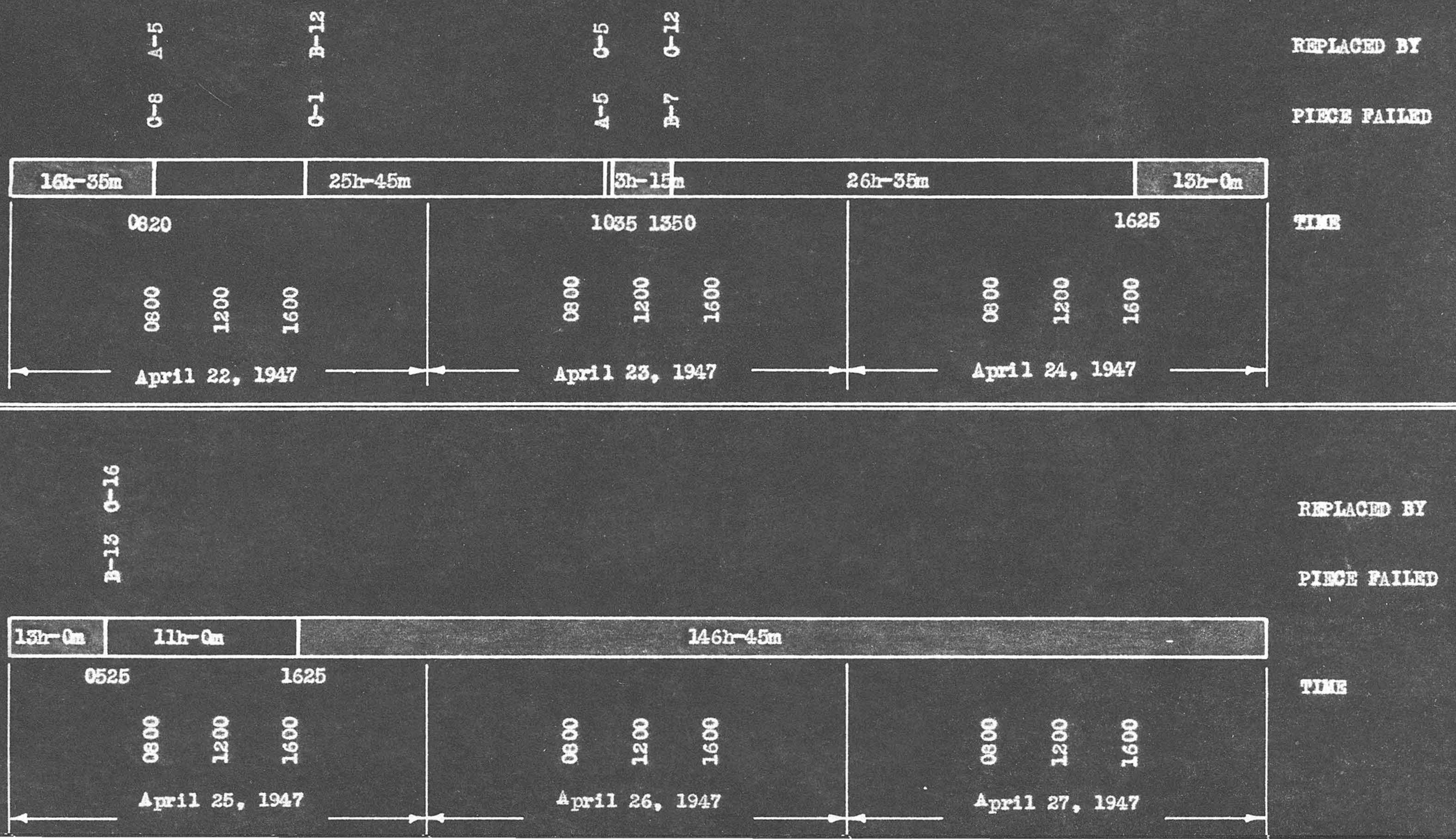


CHART I

TIME CHART OF TEST

Sheet 4 of 7

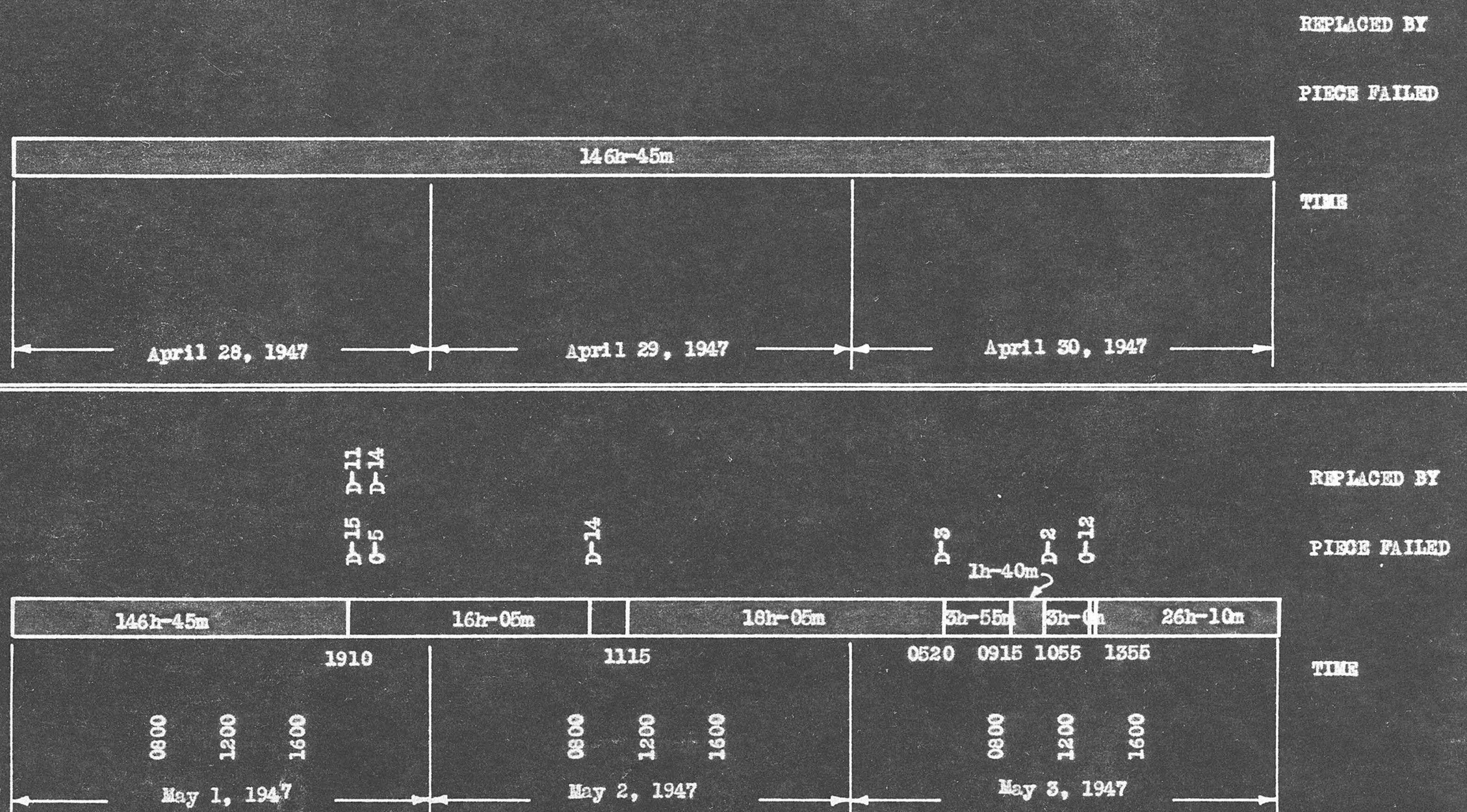


CHART I

TIME CHART OF TEST

Sheet 5 of 7

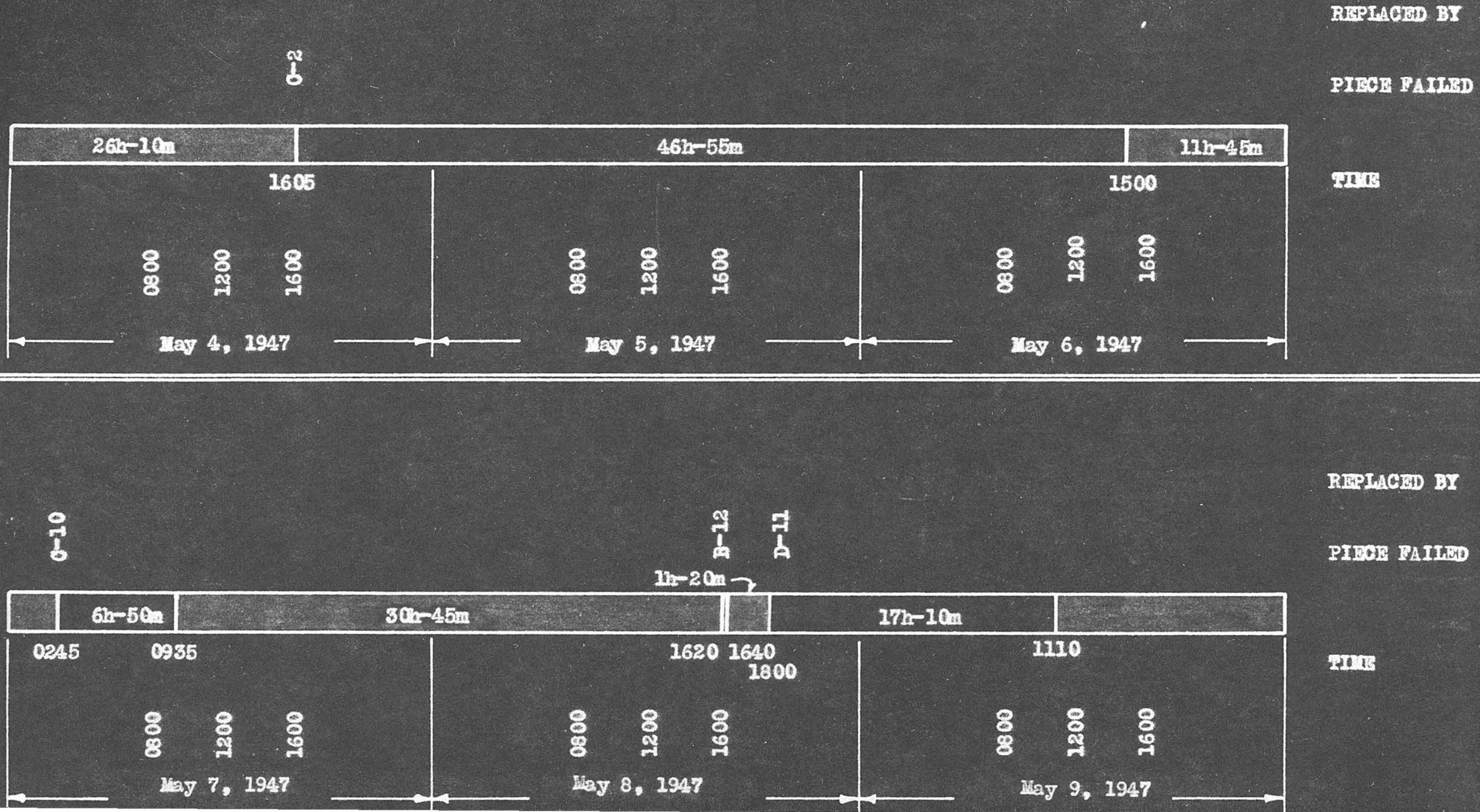


CHART I

TIME CHART OF TEST

Sheet 6 of 7

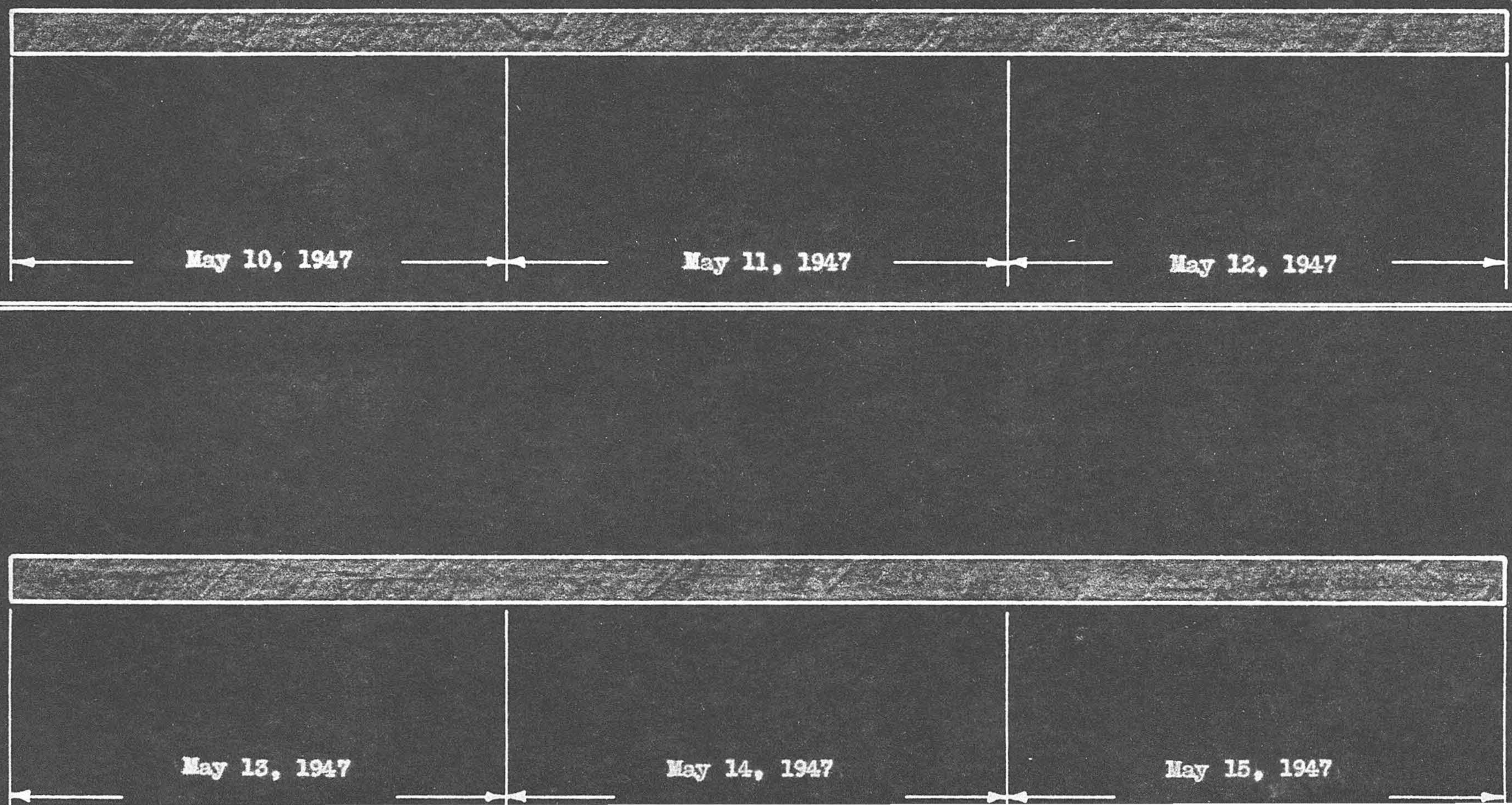
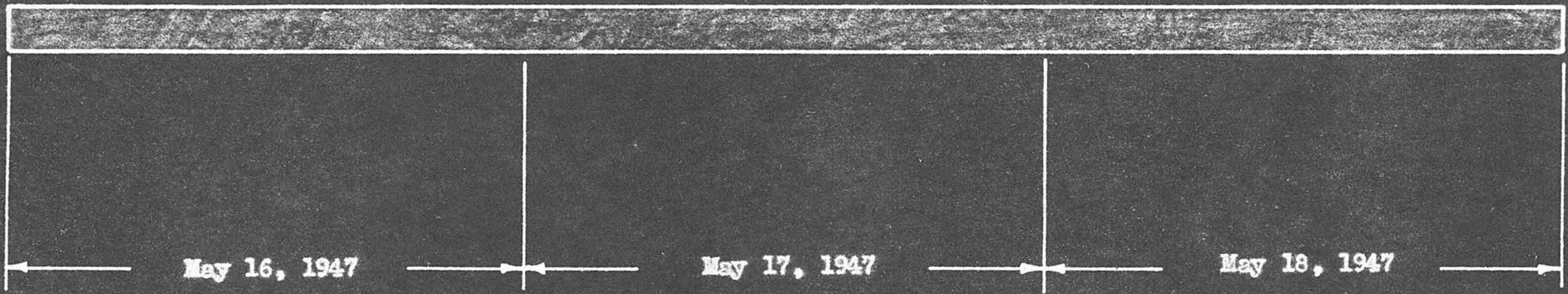


CHART I

TIME CHART OF TEST

Sheet 7 of 7



Note: As of 1600, May 20, 1947 Specimens B-2, B-3, B-5, B-6, B-15, C-6, C-11, C-13, C-15, C-16, D-6 and D-13 were still under load. Deflection had ceased, indicating that the load might be sustained indefinitely.

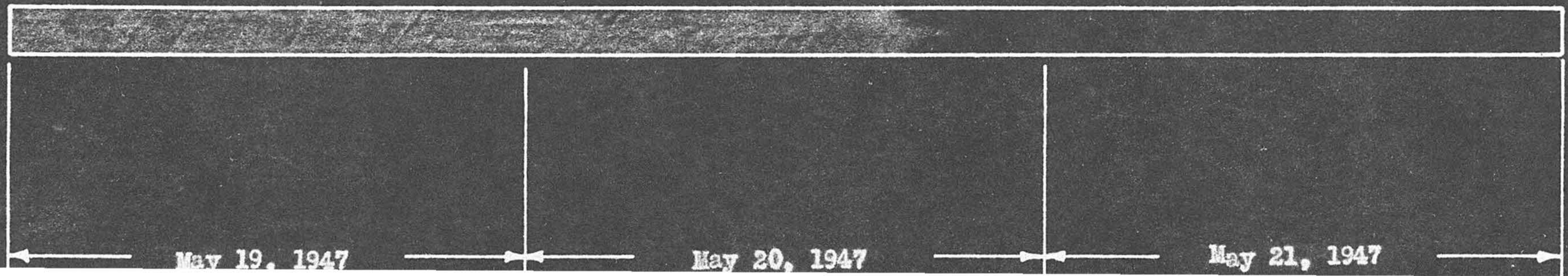


CHART II

CHART OF ATMOSPHERIC CONDITIONS OF TEST

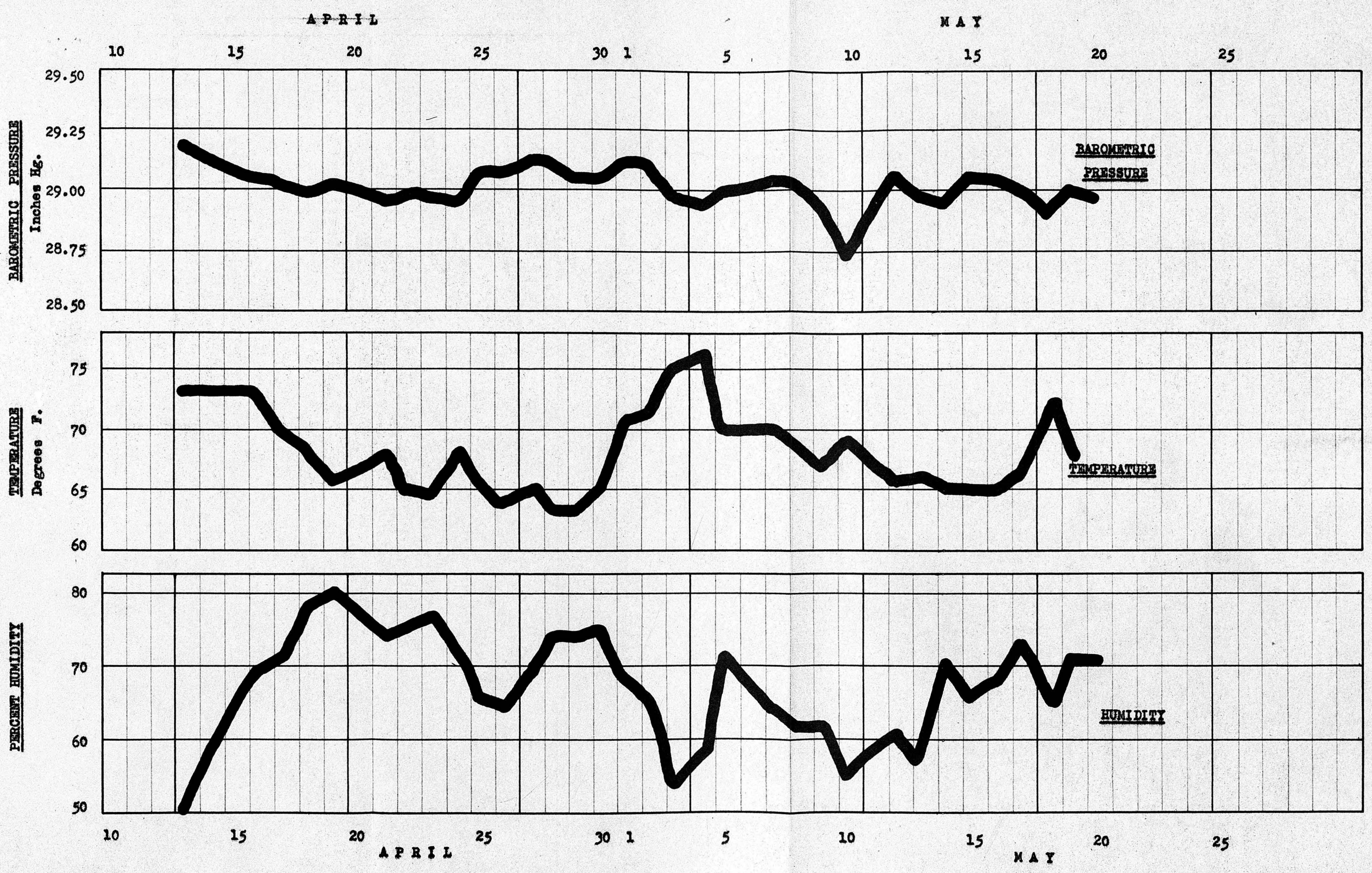


TABLE I

SUMMARY OF TEST BY SPECIMEN GROUPS

Sheet 1 of 4

Specimen Group: A
Average Short Time Ultimate Strength: 1052.5 psi
Average Original Moisture Content: 10.98%
No. Tested Short Time: 2 Long Time: 5 Total No.: 7

Spec. No.	Pct. Ult. Strength	Moisture Content	Total Time Loaded Hrs Min	Total Time Unloaded Hrs Min	No. Times Load Removed	Remark
A-1	<71.8	8.53	0h-00m	1h-30m	2	1
A-2	64.5	8.83	0h-00m	94h-25m	9	2
A-4	<60.7	8.05	0h-00m	0h-00m	0	3
A-5	<55.3	9.96	0h-00m	17h-05m	1	4
A-7	<48.8	8.90	0h-00m	0h-00m	0	5

Remarks:
1. Failed upon application of load.
2. Sustained load for few seconds only.
3. Failed on first application of load.
4. Failed upon application of load.
5. Failed on first application of load.

TABLE I

SUMMARY OF TEST BY SPECIMEN GROUPS

Specimen Group: B
Average Short Time Ultimate Strength: 798.9 psi
Average Original Moisture Content: 10.73%
No. Tested Short Time: 3 Long Time: 14 Total No.: 17

Spec. No.	Pct. Ult. Strength	Moisture Content	Total Time Loaded Hrs Min	Total Time Unloaded Hrs Min	No. Times Load Removed	Remarks
B-1	77.0	9.18	5h-35m	125h-35m	16	
B-2	41.8	--	542h-30m	314h-00m	26	1
B-3	40.7	--	542h-30m	313h-30m	25	1
B-5	41.2	--	542h-30m	247h-35m	24	1
B-6	40.4	--	542h-30m	224h-45m	22	1
B-7	41.3	9.65	25h-25m	123h-16m	10	
B-8	65.3	8.47	0h-00m	93h-40m	8	2
B-10	73.9	9.70	0h-30m	94h-49m	10	
B-11	--	--	---	---	--	3
B-12	57.4	10.36	251h-25m	114h-50m	10	
B-13	48.5	10.30	37h-55m	99h-15m	8	
B-15	41.3	--	542h-00m	198h-57m	20	1
B-16	<86.4	8.25	0h-00m	3h-40m	3	4
B-17	<65.3	8.34	0h-00m	0h-30m	1	4

Remarks:
1. Under load at time of writing. Deflection had ceased, indicating that load might be sustained indefinitely without increase in moisture content. Time computed to 0800, May 19, 1947.
2. Failed upon application of load. However, sustained load 11.2% greater than breaking load on previous load applications.
3. Accidental failure.
4. Failed upon application of load.

TABLE I

SUMMARY OF TEST BY SPECIMEN GROUPS

Sheet 3 of 4

Specimen Group: C
Average Short Time Ultimate Strength: 720.0 psi
Average Original Moisture Content: 10.96%
No. Tested Short Time: 3 Long Time: 14 Total No.: 17

Spec. No.	Pct. Ult. Strength	Moisture Content	Total Time Loaded (Hrs Min)	Total Time Unloaded (Hrs Min)	No. Times Load Removed	Remarks
C-1	60.2	10.75	22h-10m	200h-30m	18	
C-2	66.8	10.97	231h-05m	278h-40m	27	
C-3	75.5	9.50	0h-30m	124h-20m	14	
C-5	57.8	--	163h-00m	---	---	1
C-6	48.8	--	542h-00m	194h-50m	17	2
C-7	68.3	9.12	0h-00m	71h-55m	6	3
C-8	67.2	10.60	22h-10m	191h-50m	17	
C-10	73.9	10.63	242h-50m	325h-35m	28	
C-11	61.0	--	542h-30m	317h-40m	29	2
C-12	56.5	11.51	179h-30m	33h-35m	5	
C-13	49.5	--	541h-30m	195h-20m	17	2
C-15	49.6	--	541h-30m	194h-40m	16	2
C-16	57.2	--	503h-10m	64h-25m	9	2
C-17	66.9	9.60	0h-30m	121h-25m	13	

Remarks:
1. Accidental failure. Load and time indicated to time of failure.
2. Under load at time of writing. Deflection had ceased, indicating that load might be sustained indefinitely without increase in moisture content. Time computed to 0800, May 19, 1947.
3. Failed upon application of load.

TABLE I

SUMMARY OF TEST BY SPECIMEN GROUPS

Specimen Group: D
Average Short Time Ultimate Strength: 659.3 psi
Average Original Moisture Content: 9.82%
No. Tested Short Time: 3 Long Time: 12 Total No.: 15

Spec. No.	Pct. Ult. Strength	Moisture Content	Total Time Loaded Hrs Min	Total Time Unloaded Hrs Min	No. Times Load Removed	Remarks
D-1	<71.1	7.00	0h-00m	5h-10m	5	1
D-2	63.5	10.45	204h-55m	275h-40m	25	
D-3	60.1	10.55	203h-51m	269h-05m	21	
D-5	<71.0	8.65	0h-00m	4h-10m	4	1
D-6	47.2	--	541h-0m	194h-00m	15	2
D-7	40.9	9.34	0h-35m	31h-20m	7	
D-9	<71.8	8.42	0h-00m	5h-40m	6	1
D-10	59.4	9.12	0h-30m	116h-09m	7	
D-11	56.8	10.12	89h-45m	63h-20m	7	
D-13	50.1	--	536h-00m	128h-15m	14	2
D-14	<55.0	10.12	0h-00m	0h-00m	0	3
D-15	72.0	10.18	185h-10m	255h-40m	22	

Remarks:
1. Failed upon application of load.
2. Under load at time of writing. Deflection had ceased, indicating that load might be sustained indefinitely without increase in moisture content. Time computed to 0800, May 19, 1947.
3. Failed upon first application of load.

TABLE II

SUMMARY OF TEST BY LOAD GROUPS

Sheet 1 of 5

Load Group: 75% of Short Time Ultimate
No. Specimens: 10

Spec. No.	Pct. Ult. Strength	Total Time Loaded Hrs Min	Total Time Unloaded Hrs. Min	No. Times Load Removed	Remarks
A-1	< 71.8	0h-00m	1h-30m	2	1
B-1	77.0	5h-35m	125h-30m	16	
B-10	73.9	0h-30m	94h-49m	10	
B-16	< 86.4	0h-00m	3h-40m	3	2
C-3	75.5	0h-30m	124h-20m	14	
C-10	73.9	242h-50m	325h-35m	28	
D-1	< 71.1	0h-00m	5h-10m	5	3
D-5	< 71.0	0h-00m	4h-10m	4	4
D-9	< 71.8	0h-00m	5h-40m	6	5
D-15	72.0	185h-10m	255h-40m	22	

Remarks:
1. Failed upon application of load.
2. Failed upon application of load.
3. Ditto
4. Ditto
5. Ditto

TABLE II

SUMMARY OF TEST BY LOAD GROUPS

Sheet 2 of 5

Load Group: 65% of Short Time Ultimate
No. Specimens: 7

Spec. No.	Pct. Ult. Strength	Total Time Loaded Hrs Min	Total Time Unloaded Hrs Min	No. Times Load Removed	Remarks
A-2	64.5	0h-00m	94h-25m	9	1
B-8	65.3	0h-00m	93h-40m	8	2
B-17	<65.3	0h-00m	0h-30m	1	3
C-2	66.8	231h-05m	278h-40m	27	
C-8	67.2	22h-10m	191h-50m	17	
C-17	66.9	0h-30m	121h-25m	13	
D-2	63.5	204h-55m	275h-40m	25	

Remarks:
1. Sustained load for few seconds only.
2. Failed upon application of load. However, sustained load 11.2% greater than breaking load on previous load application.
3. Failed upon application of load.

TABLE II

SUMMARY OF TEST BY LOAD GROUPS

Sheet 3 of 5

Load Group: 60% of Short Time Ultimate
No. Specimens: 14

Spec. No.	Pct. Ult. Strength	Total Time Loaded Hrs Min	Total Time Unloaded Hrs Min	No. Times Load Removed	Remarks
A-4	<60.7	0h-00m	0h-00m	0	1
A-5	<55.3	0h-00m	17h-05m	1	2
B-11	--	---	---	--	3
B-12	57.4	251h-25m	114h-50m	10	
C-1	60.2	22h-10m	200h-30m	18	
C-5	57.8	163h-00m	---	--	4
C-7	68.3	0h-00m	71h-55m	6	2
C-11	61.0	542h-30m	317h-40m	29	5
C-12	56.5	179h-30m	33h-35m	5	
C-16	57.2	503h-10m	64h-25m	9	5
D-3	60.1	203h-51m	269h-05m	21	
D-10	59.4	0h-00m	116h-09m	7	
D-11	56.8	89h-45m	63h-20m	7	
D-14	<55.0	0h-00m	0h-00m	0	1

Remarks:
1. Failed upon first application of load.
2. Failed upon application of load.
3. Accidental failure.
4. Accidental failure. Load and time indicated to time of failure.
5. Under load at time of writing. Deflection had ceased, indicating that load might be sustained indefinitely without increase in moisture content. Time computed to 0800, May 19, 1947.

SUMMARY OF TEST BY LOAD GROUPS

Load Group: 50% of Short Time Ultimate
No. Specimens: 7

Spec. No.	Pct. Ult. Strength	Total Time Loaded Hrs Min	Total Time Unloaded Hrs Min	No. Times Load Removed	Remarks
A-7	<48.8	0h-00m	0h-00m	0	1
B-13	48.5	37h-55m	99h-15m	8	
C-6	48.8	542h-00m	194h-50m	17	2
C-13	49.5	541h-30m	195h-20m	17	2
C-15	49.6	541h-30m	194h-40m	16	2
D-6	47.2	541h-0m	194h-00m	15	2
D-13	50.1	536h-00m	128h-15m	14	2

Remarks: 1. Failed upon first application of load.
2. Under load at time of writing. Deflections had ceased, indicating that load might be sustained indefinitely without increase in moisture content. Time computed to 0800, May 19, 1947.

TABLE II

SUMMARY OF TEST BY LOAD GROUPS

Load Group: 40% of Short Time Ultimate
No. Specimens: 7

Spec. No.	Pct. Ult. Strength	Total Time Loaded Hrs Min	Total Time Unloaded Hrs Min	No. Times Load Removed	Remarks
A-7	<48.8	0h-00m	0h-00m	0	1
B-13	48.5	37h-55m	99h-15m	8	
C-6	48.8	542h-00m	194h-50m	17	2
C-13	49.5	541h-30m	195h-20m	17	2
C-15	49.6	541h-30m	194h-40m	16	2
D-6	47.2	541h-00m	194h-00m	15	2
D-13	50.1	536h-00m	128h-15m	14	2

Remarks:
1. Failed upon first application of load.
2. Under load at time of writing. Deflection had ceased, indicating that load might be sustained indefinitely without increase in moisture content. Time computed to 0800, May 19, 1947.

TABLE III

DESCRIPTION OF MATERIAL TESTED

Designation	Size	Grade	Kind	Number of Specimens	Obtained From	Description
A	2"x4"x8'-0"	Douglas Fir	B/Btr., S4S	8	E.K.Wood Lbr. Co.	Fairly close and straight grained. 15 rings per inch; 25-30% summerwood; 4-5° angularity of grain. Considerable pitch but no well defined pitch pockets. One large shake, approx. 3/16" open on end, running one-half length of piece.
B	2"x4"x16'-0"	Douglas Fir	B/Btr., S4S	17	E.K.Wood Lbr. Co.	Fairly close and straight grained. 15 rings per inch; approx. 30% summerwood; 2-8° angularity of grain. No noticeable defects. This appears to be best stick. (See photographs.)
C	2"x4"x16'-0"	Douglas Fir	B/Btr., S4S	17	E.K.Wood Lbr. Co.	Straight, but rather open grain. 12-15 rings per inch; 20-25% summerwood; 4-6° angularity of grain. No knots or other defects except several small pitch pockets. (See photographs.)
D	2"x4"x14'-0"	Douglas Fir	Unknown S4S	15	CalTech Materials Testing Laboratory	Straight, but rather open grain. Considerable variation across width of piece. 10-17 rings per inch; 25-35% summerwood; 1-4° angularity of grain. One or two small knots less than ½". (See photographs.)

NOTES:
1. All test specimens numbered in order that they were sawn from long sticks.
2. Total number of specimens — 56. Specimen A-8 rejected because of large, open shake running full length of specimen.
3. See accompanying photographs showing grain details.

TABLE IV

SUMMARY OF SHORT-TIME TEST

Machine: Riehle Universal Testing Machine
Capacity: 30,000# Least Reading: 10#
No.: 14745

Speed of Test: 0.025 In./min.

Loading Arrangement: Straps and shear key as for long-time tests with special adapter to testing machine grips.

Date: February 28 & March 1, 1947

Spec. No.	Shear Area Sq. in.	Breaking Load #	Ultimate Stress psi.	Pct. Diff. From Ave.	Moisture Content
A-3	3.64	3710	1020	- 3.1	11.10
A-6	3.62	3930	1085	+ 3.1	10.85
		Average	1052.5		10.98
B-4	3.64	2770	762	- 4.6	11.18
B-9	3.62	3520	972	+21.7	10.62
B-14	3.60	2380	662	-17.2	10.40
		Average	798.9		10.73
C-4	3.67	2290	625	-13.2	11.37
C-9	3.61	2650	734	+ 1.94	11.36
C-14	3.59	2870	800	+11.1	10.16
			720.0		10.96
D-4	3.75	2640	705	+ 6.9	9.93
D-8	3.74	2610	698	+ 5.87	9.65
D-12	3.74	2150	575	-12.8	9.87
			659.3		9.82

General Remarks:

1. In all cases failures were sudden and were accompanied by a sharp cracking noise. Very little warning was given prior to failure by creaking or groaning. No deformations were noticeable prior to failure.
2. All failures were by pure shear. In no case was any indication of even localized bearing failure under the key apparent.
3. Most failures -- all specimens except C-9 and those from Stick D -- occurred in double shear. Specimen C-9 and all three specimens from Stick D failed in single shear. (Stress calculated using double shear area.)