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MILITARY HANDBOOK

DRYDOCKING TIMBERS AND BLOCKS, STRENGTH PROPERTIES OF

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FOREWORD

1. This military handbook is approved for use by the Naval Sea Systems Command, Department of the Navy and is available for use by all departments and agencies of the Department of Defense.

2. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: Commander, Naval Sea Systems Command, SEA 55Z3, Department of the Navy, Washington, DC 20362-5101 by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

3. This document supplements departmental manuals, directives, military standards, etc., and provides basic and fundamental information on drydocking timbers and built-up blocks.

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1. SCOPE AND PURPOSE

1.1 Scope. This handbook presents compressive strength properties for drydocking timbers and built-up blocks, stability characteristics of high blocks, and friction coefficients for cribbing materials. These values are the result of a series of tests performed under the direction of the Naval Sea Systems Command and are intended to supplement the strength properties of clear wood specimens found in wood handbooks. The timbers used in this study were full-size white and red oak and Douglas fir and consisted of both new (unused) and in-service drydock timber. Because of the variations in strength properties of docking timbers as determined in this study, meaningful engineering calculations on hull block loading need to be conservatively based on the low end of the ranges presented for strength properties.

1.2 Purpose. The purpose of this handbook is to establish the expected degree of performance for typical drydocking timbers and built-up blocks based upon full-scale testing results of new and used docking materials.

2. APPLICABLE DOCUMENTS

2.1 Government documents.

2.1.1 Specifications. The following specification forms a part of this document to the extent specified herein. Unless otherwise specified, the issues of this document is listed in the issue of the Department of Defense Index of Specifications and Standards (DODISS) and supplement thereto, cited in the solicitation (see 7.1).

SPECIFICATIONS

MILITARY

MIL-W-15154	Wood Laminates, Oak (For Ship and Boat Use)

(Unless otherwise indicated, copies of federal and military specifications are available from the Standardization Documents Order Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.)

2.1.2 Other Government publications. The following other Government publication forms a part of this document to the extent specified herein. Unless otherwise specified, the issues are those cited in the solicitation.

PUBLICATIONS

NAVSEA

0901-LP-997-0000	Docking Instructions and Routine Work in Dry Dock, Chapter 997

2.2 Non-Government publications. The following document forms a part of this document to the extent specified herein. Unless otherwise specified, the issues of the documents which are DOD adopted are those listed in the issue of the DODISS cited in the solicitation. Unless otherwise specified, the issues of documents not listed in the DODISS are the issues of the documents cited in the solicitation (see 7.1).

001-000-04456-7	Wood Handbook U.S. Forest Service, Forest Products Laboratory, U.S Department of Agriculture, 1987

(Applications for copies should be addressed to Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402)

(Non-Government standards and other publications are normally available from the organizations that prepare or distribute the documents. These documents also may be available in or through libraries or other informational services.)

2.3 Order of precedence. In the event of a conflict between the text of this document and the references cited herein (except for related associated detail specifications, specification sheets or MS standards), the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

3. DEFINITIONS

3.1 Built-up blocks. Built-up blocks are drydocking blocks that generally consist of a large base concrete block, upon which layers of support timber are stacked, followed by a "soft cap". Figure 1 illustrates a typical built-up block.

3.2 Cribbing. Cribbing is the term used for long timbers that run between docking blocks in order to increase the lateral stability of the docking blocks. Cribbing material is held in place by the friction of the docking blocks under load.

3.3 End matching. End matching is the process by which a timber is sawn in half and each piece is subjected to differing test conditions. The results for each half may then be compared to each other.

3.4 Equilibrium moisture content (EMC). EMC is the moisture level at which timbers that are in-service and protected from direct immersion and rainwater will reach to be in equilibrium with the temperature and humidity of the surrounding air. The equilibrium moisture content is typically 12 $\pm$ 4 to 5 percent, depending on the local environment.

3.5 Fiber saturation point (FSP). FSP is the point at which moisture has left the cavities between the cells of wood fibers and is contained only in the walls of the fibers. Wood will begin to shrink at this point. The FSP is typically found at a moisture content of 25 to 30 percent.

3.6 Fiber stress at proportional limit (FSPL). FSPL is a measure of the failure point of a wood timber, defined as the stress value at the point where the ratio of stress to strain is no longer proportional. Loading beyond this point will result in a greater increase in strain per unit stress, i.e., the timber deflects more readily when loaded.

3.7 High blocks. High blocks are a taller, more complex version of a built-up block, generally consisting of a concrete base, layers of support timber, a second concrete block, additional support timber and a "soft cap". High blocks are typically used on ships that have sonar domes that protrude below their baseline. Figure 1 illustrates a typical high block.

3.8 Modulus of elasticity (MOE). MOE is a measure of the stiffness of a material, defined as the ratio of stress to strain.

3.9 Moisture content (MC). MC is a measure of the weight of the water contained within a piece of timber. Moisture content is expressed as a percentage of the oven-dry weight of the timber.

3.10 Soft cap. Soft cap is the uppermost "softer" layer of timber in a composite docking block build-up, designed to sacrificially crush so as to prevent hull deformation during drydocking. Figure 1 illustrates a "soft cap".

4. GENERAL CONSIDERATIONS FOR STRENGTH PROPERTIES OF DRYDOCKING TIMBERS

4.1 Strength properties. The strength properties of wood are intrinsically more variable than those of man-made materials, such as steel or plastic. Differences not only exist between different wood species but also among the members of the same species. These factors make it difficult to define the strength properties of an "average" piece of wood.

4.1.1 Strength is a parameter that must be considered when examining the use of wood in ship docking, because different types of wood vary widely in their ability to carry a load. This ability depends on the elasticity, density, and moisture content of the wood. The effect of each of these factors on the mechanical properties of wood and methods for quantifying these effects are discussed in the following paragraphs.

4.2 Elastic strength properties. Wood may be considered an elastic material, because it can be subjected to a compressive load and return to its original form. For example, when a load is applied to a timber, the timber will be compressed in direct proportion to the amount of the applied load. If the load is doubled, the deflection is doubled, provided the load is within the elastic range. There are two parameters used in determining the suitability of wood for ship docking: fiber stress at proportional limit (FSPL) and modulus of elasticity (MOE).

4.2.1 Fiber stress at proportional limit (FSPL). Fiber stress at proportional limit (FSPL) is used to identify the initial point at which a timber begins to behave inelastically such that the deflection is no longer proportional to the applied load. The relationship between compressive deflection and applied load is shown on figure 2. After the load exceeds the FSPL, the deflection increases greatly with each small increase in load until crushing of the timber begins. This failure may occur in the form of bulging, splitting, or diagonal shearing as viewed from the end sector. In some cases, the failure may not be visible at all.

4.2.1.1 During docking, if the load applied to the timbers in a complete block build-up does not exceed the FSPL of any individual timber in the block, the timbers will not be damaged and will recover to their original thickness. On the other hand, if the load significantly exceeds the FSPL of any of the timbers in the build-up, the timbers will undergo inelastic deformation and cannot return to their original thickness, even though they may appear to be undamaged. Therefore, variations in the thickness of ship blocking timber should be carefully examined for a possible indication of previously overstressed conditions. If the timber has evident visual signs of having been overstressed, such as reduced thickness, side bulges, etc., it may not be capable of carrying its share of the load during successive dockings and should be discarded.

4.2.1.2 The FSPL is thus an important property of ship blocking timbers. It is used to calculate the safe working stresses that can be assigned to the timbers and the loads that can safely be placed on the blocks.

4.2.2 Modulus of elasticity (MOE). Another important measure of the strength of blocking timbers is the modulus of elasticity (MOE). MOE represents the relative stiffness of a timber or stack of timbers. By definition, MOE is the ratio of the unit stress (in pounds per square inch) to the unit strain (in inches per inch of depth of the timber). MOE can be calculated from the slope of the initial straight line portion of a load/deflection curve.

4.2.2.1 Figure 2 presents both a load/deflection and a stress/strain curve. The left vertical axis shows the applied load in kips. The lower horizontal axis shows deflection, in inches. The average stress is shown on the right vertical axis, in kips per square inch (ksi). The stresses are calculated by dividing the load in kips by the surface area of the timber in square inches (in this case 14 x 48 inches). Average strain in inches per inch is calculated by dividing the deflection by the depth of the timber (in this case 6 inches). The resulting strain values are shown on the upper horizontal axis.

4.2.2.2 To calculate MOE from stress/strain test data of the type shown in figure 2, a stress is selected at some point less than the FSPL and divided by the corresponding strain. If a stress of 500 lb/in^2 is selected and the corresponding strain at this stress level is 0.011 inches/inch, the MOE that would be calculated is 45,000 lb/in^2.

4.2.2.3 The average MOE for a built-up block can be determined by using a high-capacity testing machine. This average MOE can be regarded as the spring constant of the block build-up. The compressive deflection of the entire build-up under a given load can be calculated similarly by taking into account the depth and load bearing area of the entire built-up block. When each timber in a built-up composite block has a different MOE, the calculation of block deflection is only as accurate as the assumed average MOE for the build-up. Each timber will carry a different stress for any level of total block compression.

4.2.3 Relationship between FSPL and MOE in compression perpendicular to the grain. Since wood is composed of fibers that are arranged in a parallel pattern, a piece of wood is strongest when a load is applied parallel to the grain. For example, the strength of wood under a compressive load applied parallel to the grain is approximately 5 to 10 times greater than its strength when compression is applied across the grain. In terms of tension, moreover, the strength along the grain is probably 40 to 60 times greater than across the grain.

4.2.3.1 In wood research literature, relatively little has been reported on compression perpendicular to the grain over the whole surface of the timber because wood is seldom used that way. It has been observed that the MOE in compression perpendicular to the grain is related to FSPL. This relationship was shown to be fairly consistent for tests performed on oak timbers of 6 x 14-inch cross-sections, as shown graphically on figure 3.

4.2.3.2 Similar testing on Douglas fir did not exhibit as consistent a relationship, perhaps because there were fewer samples. Nevertheless, the test results suggest that this relationship might be used in predicting the strength of drydocking timbers without destructive testing.

4.2.4 Statistical prediction of FSPL and MOE. The strength properties of wood cannot be expressed adequately in terms of averages because they vary so widely. However, other statistical parameters beyond averages can be used to understand a population of strength properties such as FSPL. Consider the following hypothetical case: FSPL is determined for each of 1,000 new and old oak drydocking timbers. The extreme FSPL values are about 200 lb/in^2 and 800 lb/in^2, and the average is 500 lb/in^2. Each FSPL value is placed in one of eight classes representing 100 lb/in^2, with classes ranging from the 100 class to the 900 class. According to the laws of probability, the classes, represented by bars in a graph, showing the number of timbers in each class, would be arranged as shown on figure 4.

4.2.4.1 On figure 4, if the midpoints of the eight bars of the bar chart are connected by a smooth line, the result is a FSPL normal distribution curve. A measure of the variation in a population such as this is the standard deviation (S). In a statistically normal population, about two-thirds of the values are within 1 standard deviation of the average (in the example on figure 3, from 400 to 600 lb/in^2, 215 + 246 + 215 = 676 timbers or about 2/3 of 1,000). Also in a normal population, about 95 percent of the values will fall within two standard deviations of the average and 99 percent will fall within 2.6 standard deviations. A distribution of a large sample of test values, as shown on figure 4, helps in setting realistic design loads for timbers, or setting lower limits for determining the acceptability of timbers for service.

4.2.4.2 Another measure of variation is the coefficient of variation (COV). This measure is simply the standard deviation divided by the average and expressed as a percent. Thus the COV of the population in the example is 100/500 lb/in^2 or 20 percent. This COV percentage is typical of the variation found in the mechanical properties of wood, regardless of the species.

4.3 Relationship of specific gravity to strength properties. The specific gravity of the basic material of which wood is composed is about 1.5 times heavier than water. Specific gravity of wood is influenced by the size and arrangement of cell cavities and pores, and the thickness of the cell walls. If the wood is straight-grained and free of defects, the specific gravity is a good indicator of strength properties, such that higher specific gravity means higher strength. For example, white oak, which has an average specific gravity of 0.60 when green or undried, is stronger than green basswood, which has an average specific gravity of 0.32. The Wood Handbook lists the compressive strengths perpendicular to the grain for undried white oak as 670 lb/in^2 and green basswood as 170 lb/in^2.

4.3.1 The relationship of specific gravity to mechanical properties is a general one. There are variations within a single species and between species of wood.

4.4 Effect of moisture content on strength properties. Another source of variation in the strength of wood within a species is the moisture content (MC) of the timber. Moisture exists in wood in two forms: that which is contained in the hollows or cavities of the elongated cells (or fibers), and that which is contained in the walls of the fibers. Wood will not begin to shrink until all of the moisture has left the cavities. This point, where all the moisture is contained only within the wall of the fibers, is called the fiber saturation point (FSP), and it reflects a moisture content of about 25 to 30 percent of the weight of most species. Wood that is at the FSP or above is called green wood. Dry wood, on the other hand, is wood that has started to shrink and may be completely dry (0 percent MC) or barely dry (for example, 24 percent MC).

4.4.1 Moisture content is determined by weighing a sample of wood, then drying the sample in an oven, weighing it again to determine its oven-dry weight, and dividing the difference between the wet and dry weights by the dry weight. The MC is expressed as a percentage of the oven-dry weight.

4.4.2 Above 25 to 30 percent MC, higher moisture content has no deleterious effect on strength properties. As wood dries below a 25 percent moisture content, all of its strength properties increase, with some properties being affected by moisture content more than others. For example, the compressive strength of wood parallel to the grain can be more than doubled simply by drying the wood out approximately half-way to the oven-dry level (i.e., to about 12 percent). On the other hand, the tension properties of wood are barely affected by extremes in moisture content below the fiber saturation point.

4.4.3 Twelve percent MC is the level selected for comparing the strength properties of dry wood, because wood that is in-service and protected from rainwater or immersion comes to equilibrium with the humidity of the atmosphere at 12 percent moisture content, plus or minus 4 to 5 percent, depending on the environment. This is called the equilibrium moisture content, or EMC.

4.4.4 However, exposure to sea water raises the EMC to a higher level and inhibits the drying of the timbers. This factor, combined with the fact that ship blocking timbers are frequently immersed in sea water and are usually stored between dockings under conditions that do not encourage drying, requires that the strength values used in drydocking calculations be taken for timbers in the green or undried condition.

5. RECOMMENDED VALUES FOR TIMBER PROPERTIES IN DRYDOCK CALCULATIONS

5.1 General. Recommended values for the strength properties of drydock timbers and lateral friction coefficients for cribbing materials have been developed based upon the compression test results and are presented below.

5.2 Compressive strength properties. The compression test results for oak (white and red) and Douglas fir sawn timbers were pooled in order to increase the sample size and obtain a better representation of the behavior of full-scale timbers. These results are broken down by species and age, i.e., whether the timbers were new or used prior to testing. The pooled test results do not reflect such differences as timber size, load-to-grain angle, or whether the timbers were frozen. All timbers tested were green and unseasoned, with moisture content at approximately 25 to 30 percent. The ranges of the recommended strength values for FSPL and MOE are shown in tables I and II for new and previously used timbers, respectively.

TABLE I. *Pooled test results for all new Douglas fir and oak timbers.*

Species	Fiber stress at prop. limit (lb/in^2)	Modulus of elasticity (ksi)	Specific gravity
Douglas fir	258–533	11.35–38.57	0.35–0.52
Oak	322–710	19.60–49.79	0.54–0.77

TABLE II. *Pooled test results for previously used Douglas fir and oak timbers.*

Species	Fiber stress at prop. limit (lb/in^2)	Modulus of elasticity (ksi)
Douglas fir	279–570	4.30–24.00
Oak	241–821	6.57–56.58

5.2.1 The values presented in tables I and II should be used to supplement the published data for small, clear wood specimens, as very little data is available for full size timbers. Table III is provided to compare the average test results with published values. Design calculations based upon the data in tables I and II must incorporate a high degree of engineering judgement. Specifically, design values for used timbers should be taken very conservatively from the low end of the strength range, especially since timbers that may have been previously overstressed are difficult to identify visually. Design values for new timbers, however, should be taken from the middle of the strength range, as new timbers tend to behave with a higher degree of predictability.

TABLE III. *Comparison to published values for new oak and Douglas fir.*

	Moisture content percent	Avg. specific gravity	Avg. FSPL (lb/in^2	Avg. MOE (lb/in2)
New Douglas fir	30	0.42	367	26,810
New oak	30	0.62	539	37,220
Wood Handbook[1]				
Douglas fir (coast)	36	0.45	380	–
White oak	70	0.60	670	–
Red oak	80	0.56	610	–

[1]Wood Handbook values for FSPL are based on loading a 2-inches wide bearing plate at a right angle across a 2 x 2 inch clear specimen. There are no values in the table for MOE in compression perpendicular to the grain.

5.3 Lateral friction coefficients. Table IV presents coefficients of friction for cribbing material for several material interfaces. These values are tabulated by dry and wet conditions, and may be used for design calculations with a good degree of certainty, since the ranges of the results are relatively small.

TABLE IV. *Summary of coefficients of friction for various interfaces (150 lb/in^2 vertical load).*

Surface condition	Friction surfaces			
	Fir/fir	Fir/oak	Oak/oak	Oak/steel
Dry	0.38–0.51	0.40–0.47	0.36–0.57	0.46–0.59
Wet	0.65–0.67	0.66–0.76	0.71–0.86	0.69–0.88

6. COMPRESSIVE TESTING

6.1 General. Detailed information on strength properties perpendicular to the grain, based on compression testing results, is presented for individual and layered timbers, and medium-height composite block build-ups. Additionally, the stability of high blocks and friction characteristics for cribbing material are discussed.

6.2 Compression tests on individual timbers.

6.2.1 Tests on oak and Douglas fir. Tests were conducted on a series of individual timbers in order to determine compressive strengths perpendicular to the grain of full-size oak (white and red) and Douglas fir drydocking timbers. The timbers were received from several U.S. Navy dry docks. The oak timbers were of two sizes-12 x 14 x 48 and 6 x 14 x 48 inches, and the Douglas fir timbers were all 6 x 14 x 48 inches. The initial series of compression tests was performed to determine differences in compressive strength between timbers that were new (unused) and timbers that had been in-service. Additional, or secondary compression tests were performed to determine the effects of freezing and varying load-to-grain angle on the compressive strength of drydocking timbers.

6.2.1.1 Initial compression tests.

6.2.1.1.1 Test results. A summary of compressive test results for individual oak and Douglas fir timbers is presented in tables V and VI. Although the number of tests was fairly low, the results are consistent with known data, and the values may be considered typical.

TABLE V. *Summary of compressive tests on individual timbers, FSPL (lb/in²).*

Size		Species			
		Oak		Douglas fir	
		6 x 14 inches	12 x 14 inches	Avg.	6 x 14 inches
New	N	15	15	–	15
	$\bar{x}$	567	487	527	328
	R	522–710	389–570	–	263–390
	S	113.75	58.8	–	39.9
	COV	20.1 percent	12.1 percent	–	12.2 percent
Old	N	15	15	–	10
	$\bar{x}$	561	410	486	405
	R	241–821	257–784	–	279–570
	S	153.6	138.9	–	131.70
	COV	27.4 percent	33.7 percent	–	32.5 percent
Average of averages		564	449	506	359

N = Number of tests
$\bar{x}$ = Average or mean
R = Range of values
S = Standard deviation
COV = Coefficient of variation

TABLE VI. *Summary of compressive tests on individual timbers, MOE (ksi).*

Size		Species			
		Oak		Douglas fir	
		6 x 14 inches	12 x 14 inches	Avg.	6 x 14 inches
New	N	15	15	–	15
	$\bar{x}$	35.88	39.86	37.57	26.45
	R	21.5–55.84	31.04–49.79	–	11.4–38.6
	S	8.80	5.4	–	7.17
	COV	24.5 percent	13.5 percent	–	27.0 percent
Old	N	15	15	–	10
	$\bar{x}$	29.88	21.64	25.76	18.59
	R	15.13–45.83	6.57–56.58	–	4.3–24.0
	S	9.14	13.75	–	6.04
	COV	30.6 percent	63.5 percent	–	32.5 percent
Average of averages		32.9	30.45	31.67	23.31

N = Number of tests
$\bar{x}$ = Average or mean
R = Range of values
S = Standard deviation
COV = Coefficient of variation

6.2.1.1.2 Table V contains the values for fiber stress at proportional limit; table VI contains values for modulus of elasticity. Within each box of the table are the number of specimens tested, the average test value, the range of test values, the standard deviation, and the coefficient of variation (standard deviation divided by the average expressed as percent, see 4.2.4).

6.2.1.1.3 The data in table V provides strength values that may be helpful in calculations for timbers used in drydocking. The average values are within the normal range of expected strengths for these species.

6.2.1.1.4 Conclusions. The following several conclusions may be drawn from the data presented in the tables:

a. A troubling aspect of the results is the range of strength values: FSPLs from 241 to 821 for old oak and 279 to 570 lb/in^2 for old Douglas fir. This data shows that some timbers in service are at the lower end of the expected range for FSPL.

b. Although oak is generally considered stronger than Douglas fir, there is some overlap in properties between the species, particularly between the old oak and old Douglas fir for both FSPL and MOE, and between the new oak and new Douglas fir for MOE. There was no overlap of FSPL values for new oak and new Douglas fir.

c. The 6 x 14 inch oak timbers appear to be stronger than the 12 x 14 inch oak timbers (both new and old). There could be several reasons for this: more and deeper checks in larger cross-sections; weaker wood in the area of the "boxed heart," which the larger timbers invariably had; or perhaps simply the geometry of the larger cross-sections (height-to-width ratios of the larger versus smaller timbers).

d. The old timbers varied more in strength than the new timbers. Note the greater coefficients of variation in table V.

e. The greater average strength of old versus new Douglas fir is probably due to the smaller sample size of the old timbers and the fact that the old timbers had been used little or as cribbing layers.

f. Oak is, on the average, stiffer than Douglas fir, which is well documented; however, the ranges of MOE values overlap. It was noted that some Douglas fir timbers have higher MOEs than oak.

g. The most significant differences between sets of data in table VI are between the MOEs of old and new timbers. This fact suggests that some of the old timber may have been stressed beyond its FSPL. Once a timber has been stressed beyond its proportional limit, its MOE on subsequent loadings will be much lower. The greater variations in FSPL for the old timbers may also reflect this phenomenon.

6.2.1.1.5 Test procedures. The initial set of compression tests was designed to show comparative compressive properties of oak and Douglas fir (both old and new timbers) and, in the case of oak, a comparison of larger timbers (12 x 14 inches) with smaller timbers (6 x 14 inches). (Since Douglas fir is used mainly for the capping timbers, no 12 x 14 inch fir timbers were tested.)

6.2.1.1.6 The timbers were selected from several naval dry docks to provide samples of typical species, sizes, and ages (i.e., used or unused). They were shipped on pallets to the University of Washington in the fall of 1984 and stored outdoors. No attempt was made to shelter the timbers except from direct rainfall. Prior to testing, the timbers were moved to the University of Washington Structural Research Laboratory, where they were again stored outside until preparations for testing began. Each timber was marked with an identification code number, and an identification sheet was prepared for each timber. A sample identification sheet is shown on figure 5.

6.2.1.1.7 Preliminary work. The dimensions and weight of each timber were recorded on the identification sheet. A photograph was taken of the bearing surface, and a sketch was made of one end of the timber to record the location of the pith, checks, etc. A grid of 1-inch squares was drawn on one end of the timber to aid in examining photos of the distortion that occurred during compression testing.

6.2.1.1.8 Shortly before testing, a 1-inch core was drilled through the central area of each timber for determining the moisture content. The cylindrical core was immediately removed and wrapped in plastic film to retain moisture. At the end of the daily testing period, the cores that had been removed from the timbers were unwrapped and cut into six approximately equal sections. Each section was weighed, dried at 105 degrees Celsius (°C) until no further weight loss occurred, and reweighed so that the oven-dry moisture could be calculated for each section. The moisture content of the outer two sections, sections 1 and 6, was averaged to provide a surface moisture content for the outer one-third, and the moisture content of the inner four sections, sections 2,3,4 and 5, was averaged for the interior moisture content.

6.2.1.1.9 In addition to moisture content, the specific gravity was determined on two of the core sections from each timber. Figure 6 is a sample laboratory data sheet illustrating moisture content and specific gravity.

6.2.1.1.10 Compression test. Each timber to be tested was centered under the head plate of the Baldwin test machine such that the load was applied perpendicular to the grain, similar to normal drydock loading conditions. Vertical and horizontal scales were arranged next to the specimen for reference, and the machine head was lowered to contact the timber. Two linear variable differential transformers (LVDTs) were placed against the head at opposite corners of the timber to measure deformation. After applying an initial load of 3 kips, the machine head was stopped for a close-up photograph of the end of the timber that contained the marked grid. Loading was then begun at a rate of 30 kips/minute; data was recorded at 30-second intervals. The instrumentation produced a plot of the deflection versus the load for each LVDT on the x-y plotter while loading was in progress. Figure 7 shows the plot for each LVDT.

6.2.1.1.11 A second photograph was taken at 0.5 inch deflection, which was usually past the proportional limit. Additional photographs were taken after deflections of 1 inch and 1-1/2 inches (see figure 8). Visible damage at the 1 inch deflection can be seen on figure 8. For the timbers that were 12 inches thick, a photo was also taken at 3 inches of deflection.

6.2.1.1.12 At the conclusion of the test, the timbers were returned to storage. After the tests, the plots were examined to determine a yield point or proportional limit (where the load-deflection curve departs from a straight line).

6.2.1.2 Additional compression tests. Two series of additional compression tests were performed on another group of timbers to ascertain the effects of freezing and varying load-to-grain angle on the strength of drydocking timbers. These tests were performed on new Douglas fir and oak timbers.

6.2.1.2.1 Tests on frozen and unfrozen timbers. This set of compressive tests on individual timbers was performed on six new Douglas fir and six new oak timbers. All measured 6 x 14 x 48 inches initially. Each was cut into two 6 x 14 x 24 inch sections. One section of each timber was frozen prior to the compression test. Both the frozen and unfrozen sections were tested to determine the effect of freezing on strength. Each timber in this group was also tested in a second compression test either frozen or in the ambient condition, to determine any deleterious effects resulting from the previous compressive loading above the proportional limit.

6.2.1.2.1.1 Test results. A summary comparison of compressive test results for frozen and unfrozen individual oak and Douglas fir timbers is presented in Tables VII and VIII.

TABLE VII. *Summary of compressive tests on unfrozen/frozen timbers (FSPL). Stress at proportional limit (lb/in²).*

		Species			
		Oak		Douglas fir	
		I[1]	II[2]	I	II
Overall					
Unfrozen	N	6	6	6	6
	$\bar{x}$	596	689	328	444
	R	490–673	485–895	258–421	315–461
	S	64.1	144.9	56.5	67.2
Frozen	N	6	6	6	6
	$\bar{x}$	856	875	444	548
	R	755–999	654–1297	343–477	424–662
	S	95.5	224.7	52.4	91.7
Average of Averages		726	782	375	496
		754		436	

[1]Loaded just above the proportional limit and then returned to ambient or frozen condition.
[2]The same specimen re-loaded to destruction.

N = Number of tests
$\bar{x}$ = Average or mean
R = Range of values
S = Standard deviation

The test data is shown in table VII for FSPL and in table VIII for MOE. The data is shown graphically on figure 9. The results show the increased strength and stiffness brought about by freezing. FSPL increased about 44 percent for frozen oak and 29 percent for frozen Douglas fir. In the case of MOE values, oak increased 35 percent and Douglas fir increased 32 percent.

The most interesting results of this set of tests are best seen in figure 9, the graphs of the ranges and averages of FSPL and MOE. Note that in each case, frozen and unfrozen oak and Douglas fir, the FSPL averages increase and ranges widen in the second compression test (after the original proportional limit has been exceeded). Furthermore, the MOE averages decrease and the ranges narrow in the second compression test.

TABLE VIII. *Summary of compressive tests on unfrozen/frozen timbers (MOE). Modulus of elasticity (kis).*

		Species			
		Oak		Douglas fir	
		I[1]	II[2]	I	II
Overall					
Unfrozen	N	6	6	6	6
	$\bar{x}$	35.48	19.86	26.67	8.05
	R	19.6–47.9	12.93–26.80	13.46–35.58	5.85–10.48
	S	9.87	5.00	7.83	1.64
Frozen	N	6	6	6	6
	$\bar{x}$	47.77	33.50	35.27	12.16
	R	33.13–57.59	28.18–41.05	24.36–47.05	9.89–15.49
	S	8.78	5.00	7.88	2.12
Average of Averages		41.6	26.7	31.0	10.1
		34.2		20.6	

[1]Loaded just above the proportional limit and then returned to ambient or frozen condition.
[2]The same specimen re-loaded to destruction.

N = Number of tests
$\bar{x}$ = Average or mean
R = Range of values
S = Standard deviation

6.2.1.2.1.2 Conclusions. Frozen docking timbers have higher strength and stiffness than unfrozen timber. The effect on a timber from successive loadings above its proportional limit is unknown. But even one overloading appears to lower MOE significantly; approximately 70 percent for unfrozen Douglas fir, and 44 percent for unfrozen oak.

These test results suggest that while wood can carry loads of approximately the same magnitude even after overloading, the stiffness decreases along with predictability of deflection.

6.2.1.2.1.3 Test procedures. The preliminary preparations for testing were the same as those described in Sections 6.2.1.1.7, 6.2.1.1.8, and 6.2.1.1.9 for individual timber tests. After each of the six oak and Douglas fir 6 x 14 x 48 inch timbers had been identified, they were sawn in half. One end was placed in a freezer at 0 degrees Fahrenheit (°F), and the other was stored outdoor under conditions similar to those for other timbers in the project. (End-matching of test specimens provides a method of increasing confidence in testing differences between two treatments without requiring as large a sample.)

6.2.1.2.1.4 The timbers were stored in the freezer several days before testing. A small hole was drilled into the center of each timber, and its internal temperature was monitored during storage and during the compression test. Prior to testing, they were removed from the freezer, placed in an insulated box and taken to the test machine. The temperatures of the 12 frozen timbers averaged approximately minus 1 °F at the start of testing and plus 3 °F at the end.

6.2.1.2.1.5 Each of the timbers was compressed to slightly above its proportional limit (see figure 10, test I), as observed on the x-y recorder which plotted load and deflection during the test. At this point, they were taken out of the test machine and returned to storage, either to the freezer for the frozen test specimens, or to outdoor ambient temperature for the unfrozen test specimens. Several days later, the compression tests were repeated, (see figure 10, test II) except that in the second test they were continued well past the proportional limit. The reloading curve of test II is offset from the unloading of test I because the stress-strain plot was started at zero deflection on the figure.

6.2.1.2.2 Tests on varying load-to-grain angle. A set of compressive tests on individual timbers was performed to determine the effect of the slope of the annual rings on the compressive strength of the timber (see figure 11). The initial plan was to test 18 4 x 12 x 48 inch Douglas fir timbers with 3 different angles of annual rings relative to the direction of the load, 6 each with 0, 45 and 90-degree angles. The actual annual ring angle orientations of the 18 timbers were not distributed as planned, however. Unless the logs were of larger diameter than are typically seen today, it would be difficult to saw a timber from each of 18 different logs with a highly consistent grain angle through a 4 x 12 inch cross-section, particularly for the 90-degree angle and to a lesser extent the 0-degree angle. Based on the nearest actual angle, however, the data was divided between two angles; 8 timbers were at a 0-degree angle, and 10 were at a 45-degree angle.

6.2.1.2.2.1 Test results. The results for FSPL and MOE for the two grain orientations are shown in table IX. Clearly, there is no significant difference in strength or stiffness between the two sets of timbers with grain angles of 0 and 45 degrees to the direction of the load. However, whether a 90-degree angle of the annual rings to the load would have shown significant changes in the strength properties is unknown as this case was not evaluated.

TABLE IX. *Summary of compressive tests on timbers with varying load-to-grain angles.*

Orientation		Dougles fir	
		Stress at proportional limit (lb/in^2)	Modulus of elasticity (ksi)
0 Degrees to load direction	N	8	8
	$\bar{x}$	427.6	26.67
	R	376–515	20.86–35.56
	S	49.20	5.24
	COV	11.5 percent	19.65 percent
45 Degrees to load direction	N	10	10
	$\bar{x}$	430.8	27.53
	R	373–553	20.84–35.86
	S	53.40	4.95
	COV	12.4 percent	17.98 percent

N = Number of tests R = Range of values COV = Coefficient of variation
$\bar{x}$ = Average or mean S = Standard deviation

6.2.1.2.2.2 Conclusions. No conclusive relationship between the grain angle of timbers to the direction of the load was determined, thus requiring more testing, especially for the 90-degree case. If, for example, the wood were a low-density softwood with wide annual rings, compressive strength might be different between 0 and 90-degree angle to the load. Mostly the effect of grain angle, if any, is likely to be much less than other factors producing variation in timber strengths. Furthermore, as tree size at harvest has continued to decline and logs at the saw mill become smaller, the possibility of sawing timbers with specific grain angle orientations becomes more remote.

6.2.1.2.2.3 Test procedures. The 18 4 x 12 x 48 inch Douglas fir timbers for this set of tests were received from the Puget Sound Naval Shipyard (PSNSY). Preparation, identification of the timbers, compression tests, and the load-deflection plots were carried out in the same manner as described in 6.2.1.1.5 tests on individual timbers. As mentioned previously, the timbers received did not conform to grain angles planned for this experiment, so tests were made on 0- and 45-degree grain angles only.

6.2.2 Tests on laminated red oak. Tests were conducted on a series of laminated timbers in order to determine compressive strengths so that a comparison could be drawn between laminated and solid sawn timbers. Tests included new 6 x 14 x 20 inch sections of laminated red oak, both pressured treated and dry, a 6 x 12.5 x 24 inch section of Micro-Lam, and a 6 x 14 x 48 inch section of a used laminated red oak timber. Further description of these timbers and the laminating processes used is contained in 6.2.2.3 test procedures.

6.2.2.1 Test results. The results of the compressive tests, which include FSPL and MOE for each of the eight laminated red oak specimens, are shown in table X. Table XI shows the average, standard deviations, and coefficient of variation for the six "wet" timbers. This data is presented for comparison with the solid timbers previously tested. Average values are also shown in table X for the timbers with respect to each grade of lumber, select and #1 common. The sample is very small, but there does not appear to be a significant difference between the two grades.

6.2.2.1.1 The results of the tests on the six laminated red oak timbers can also be seen in the stress-strain graph on figure 12. Curves for all of the six timbers with high moisture content and the two dry timbers are shown on the same graph. The similarity of slope and general shape of the high moisture content timber curves reflect the relative uniformity of the timber responses to the same loads. The steep slope and high proportional limit of the dry timbers in comparison with the others shows the strong effect that high moisture content has on the compressive properties of wood. The curves on figure 13 are stress-strain curves of six new (unused) 6 x 14 x 48 inch Douglas fir timbers tested in compression in previous work. Note the wider spread and less consistent shape of the latter set of curves compared to those for the laminated timbers.

TABLE X. *Compressive test results for laminated timbers.*

Specimen	Wet/Dry	FSPL (lb/in^2)	MOE (lb/in^2)	Averages of wet timber by grade FSPL (lb/in^2)	Averages of wet timber by grade MOE (lb/in^2)
#1 Com (Red Oak)	Wet	551	69,025	–	–
#1 Com (Red Oak)	Wet	495	59,275	516	57,397
#1 Com (Red Oak)	Wet	502	43,890	–	–
Select (Red Oak)	Wet	621	48,670	–	–
Select (Red Oak)	Wet	633	63,320	591	55,295
Select (Red Oak)	Wet	518	53,895	–	–
#1 Com (Red Oak)	Dry	1,202	329,053	–	–
Select (Red Oak)	Dry	1,162	231,023	–	–
Micro-Lam	Wet	413	22,877	–	–
Used PSNSY laminated red oak timber	Wet	478	11,006	–	–

TABLE XI. *Comparison of strength properties of laminated and sawn timbers.*

Laminated timbers (6 x 14 x 14 inches)			Sawn timbers (New, all sizes)		
	FSPL (lb/in^2)	MOE (lb/in^2)		FSPL (lb/in^2)	MOE (lb/in^2)
Mean	553	56,346	Mean	575	35,759
Std dev	55.1	8,545	Std dev	101	8,870
Coef var	10.9 percent	16.6 percent	Coef var	17.6 percent	24.8 percent

Notes: Laminated timbers data extracted from table X.
Sawn timbers data extracted from tables V, VI, VII, and VIII.

6.2.2.1.2 Test values for Micro-Lam and the used laminated timber from Puget Sound Naval Shipyard are also included in table X. The Micro-Lam was expected to have greater strength, especially stiffness, than the tests indicated because the 1/10-inch veneer of which it is constructed is selected for superior quality before it is laminated into a beam. Ordinarily, Micro-Lam is not used in compression, and the effect of long saturation in a wood preservative solution on its mechanical strength is unknown. Its FSPL of 413 lb/in^2 and MOE of 22,877 lb/in^2 compare well with the averages of the 39 6 x 14 inch new Douglas fir timbers tested previously.

6.2.2.1.3 FSPL of 367 lb/in^2 and MOE of 26,810 lb/in^2 (see table I). Micro-Lam can be expected to exhibit a high degree of consistency because of the large number of veneers in each timer, i.e., as many as 150 in a timer 14 inches wide.

6.2.2.1.4 The compression test results on the laminated timber from the Puget Sound Naval Shipyard inventory (table X) were similar to other data seen on well-used drydocking blocks. The FSPL has stayed fairly high in relation to averages for unused timbers, but the MOE has declined substantially from those of unused timbers.

6.2.2.1.5 Included in table XI is data for 21 solid sawn new oak timbers that measured 6 x 14 x 48 inches and were tested in compression during the earlier work on timbers from drydocking inventories.

6.2.2.2 Conclusions. The data clearly show the relative equivalence of the load-carrying capacity of new laminated and sawn oak timbers. In addition, the reduction of variability with the laminated timbers is apparent. Standard deviations and coefficients of variation are little more than half those for sawn timbers, which, as expected, indicated that laminated timbers would have less variation between timbers. With a larger sampling of laminated timbers, it is anticipated that the variability would prove to be even less.

6.2.2.2.1 The MOEs of the laminated timbers appear to be significantly higher than those of the unused sawn timbers. In view of the close similarity of the FSPLs of the two types, it is not clear what this data suggests. It may be related to the grouping of essentially the same annual ring orientation in most of the boards in the laminated timbers. Large sawn timbers, on the other hand, particularly those that include the pith, have a highly varied annual ring orientation within the cross-section.

6.2.2.3 Test procedures. The lamination of timbers, pressure treatment, and compressive test procedures are described in the following sections.

6.2.2.3.1 Lamination of timbers. Six 6 x 14 x 20 inch laminated red oak timbers were ordered from a Midwest timber laminator with substantial experience in the manufacture of laminated oak frames for U.S. Navy MCM class minesweepers. The timbers were composed of 18 layers of nominal 1-inch lumber. (Nominal 1-inch lumber is 13/16-inch thick, which after surfacing for gluing accounts for the use of 18 boards for the 14-inch wide timber).

6.2.2.3.1.1 Three of the timbers were made of select or better grades, and three were made of #1 common lumber. The red oak lumber selected for these timbers was from the inventory of material purchased by the laminator from saw mills in the upper Midwest. The lumber was dried to 12–15 percent moisture content, planed, and graded before selection for gluing.

6.2.2.3.1.2 The timbers were glued with a phenol-resorcinol adhesive approved for use in oak laminates under MIL-W-15154. Clamping pressure was 150 lb/in^2, and the glue was cured by heating the timbers in a chamber overnight for approximately 14 hours. The center glueline temperature reached 150 °F which enhanced the quality of the bond of the oak laminates.

6.2.2.3.1.3 After gluing, the timbers were surfaced to the exact dimensions of 6 x 14 inches and shipped to Seattle. On arrival the timbers were marked for identification and cut in the pattern shown on figure 14. The portion to be pressure-treated was weighed and then transported to the wood preservation plant. (See table XII for weights before and after pressure- treating.) The untreated portions were wrapped in plastic and stored temporarily. The portions marked "Field Test" were sent to shipyards for use in their drydocks. No in-service data has yet been collected for these pieces.

TABLE XII. *Before and after treatment weights and estimated moisture contents of laminated compression test specimens (6 x 14 x 24 inches).*

Specimen No.	Original weight (lbs)	Weight after preservation treatment (lbs)	Estimated moisture content	
			If originally 12 (percent)	If originally 16 (percent)
1	52.0	72.1	56	65
2	52.5	67.6	44	49
3	51.0	68.1	50	55
4	50.5	72.8	49	67
5	52.3	69.0	48	53
6	50.0	70.5	58	64

6.2.2.3.2 Pressure treatment of laminated timbers. Since drydocking timbers are at high moisture content, their strengths are low compared to dry timbers. Therefore, for fair comparison of the properties of laminated and sawn timbers, it was necessary to raise the moisture content of the laminated timbers above 25–30 percent.

6.2.2.3.2.1 Because considerable time is required to thoroughly wet large cross-sections of wood underwater at normal pressures, the timbers in this study were pressure-treated with a waterborne preservative to achieve moisture contents above the fiber saturation point. It is important to note here that the use of a preservative was incidental to the evaluation of the laminated timbers. This was a simple method of obtaining the use of a large enough pressure vessel so that moisture content could be increased rapidly. This approach would not have worked with white oak because it is very resistant to absorption of liquids, even under pressure. Red oak is much more easily treated and, in contrast to white oak, is only slightly resistant to decay. Preservative treatment would be mandatory for red oak if it were used in drydocking. The mechanical strengths of red and white oak are generally similar; therefore, in this case, red oak made a good substitute for laminated white oak for the purposes of these tests.

6.2.2.3.2.2 The laminated timbers for this study were pressure-treated with chromated copper arsenate in a water solution. The timbers were included in the retort with other wood products being treated. In the treating process, first an initial vacuum of 26 inches was drawn for 30 minutes. Then, while the vacuum was still on, the retort was filled with the treating solution. This step required 50 minutes.

6.2.2.3.2.3 The treating solution was 1.6 percent preservative-in-water by weight. The vacuum was removed and 110 lb/in^2 applied to the liquid in the retort for 4 hours and 20 minutes. The retort was then emptied and a final vacuum of 26 inches was applied again for 30 minutes. Results for solution absorption and salt retention for the compression test specimens of this project are shown in table XIII.

TABLE XIII. *Chromated copper arsenate solution absorption (solution concentration 1.6 percent).*

Compressive test specimens – 6 x 14 x 24 inches – 1.167 cubic feet		
Specimen	Solution absorption (gallons/cu ft)	Salt retention (lbs/cu ft)
1	2.03	0.28
2	1.53	0.21
3	1.73	0.23
4	2.25	0.31
5	1.69	0.23
6	2.07	0.28

6.2.2.3.2.4 The treated wood was allowed to drain for five days and then was returned to Seattle for the compressive tests. Table XII shows the weights before and after treatment and calculations of approximate moisture content. As that table shows, the moisture content of all of the treated specimens appeared to be greater than 30 percent; therefore, strength values could be compared with the earlier results with the high moisture content sawn timbers from the drydocks.

6.2.2.3.3 Compressive tests. The dimensions of the timbers had changed slightly because of swelling during the treating process. In addition, the 14 x 24 inch surfaces were uneven between the layers due to differential swelling that occurred during and after pressure treatment. Adjacent laminae in the timber, having some variation in orientation of annual rings, density, or initial moisture content, sometimes swelled different amounts, creating 1/8 to 3/16-inch variations in height across some timbers. The surfaces were passed over a jointer to smooth them in order to make possible equal application of pressure across the specimens during the compressive testing.

6.2.2.3.3.1 Two-foot sections of each of the six treated timbers and two of the untreated 2-foot sections were subjected to compressive tests in a 600,000 pound capacity Satec universal testing machine. A photograph of the test specimen in place in the test machine is shown on figure 15. Each timber was loaded over the entire 14 x 24 inch surface until deflection reached 1 inch. At intervals of .005, .010, .020, or .050 inches, depending on the specimen and the part of the loading cycle, the loads were recorded and used to plot the stress-strain curve for each timber (see figure XII).

6.2.2.3.3.2 Photographs at various stages of a compression test are shown on figures 16 through 19. The FSPL and MOE were calculated for each laminated timber.

6.2.2.3.3.3 Compression tests were also performed on two dry laminated timbers, one each from the select and #1 common grades. These dry sections were cut from the original timbers immediately adjacent to the sections that 5 were pressure-treated so that wood in each was nearly identical and therefore could provide good evidence of the effect of high moisture content on the strength properties.

6.2.2.3.3.4 In addition to the above tests, one compression test was conducted on a section of Micro-Lam, a 6 x 12.5 x 24 inch timber laminated from 1/10-inch pieces of Douglas fir veneer with the grain of all of the veneers parallel, as opposed to the grain of adjacent veneers at right angles to each other, as in plywood. (Micro-Lam is a trademark owned by Trus-Joist Co., Boise, ID.) The Micro-Lam had been vacuum pressure-treated with a waterborne preservative solution and then wrapped in a plastic sheet and stored for more than a year. This recently developed laminated product is used more often in beams and truss members. Its mechanical properties are consistent because of the large number of veneers in a piece the size of a drydocking timber; therefore, it was suggested as another possible substitute for solid, sawn Douglas fir drydocking blocks.

6.2.2.3.3.5 Tests were also conducted on an old laminated 6 x 14 x 48 inch timber from Puget Sound Naval Shipyard. This timber was all red oak and approximately 1-5/8 inches thick. It had been in service an undetermined period of time and had some glueline delamination.

6.3 Compression tests on layered timbers. Compression tests were made on two different configurations of layers of timbers in order to compare the FSPL and MOE of layers versus individual timbers. These tests were designed to allow observation of the strengths of multiple timbers under compression without the influence of the composite block build-ups.

6.3.1 The single-layer tests were performed on three adjacent 6 x 14 x 48 inch timbers. The three-layer configuration consisted of a top and bottom layer of three timbers measuring 6 x 14 x 48 inches and a middle layer of four timbers measuring 6 x 12 x 42 inch. The middle layers were placed at a right angle to the top and bottom layers (see figure 20).

6.3.2 Test results. Layer test results are summarized in table XIV and presented graphically on figure 21.

TABLE XIV. *Summary of compressive tests on one and three layers of timbers.*

Layers	Age-species		Stress at proportional limit (lb/in^2)	Modulus of elasticity (ksi)
1	New fir	N	5	5
		$\bar{x}$	418	25.92
		R	348–472	19.07–29.97
		S	48.3	4.24
		COV	12 percent	16 percent
1	New oak	N	5	5
		$\bar{x}$	609	20.25
		R	458–866	14.82–26.64
		S	176.4	4.78
		COV	29 percent	24 percent
1	Old oak	N	5	5
		$\bar{x}$	793	32.57
		R	481–1009	16.73–42.32
		S	241.6	11.85
		COV	30 percent	36 percent
1	New pine	N	3	3
		$\bar{x}$	434	16.18
		R	334–488	11.61–23.99
		S	86.4	6.8
		COV	20 percent	42 percent
3	New fir	N	2	2
		$\bar{x}$	340	26.41
		R	324–356	24.37–28.45
		S	–	–
		COV	–	–
3	Old oak	N	3	3
		$\bar{x}$	494	23.98
		R	416–548	22.83–25.02
		S	69.0	1.10
		COV	14 percent	5 percent

N = Number of tests
$\bar{x}$ = Average or mean
R = Range of values
S = Standard deviation
COV = Coefficient of variation

6.3.2.1 The average test values for FSPL in the single layers indicate that the strength of new Douglas fir is approximately equal to new southern pine (418 lb/in^2 and 434 lb/in^2, respectively) and that the strength of both types of wood is less than new oak (609 lb/in^2).

6.3.2.2 The average MOEs for the single-layer tests with new wood were highest for Douglas fir (25,920 lb/in^2), followed by oak (20,250 lb/in^2) and southern pine (16,180 lb/in^2). There was no obvious reason for the unexpectedly low MOE for the oak, because in the pooled data for individual timbers, the average MOE for oak was 37,220 lb/in^2. Also, while the Southern pine FSPL was about the same as the FSPL for Douglas fir, the MOE for the pine was somewhat lower. Because MOE is not ordinarily measured in compression perpendicular to the grain, it is not possible to compare these test results with published values.

6.3.2.3 The five tests on single layers of old oak timbers also produced unexpected results. The FSPL average was higher than the new oak and higher than the previous average of the pooled individual oak timbers. Despite being in the "old" category, however, it is apparent that this group of timbers had not been used much and that some timbers were superior, they had wide growth rings, which is consistent with higher density and strength in ring-porous woods such as oak. The three-layer new Douglas fir test results more closely followed predictable lines. The average values were about the same as the pooled values for new individual timbers of Douglas fir (i.e., 340 lb/in^2 for the three-layer FSPL and 367 lb/in^2 for the individual timber FSPL, and 27,410 lb/in^2 for the three-layer MOE and 26,810 psi for the individual timber MOE).

6.3.2.4 The three layers of old oak had relatively low FSPL and MOE values, but they were consistent within the range of lower readings in comparison to other sets of data for oak timbers, layered or individual timbers.

6.3.3 Conclusions. The layer tests were relatively limited; two to five tests for each condition. Even though the sample size was small, the data in general seems to correlate to the individual timber strength test results. There is no obvious enhancement of collective strength by forming layers. It was expected, however, that as the number of timbers in the assembly increased, the variation of strength properties between similar assemblies would decrease. In comparing the coefficients of variation in table XIV with the coefficients of variation for individual timbers, there is no consistent evidence that variation decreases with multiple timbers. This is probably due in part to a smaller sample size for the layer tests; in a larger population, it is reasonable to expect less variation in strength between groups of timbers acting together rather than individually. The apparent anomalies found in the layer test results are indicative of the fact that while the individual timbers are statistically similar, a large enough degree of variation exists such that even a combination of timbers is not a predictable construction. Therefore, care must be taken to design composite blocks to the low end of the expected strength range.

6.3.4 Testing procedures. The timbers were acquired and assembled at the same time and in the same manner as the individual timbers described in 6.2.1.1.5 except the southern pine, which arrived late because of procurement difficulties. An identification sheet for each layer test was prepared to record timber dimensions and to calculate the area under compression (see figure 22). Because of the large amount of data acquired on individual timbers, the weight of the timbers was omitted in the layer test data and the moisture content was measured with a moisture meter. The moisture meter gives a much faster measurement and appeared to be adequate because the individual timbers tested were from the same stock of timbers and proved to be at the fiber saturation point or above. The exception to this procedure was the southern pine timbers, which had not been tested previously. They were weighed, cores were drilled, and moisture content and specific gravity were determined as done previously with the individual timber tests on oak and Douglas fir.

6.3.4.1 One-inch grids were applied to one end of each timber to aid in analyzing the photographs (see figure 23). For compression tests, the layers were assembled and centered under the machine head and the two linear variable differential transformers (LVDTs) for deflection measurement were placed against the head at opposite corners of the assembly, a procedure similar to that used in the individual timber tests. An initial load of 10 kips was applied before the test began to settle minor variations in thickness. Loading was increased to the proportional limit at a rate of 35 to 40 kips per 30-second interval, then controlled by limiting the deflection to 0.1 inches per 30-second interval. Photographs were taken of one end of the single-layer assembly before loading, at 0.5 inches and 1.0 inch deflection, and again after the load was removed. Photos were also taken at 1.5 inches, 2.0 inches, and 3.0 inches of deflection on the three-layer tests. Tests were stopped at the machine load limit of 2,400 kips.

6.4 Compression tests on medium height (standard U.S. Navy) composite block build-ups. Composite block build-ups consisting of concrete blocks combined with oak and Douglas fir timbers were assembled to a nominal 57-inch total height, as shown in figure 24. The total height of wood in each composite was a nominal 42-inch, but actual wood height varied slightly because of variations in individual timber thickness.

6.4.1 To represent the quality of docking blocks encountered at shipyards, five composite blocks were formed using new timbers and five using old timbers. The 10 concrete components furnished by the Puget Sound Naval Shipyard from their operating inventory were identified as half-pier blocks, each consisting of a steel reinforced concrete block measuring 24 inches wide by 48 inches long and 15 inches high. On the bottom of each concrete block were three 6 x 14 x 48 inch oak timbers attached by stud bolts and countersunk nuts.

6.4.1.1 None of the concrete blocks were new; therefore, the five appearing to be in the best condition were assigned to be used with new timbers, and the remaining five were assigned to tests using old timbers. The oak timbers attached to the bottom of the concrete blocks were old in both the new and old test series (see table XV).

6.4.2 Test results. The results of the tests are presented in table XV, which summarizes the fiber stress at proportional limit (FSPL) and modulus of elasticity (MOE) within the elastic zone for each composite build-up. Included in the table are the averages, ranges of values, standard deviations, and coefficients of variation for the new and old timber block build-ups. The averages and ranges are also shown graphically on figure 25. Examples of typical stress/strain diagrams for the new and old timber build-ups are shown on figure 26. Note that the FSPL is about the same for each block, but the MOE of the old block is much lower.

6.4.2.1 The averages of FSPL and MOE for the medium height composite block tests are shown in table XVI with the average results of tests on individual timbers from 6.2 (tables V and VI). The results for the medium blocks (with two layers of 12 x 14 inch oak) appear to be well in line with the results of 12 x 14 inch new and old oak individual timbers, given that the block build-ups had Douglas fir capping and a layer of used oak on the concrete block in each case.

TABLE XV. *Summary of compressive tests on medium block build-ups.*

Age	Species		FSPL (lb/in^2)	MOE (ksi)
New	Oak (Douglas fir capping)	Test values	387, 390, 410, 518, and 540	42.54, 38.97, 36.86, 29.80, and 36.41
		Average	449	36.92
		Range	387−540	29.8−42.5
		Std Dev	73.97	4.66
		COV (percent)	16	13
Old	Oak (Douglas fir capping)	Test values	304, 356, 383, 400, and 411	16.59, 19.64, 20.18, 12.58, and 12.95
		Average	371	16.39
		Range	304−411	12.6−20.2
		Std Dev	42.72	3.58
		COV (percent)	12	22

TABLE XVI. *Comparison between medium height build-ups and individual timbers.*

	FSPL (lb/in^2)	MOE (lb/in^2)
New oak block build-ups	449	36.92
Old oak block build-ups	371	16.39
New oak individual timbers, 12 x 14 inches	487	39.86
Old oak individual timbers, 12 x 14 inches	410	21.64

6.4.3 Conclusions. The results show that the average FSPL for the composite blocks containing old timbers was lower than for those containing new timbers, and that the MOE of old timber composites was much lower than composites with new timbers. FSPLs for old timber composites averaged 17 percent lower than new timber composites, and the MOE for the old timber composites averaged 56 percent lower than the new composites.

6.4.3.1 These results are influenced by the effect of the Douglas fir capping. The FSPL of the new timber composite is mostly due to the Douglas fir capping reaching its FSPL. But in the old wood composite, the effect of the capping is not so clear; some of the old 12 x 14 inch oak timbers immediately beneath the Douglas fir capping were so deteriorated that the capping was able to press down into the oak (see figure 27). Note in the figure that the Douglas fir capping timbers on the left and right appear to have compressed relatively less than the oak timbers beneath them, while the Douglas fir and oak in the middle show the more expected pattern. The old oak layer permanently affixed to the concrete block also has a small effect on the new timber block results.

6.4.4 Comparison of medium block tests with previous tests. The results of this research can be compared to the results of earlier tests. Tests of similar composite block build-ups are described in NAVSEA 0901-LP-997-0000 Chapter 997. The tests were performed at David Taylor Naval Ship Research and Development Center.

6.4.4.1 The tests of eight docking blocks reported in Chapter 997 differ from those of the blocks tested here in several ways: they used a 33.5-inch timber height instead of 42-inch, hard caps on at least three of the blocks, and a load distributed by means of a steel plate 36 inches wide to simulate a keel. However, the horizontal cross-sections of the blocks were the same 42 x 48 inch dimensions. Because of the different heights of wood in the two tests, an "apparent modulus of elasticity" (AMOE) was calculated for all of the blocks in both sets of data using the applied stress, observed compressive deflection, and the height of wood. The results for the David Taylor tests on composite blocks supplied by Norfolk Naval Shipyard are shown in table XVII for assumed loads of 496 lb/in^2.

6.4.4.2 In tables XVIII and XIX, data on the medium blocks of this work is shown using an assumed load of 500 lb/in^2 and an assumed wood height of 33.5 inches. The data is based on the test results shown in table XV. Table XVIII contains the old oak medium block data, and table XIX contains the new oak medium block data.

6.4.4.3 Table XX summarizes the figures for compression of blocks in the David Taylor tests and the compression of old and new blocks in this testing program, both calculated for a nearly identical load and the same assumed height of wood. Note from table XX that, on the average, the old oak timber blocks compress about twice as much as the new blocks. The similarity between MOEs of the David Taylor blocks and the old oak timber blocks is also significant.

6.4.4.3.1 This data, and other tests on old oak timbers in this research, suggest that timbers in service have average MOEs that are one-half or less of the expected MOE of new oak timbers. This indicates that at some time in their service lives, many (or most) timbers have been loaded beyond their proportional limit or have developed areas of decay. The case for over-loading as a cause of low MOEs is supported by the work reported in 6.2.1.2.1. In summary, it was found that exceeding the proportional limit lowered the modulus of elasticity by 70 percent for Douglas fir and 44 percent for oak.

6.4.4.3.1.1 The greater deflection that results from loads on low MOE timbers suggests that safety can be improved with greater heights of wood in blocks. Also, the use of timbers or other material with higher and less variable strength and stiffness would contribute to safer, more reliable drydocking.

6.4.5 Testing procedures. The 10 concrete blocks (with attached bottom oak) were received by truck from the Puget Sound Naval Shipyard. To prepare for each test, a concrete block was moved into the test machine by overhead crane and centered on the lower platen. Sixteen individual timbers were then randomly selected and positioned in layers, as shown previously in figure 24. The thickness of the timbers within a layer was matched as closely as possible in order to provide uniform loading over the entire area. Thus the assembled build-up contained two layers of three 6 x 14 x 48 inch oak timbers each, one layer of four 12 x 12 x 42 inch oak timbers, one layer of three 12 x 14 x 48 inch oak timbers, and a capping layer of three 6 x 14 x 48 inch Douglas fir timbers.

6.4.5.1 As the timbers were assembled, the moisture content within the outer 1-inch zone was measured with a moisture meter equipped with insulated pins to determine the moisture content gradient. During the earlier individual timber tests, core samples through each timber showed that the moisture content was generally above the fiber saturation point, even near the surface. Therefore the moisture meter proved to be an adequate check that the moisture content of the timbers in the build-ups was also at the fiber saturation point in the cross-section of each timber.

6.4.5.1.1 As each build-up was assembled, a sketch was made on the worksheet of each timber's growth ring orientation, moisture content, and dimensions.

6.4.5.1.2 After each composite build-up was assembled, the test machine head was lowered and a 10-kip pre-load was applied. The vertical deflection LVDTs were placed at opposite corners of the assembly and a reference photograph was taken (see figure 28). Reference grid lines had previously been applied to the end-grain of the timbers. The composite build-up was then loaded at a rate of approximately 80 kips per minute; a load and deflection data point was recorded at 30-second intervals. When the proportional limit had been reached, the rate of loading was increased and controlled by deflection at approximately 0.4 inches per minute and continued until the total deflection of the composite reached 4 inches. The load was then slowly released and the build-up allowed to relax for two minutes, then reloaded to 10 kips to measure and record set. Photographs were taken at approximately 500 kips, 1000 kips, 1500 kips and after the load was removed.

6.5 Stability characteristics of high blocks. The purpose of testing the high block was to determine its lateral stability under horizontal loads. The proposed plan was complicated by the possibility of damaging the 2.4 million-pound test machine through a lateral load. Therefore, it was decided to use a 1/10 scale model and to apply a horizontal force to the block by use of wedge-shaped top-loading head (see figure 29).

TABLE XVII. *Tests on Norfolk composite blocks (timber and concrete).*

Reported in NAVSEA CH-997[1]								
Wood in composite blocks was assumed to be white oak except for cap: hard-oak, soft-Douglas fir, age of wood not indicated.								
Composite block No.	1	2	3	4	5	6	7	8
Cap type	Not reported	Hard cap	Hard cap	Hard cap	Soft cap	Soft cap	Soft cap	Soft cap
Cap height, inches	5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Total wood height, inches	33	33.5	33.5	33.5	33.5	33.5	33.5	33.5
Cap load width x length, inches	42 x 48[2]	36 in. SP[3]	36 in.SP[3]	36 in. SP[3]	36 in.SP[3]	36 in. SP[3]	48 x 42[4]	48 x 42[4]
Applied load, kips	1000	1000	1000	1000	1000	1000	1000	1000
Stress, psi[5]	496	496	496	496	496	496	496	496
Block compression, inches	1.32	0.67	1.11	1.28	1.49	1.74	1.01	1.12
Strain, inch/inch[6]	0.04	0.02	0.033134	0.038209	0.0444776	0.0519403	0.0301493	0.0334328
Apparent modulus of elasticity[7]	12400	24800	14969	12981	11152	9549	16451	14836

[1]Naval Ships' Technical Manual NAVSEA 0901-LP-997-0000/CH-997R1 Docking Instructions and Routine Work in Drydock 15 Dec 1977 Ch1 1 Sep 1982, Page 15.

[2]Description of the test did not indicate that the load was applied other than over the entire 42 x 48 inch area.

[3]Load was applied through a 36 inch wide plate by 42 inches.

[4]Load was applied over entire 42 x 48 inch area.

[5]Applied load divided by 42 x 48 inches (2016 sq. inches).

[6]Calculated from block compression divided by total wood height.

[7]Apparent modulus of elasticity (AMOE) calculated from stress divided by strain assuming a straight line between 0 and 496 psi; although the fiber stress at proportional limit (FSPL) of some timbers may have been exceeded.

TABLE XVIII. *Tests on composite blocks, old (timber and concrete).*

Performed at University of Washington, Civil Engineering Laboratory					
Five composite blocks composed of old wood[1]					
Composite block No.	BM001	BM002	BM003	BM004	BM005
Cap type[2]	Soft	Soft	Soft	Soft	Soft
Cap height, inches	Nom 6	Nom 6	Nom 6	Nom 6	Nom 6
Total wood height, inches[3]	33.5	33.5	33.5	33.5	33.5
Cap load width x length, inches	Nom 42 x 48[4]	Nom 42 x 48[4]	Nom 42 x 48[4]	Nom 42 x 48[4]	Nom 42 x 48[4]
Applied load, kips[5]	Nom 1008 kips	Nom 1008 kips	Nom 1008 kips	Nom 1008 kips	Nom 1008 kips
Stress, psi[6]	500	500	500	500	500
Apparent modulus of elasticity[7]	11856	15796	14073	10498	10492
Strain, inch/inch	0.0421727	0.0316536	0.035529	0.0476281	0.0476554
Block compression, inches[8]	1.42	1.06	1.19	1.6	1.6

[1]Timbers in build-up below cap were old oak including 6 x 14 x 48 oak on bottom of concrete.
[2]Soft caps were old Douglas fir.
[3]When tested, nominal wood height was 42 inches; for comparison with CH-997 tests, height calculated as if 33.5 inches.
[4]Actual dimensions of each build-up were used during testing; load was applied over entire area.
[5]Applied load varied according to actual load area of each composite block.
[6]Stress calculated from actual area and applied load.
[7]Calculated as straight line between 0 and 500 psi.
[8]Calculated from the apparent modulus of elasticity for each block as if wood height were 33.5 inches.

TABLE XIX. *Tests on composite blocks, new (timber and concrete).*

Tests on composite blocks (timber and concrete) Performed at University of Washington, Civil Engineering Laboratory					
Five composite blocks composed of new wood[1]					
Composite block No.	BMN01	BMN02	BMN03	BMN04	BMN05
Cap type[2]	Soft	Soft	Soft	Soft	Soft
Cap height, inches	Nom 6	Nom 6	Nom 6	Nom 6	Nom 6
Total wood height, inches[3]	33.5	33.5	33.5	33.5	33.5
Cap load width x length, inches	Nom 42 x 48[4]	Nom 42 x 48[4]	Nom 42 x 48[4]	Nom 42 x 48[4]	Nom 42 x 48[4]
Applied load, kips[5]	Nom 1008 kips	Nom 1008 kips	Nom 1008 kips	Nom 1008 kips	Nom 1008 kips
Stress, psi[6]	500	500	500	500	500
Apparent modulus of elasticity[7]	27682	27689	25557	26855	22995
Strain, inch/inch	0.0180623	0.0180577	0.0195641	0.0186185	0.0217439
Block compression, inches[8]	0.61	0.61	0.66	0.62	0.73

[1]The timbers in the build-up below the cap were new oak except the 6 x 14 x 48 oak on bottom of concrete were not new.
[2]Soft caps were new Douglas fir.
[3]When tested, nominal wood height was 42 inches; for comparison with CH-997 tests, height was calculated as if 33.5 inches for block compression.
[4]The actual dimensions of each buildup were used during testing; load was applied over entire area.
[5]Applied load varied according to actual loaded area of each composite buildup.
[6]Stress calculated from actual area and applied load.
[7]Calculated as straight line between 0 and 500 psi.
[8]Calculated from the apparent modulus of elasticity for each block as if wood height were 33.5 inches.

TABLE XX. *Comparison of deflections and apparent MOEs of block compression tests.*
(Assumed wood height – 33.5 inches)

	"David Taylor" timbers (load 496 lb/in^2)			"Old" timbers (Load 500 lb/in^2)			"New" timbers (load 500 lb/in^2)		
Block No.	Compression (inches)	Apparent MOE (lb/in^2)	Comment	Compression (inches)	Apparent MOE (lb/in^2)	Comment	Compression (inches)	Apparent MOE (lb/in^2)	Comment
1	1.32	12400	(33" wood height)	1.42	11856	soft cap	0.61	27682	soft cap
2	0.67	24800	hard cap	1.06	15796	soft cap	0.61	27689	soft cap
3	1.11	14969	hard cap	1.19	14073	soft cap	0.66	25557	soft cap
4	1.28	12981	hard cap	1.6	10498	soft cap	0.62	26855	soft cap
5	1.49	11152	soft cap	1.6	10492	soft cap	0.73	22995	soft cap
6	1.74	9549	soft cap	–	–	–	–	–	–
7	1.01	16451	soft cap	–	–	–	–	–	–
8	1.12	14836	soft cap	–	–	–	–	–	–
Mean	1.22	14642	–	1.37	12543	–	0.65	26156	–
Std dev	0.301	4668	–	0.243	2334	–	0.051	1970	–
Range	0.67 to 1.79	9549 to 24800	–	1.06 to 1.6	10492 to 15796	–	0.61 to 0.73	22995 to 27689	–

6.5.1 Test results. The load-deflection curve for the high block model is shown in figure 30. This is the combined deflection of the entire build-up, and it actually shows the movement of the loading head of the test machine. Examination of this curve showed that for loads below 1,000 pounds (equivalent to 50 lb/in^2), the curve was non-linear, which was interpreted as tightening up of the stack. As loading increased above 1,000 pounds, the curve became linear until reaching 4,300 pounds (equivalent to 215 lb/in^2). From that point, the curve was non-linear until 6,000 pounds (equivalent to 300 lb/in^2). Above 6,300 pounds, the curve was straight again until the test was stopped at almost 7,600 pounds (equivalent to 375 lb/in^2). The approximate modulus of elasticity for the build-up was determined from the straight-line portion of the curve between 1,000 and 4,300 pounds (215 lb/in^2). This should be regarded as the spring constant of the block, since the 30-degree wedge complicates the actual modulus of elasticity calculation. The total height of the build-up at the start of the test was 15.71 inches at the low edge of the wedge, with a wood height of 8.78 inches The high edge of the wedge was 18.18 inches with a wood height of 11.01 inches, as measured from the photograph at the start of the test. The deflection from 1,000 pounds (50 lb/in^2) to 4,300 (215 lb/in^2) was 0.19 inches. Strain as inches per inch of height was calculated as follows:

Characteristic	Low edge (wood only)	High edge (wood only)	Average
Point a to b			
Strain change, in/in	0.02164	0.01726	0.01945
Stress change, lb/in^2	165	165	165
MOE, lb/in^2		7625	95618483

*Based on average strain.

The high block model had a MOE and FSPL lower than the full-scale composite build-ups and layers tested. The possible factors contributing to this were:

a. The model was composed of 15 layers of wood and 2 layers of concrete, with 18 interfaces that all must be brought into intimate contact for full stress transfer between layers. It is reasonable to expect that some adjustment of contact is still occurring after point a on the curve, even though the curve has become essentially straight.

b. The Douglas fir and oak timbers used for the model were fine-grained, meaning that they grew at a slower rate than most of the wood used in the full-scale tests. Slow growth is associated with somewhat lower strength properties than with faster growth, particularly with Douglas fir.

c. The oak layers were analyzed from the photographs to determine their modulus of elasticity. The combined height of oak was 6.82 inches The deflection of the oak from initial loading to a stress of 375 lb/in^2 was 0.115 inches or 0.016862 inches/inch. The modulus of elasticity was calculated as 22,200 lb/in^2.

d. A similar analysis was made of the Douglas fir wood composing the wedge and the capping layer under the wedge. From measurements of the photographs, the Douglas fir modulus of elasticity was calculated as approximately 7,100 lb/in^2 up to a stress of 200 lb/in^2.

6.5.1.1 Measurements from the photographs taken during loading provided data on the deflection of each layer of wood during the test. Each photograph was examined under magnification in order to read the location (from the right-hand vertical scale) of the top and bottom of each layer of wood. This was done at each imposed load for which a picture had been taken. The measurements provided data on the progressive compression of each layer.

6.5.1.1.2 The Douglas fir wedge and the capping layer just under the wedge were expected to have the lowest FSPL. The plot of thickness measurement versus load was examined, and it was noted that the first slight failure was at the low edge of the wedge at about a 200 lb/in^2 load (slightly below point b on figure 30). The next failure appeared to be at the high side of the wedge at approximately 295 lb/in^2, followed by failure in the Douglas fir capping layer at approximately 313 lb/in^2.

6.5.2 Conclusions. It was concluded that the lower MOE and FSPL were primarily due to the lower strength properties of the Douglas fir used in the model.

The photographs taken during the loading sequence were examined under magnification to detect any horizontal movement. This examination revealed that up to the limit of the imposed load (equivalent to 375 lb/in^2), there was no detectable horizontal movement in relationship to the reference threads. The block was stable. It is noted that the wedge surface was sandblasted; therefore, it may not be representative of a painted hull in contact with the Douglas fir wedge surface.

6.5.3 Testing procedures. The model components were made on a 1/10 scale, yielding a completed model that was 4.2 x 4.8 x 14.4 inch using the sizes and materials shown on figure 28. Before testing, the moisture content of the wood was increased to the levels found in the earlier timber tests.

6.5.3.1 The model consisted of layers of oak timbers and concrete blocks. The top cap layer of Douglas fir timbers supported the 30-degree angle wedge build-up, providing a snug fit against the simulated hull of the ship. Both oak and Douglas fir model timbers were cut from fine-grain stock, about 20 to 30 rings per inch.

6.5.3.1.1 The ship hull surface was represented by a steel wedge cut at 30 degrees to the horizontal and attached to the loading head of the test machine. The wedge surface was commercially sandblasted and left unpainted for this test. This procedure added some friction against the wood block but there was no attempt to duplicate any of the hull surface effects caused by paint, rust, or fouling.

6.5.3.1.2 The high block model rested on a steel plate in the test machine. The steel plate provided attachment points for four vertical reference lines of tensioned threads spaced 1/2-inch from the vertical surface of the model. The wood was not attached to the steel base plate except by friction and was allowed to move in response to imposed forces.

6.5.3.1.3 The four vertical, tensioned reference threads were attached to the loading head by means of a roller system that maintained thread tension during loading of the model. Four horizontal reference scales were attached to the front surfaces of the two concrete blocks to detect horizontal movement and distortion under loading.

6.5.3.1.4 The test machine was equipped to record applied force and vertical movement of the loading head as a single pen trace on a strip chart system.

6.5.3.1.5 The model contained nine layers of wood and the seven-layer wedge. To detect deflection within each layer, two vertical scales were installed and a camera with a telephoto lens was set up to take frequent pictures during loading. Measurements made on the photographs using the reference lines and scale grids would provide deflection measurements for each layer.

6.5.3.1.6 A vertically applied force was brought to bear on the model via the 30-degree angle steel wedge. Increasing the vertical load on the model resulted in an increasing force in the horizontal direction, thus increasing the potential for block instability.

6.5.3.1.7 After the photographs were developed, they were analyzed along with the overall load-deflection curve to determine component reactions.

6.6 Friction tests for cribbing materials. Cribbing between keel blocks takes different forms in different dry docks. The purpose of cribbing is to enhance lateral stability, particularly during earthquakes or high winds. In many cases, the cribbing between blocks consists of timbers running through more than one block assembly and held in place only by the friction of the bilge or keel block under load. Some dry docks use steel plates rather than wood. This part of the testing program was undertaken to provide data on the amount of friction between several possible surfaces used in the assembly of keel block cribbing. This data can be useful in developing more reliable design criteria.

6.6.1 Each friction test involved two stacks of three layers of timbers. The cribbing timbers were placed parallel to each other and at right angles to the top and bottom layers of each stack (see figure 31). The equipment was arranged to permit applying a horizontal force to the ends of the middle layers while both stacks were under a header that applied a vertical load to both. The required force to produce horizontal movement would be recorded to determine coefficients of friction, both dry and wet, for various combinations of oak, Douglas fir, and steel.

6.6.2 Test results. The summary results in table XXI and figure 32 show the average, range, and standard deviation for each of the tests.

TABLE XXI. *Summary of coefficient of friction for four interfaces based on laterally-loaded cribbing-friction tests (150 lb/in^2 vertical load).*

Surface condition		Friction surfaces			
		Fir/fir	Fir/oak	Oak/oak	Oak/steel
Dry	N	4	4	4	2
	$\bar{x}$	0.45	0.44	0.43	0.53
	R	0.38–0.51	0.40–0.47	0.36–0.57	0.46–0.59
	S	0.06	0.03	0.10	–
Wet	N	4	4	4	4
	$\bar{x}$	0.66	0.69	0.79	0.76
	R	0.65–0.67	0.66–0.76	0.71–0.86	0.69–0.88
	S	0.01	0.05	0.08	0.09

N = Number of tests
$\bar{x}$ = Average or mean
R = Range of values
S = Standard deviation

6.6.3 Conclusions. The obvious conclusion is that wet surfaces under a significant load (150 lb/in^2 in this case) have higher coefficients of friction than dry surfaces, at least where wood is one of the surfaces. It appears that in the wet condition, oak presents a somewhat higher friction surface than Douglas fir.

6.6.3.1 Given the planned load on bilge blocks, or other blocks using cribbing, friction values may be useful in calculating lateral stability of blocks under seismic or wind loading.

6.6.4 Testing procedures. The timbers used in these tests were all 6 x 14 x 48 inch new oak and Douglas fir. They came from the same inventory of timbers from various shipyards that had been acquired for the compression tests. The steel plates measuring 1 x 14 x 48 inch were prepared at the Puget Sound Naval Shipyard.

6.6.4.1 An identification sheet was completed for each friction test (see figure 33). The timbers and plates were measured so that areas under load could be calculated. Moisture content was determined with a moisture meter.

6.6.4.1.1 The two stacks of timber or timber and steel were assembled for each test in the test machine, as shown on figures 34 and 35. Two hydraulic rams were placed horizontally between the two stacks and between the cribbing layers. Two metal headers were placed between the rams and the cribbing layers to distribute the load to the three timbers or steel plates.

6.6.4.1.2 The top and bottom layers of the test stack were braced by angle irons bolted to the head and base plates of the test machine. The other stack was braced behind all three layers so that it could not move horizontally when the load was applied. This meant that the cribbing in the test stack was the only part that could slide under pressure when the friction had been overcome.

6.6.4.1.3 Initially the test was designed to determine the friction at two different pressures on the stacks: 150 lb/in^2 and 300 lb/in^2. Preliminary work with smaller stacks, however, indicated that the coefficients of friction were likely to be so high at the higher load that the friction force would exceed the capacity of the horizontal force available. Therefore, only the 150 lb/in^2 vertical load was used.

6.6.4.1.4 A single LVDT was placed against the headplate at a corner of the friction test assembly to measure vertical deflection. The horizontal movement was measured by two linear motion potentiometers mounted so that they were touching the ends of the cribbing layer.

6.6.4.1.5 After the test stacks were assembled and the instruments put in place, the head plate was lowered to the two stacks and the load increased to 150 lb/in^2. The data acquisition program for the computer was written to record the vertical force and deflection in this stage of the test. Note on figure 36 the short stress/strain diagram in the lower left-hand corner reflecting the 150 lb/in^2 loading. The vertical and horizontal scales for this curve are at the top and the right-hand side of the graph. When 150 lb/in^2 was reached, the horizontal load was applied by means of a hydraulic pump and the two rams, and the computer program began data acquisition to record the lateral load and deflection. The horizontal pattern of data points near the middle of figure 36 shows the magnitude of the lateral load and the resulting lateral deflection. The points show an irregular rate of lateral deflection indicative of the load building until a short slippage of the cribbing material occurs.

6.6.4.1.6 After sufficient deflection to determine the friction coefficient, the load was released and the layered assemblies were dismantled. Four different tests of each friction interface were done, each time using fresh surfaces for friction. Testing was not performed on the steel-to-Douglas fir interface, as it is unlikely that cribbing and capping materials would come into direct contact. After the dry tests, the timbers and steel were soaked in a water bath and then the tests were repeated with wet surfaces. Following the tests, the coefficient of friction was determined for each test and tabulated, as shown previously in table XXI.

7. NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.

7.1 Issue of DODISS. When this handbook is used in acquisition, the applicable issue of the DODISS must be cited in the solicitation (see 2.1.1, and 2.1.2).

7.2 Subject term (keyword) listing.

Douglas fir
Southern pine
Red oak
White oak
Laminated timbers
Frozen timers
Unfrozen timbers
Timber properties
Soft cap
Build-up block

Preparing activity:
Navy-SH
(Project 1950-N008)

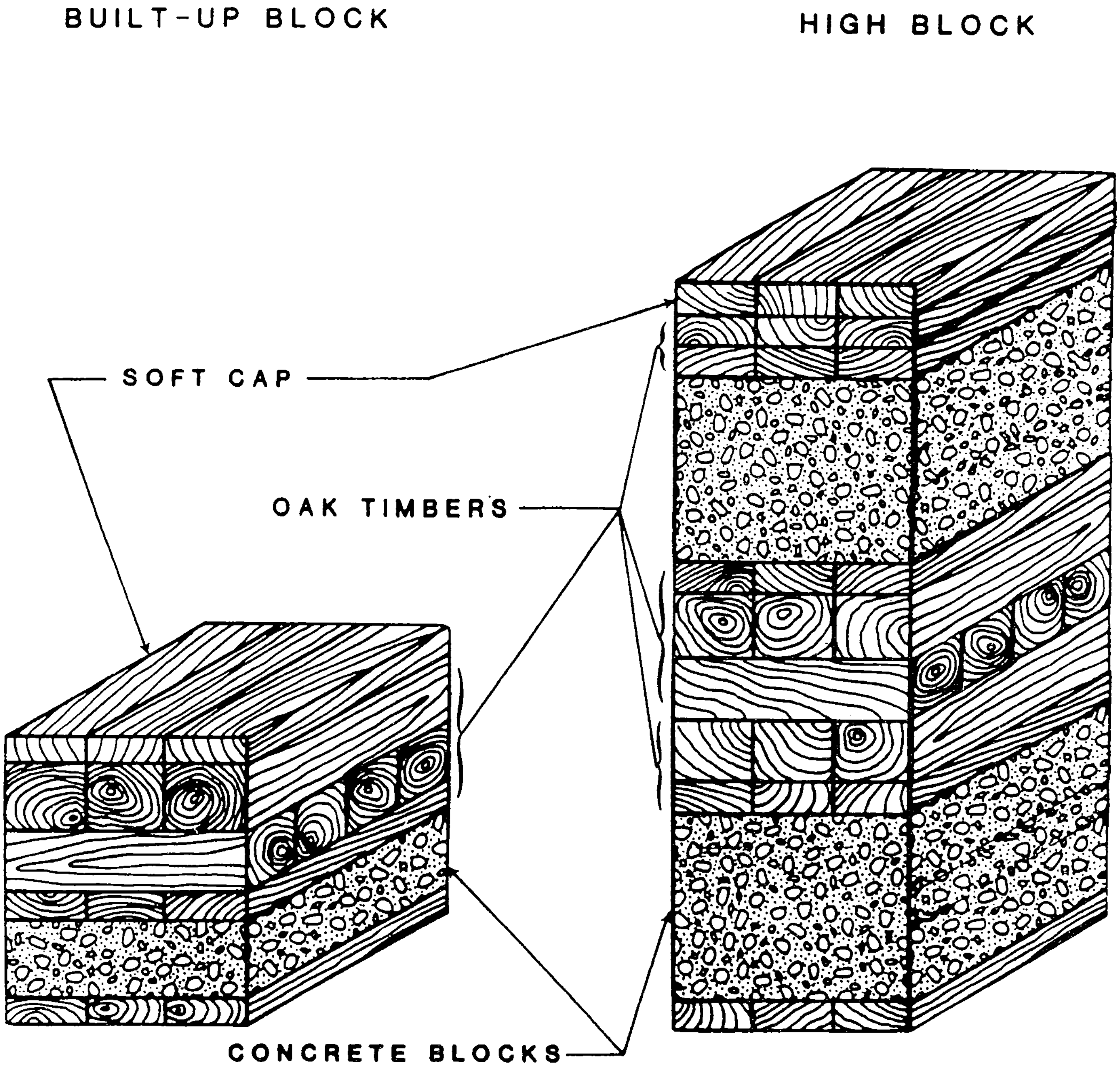


FIGURE 1. *Sample dry dock blocks.*

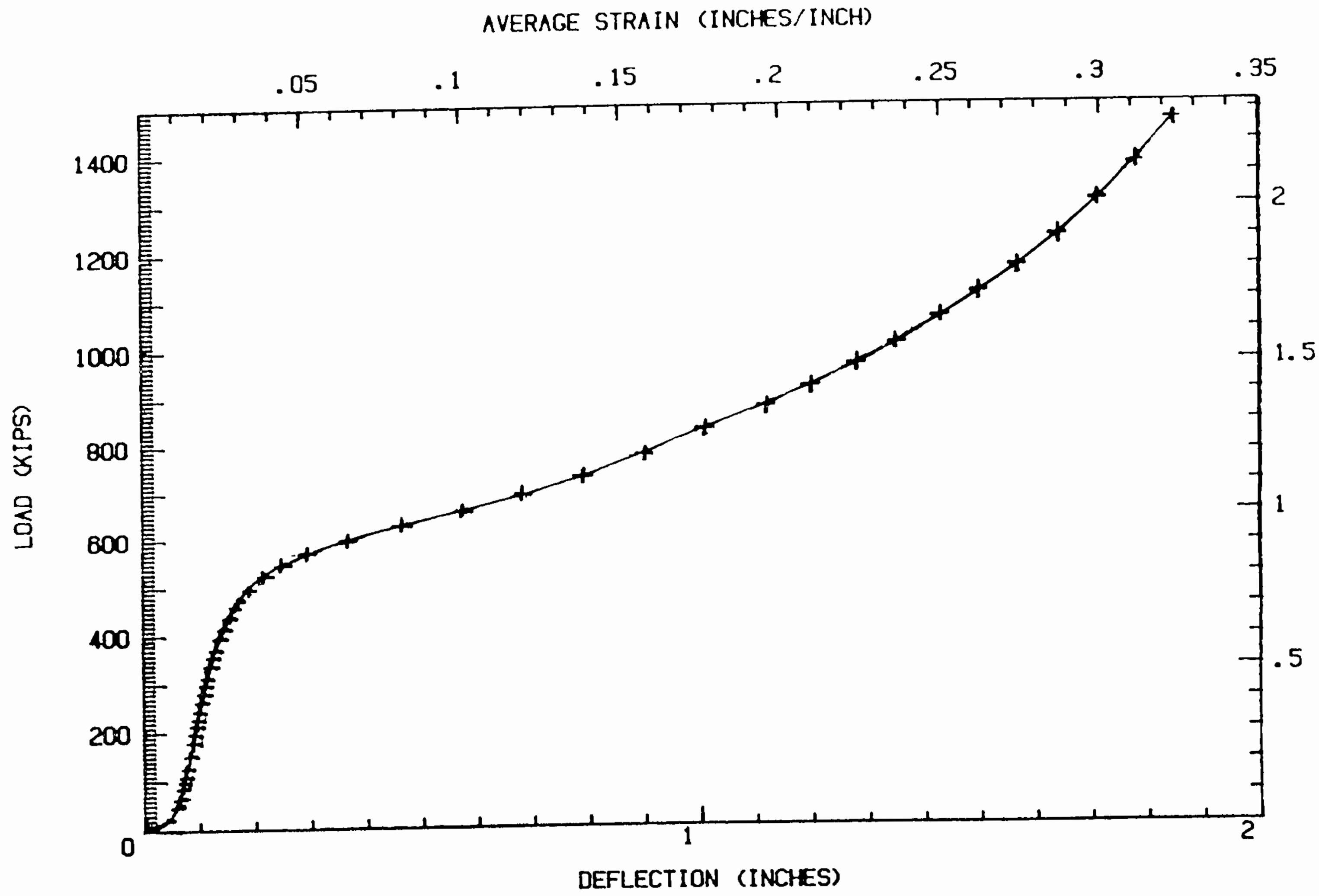


FIGURE 2. Relationship between compression and load.

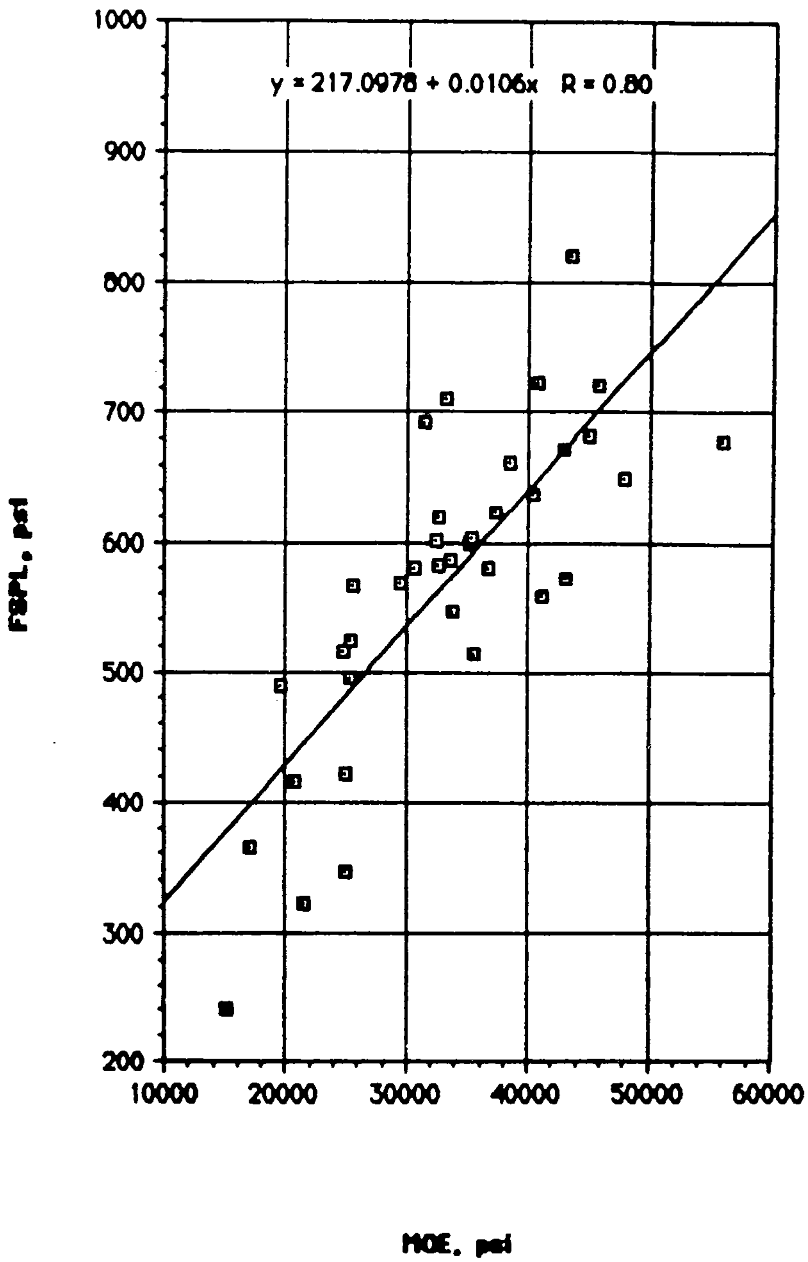


FIGURE 3. Relationship of FSPL and MOE for new and used oak timbers.

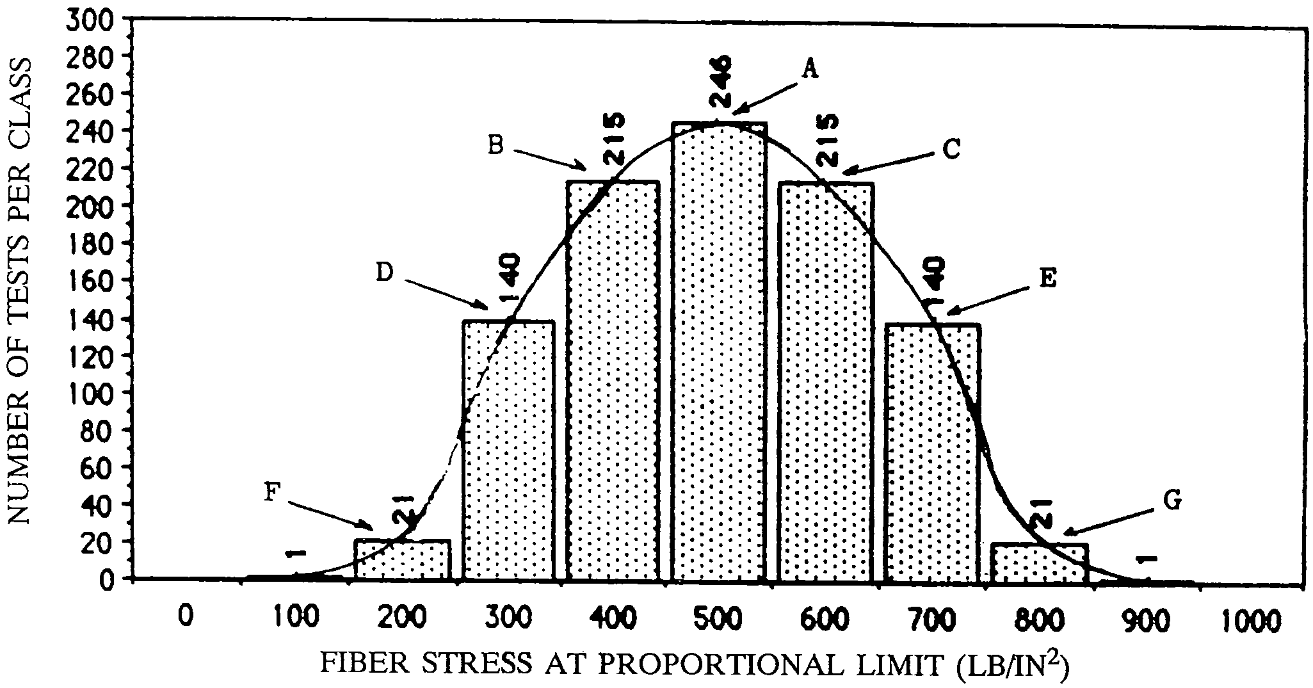


FIGURE 4. *Distribution of oak timbers in transverse compression.*

U.S. Navy Dry Dock Block
Compression Test Program

TEST FILE NO. TOBN 15

SPECIES OAK, RED WEIGHT 286 lbs.

DIMENSIONS: Width 13.53 ins. Height 12.06 ins. Length 47-7/8 ins.

Load Bearing Area 647.7-1.4=646.35 ins.^{2} Volume ________ ins.^{3}

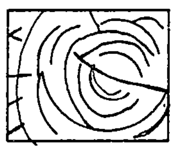
TIMBER CONDITION: New, unused X New, used ________ old ________

TIMBER END SKETCHES

(Sketch in distinguishing features -- pith, checks, grain orientation)

"A" End (Photo)
13-9/16"

12-1/16"



"B" End
13-1/2"

12-1/16"

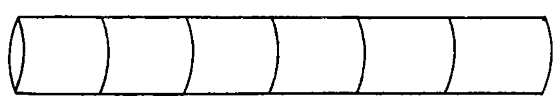
RINGS PER INCH (APPROXIMATE): Maximum 8 Minimum 4

BOXED HEART? Yes____ No____ DECAY? Yes X No____ Omitted from test__________

PHOTOS TAKEN? Bottom view X Loading: Initial X Pl_____ One in. def._____

FILM IDENTIFICATION NUMBER(S) ______________________________

Core Sample



(See attached sheet)

MOISTURE CONTENT (%)

SPECIFIC GRAVITY

COMMENTS:

DATE________________________ COMPLETED BY______________________________

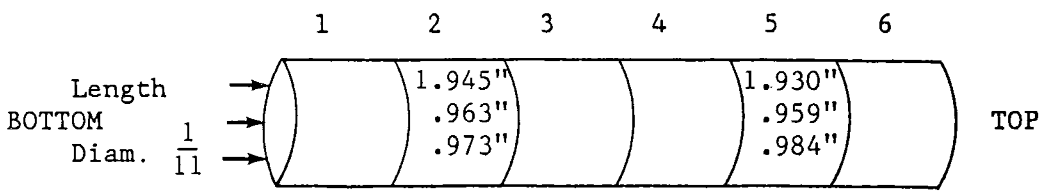
FIGURE 5. Test specimen identification sheet.

U.S. Navy Dry Dock Block
Compression Test Program

TEST FILE NO. TOBN 15

SPECIES OAK, RED DATE JANUARY 7, 1985

TIME WEIGHED 4:00 1/7 TIME OUT OVEN 4:00 1/9 TIME IN OVEN 47 HOURS



	1	2	3	4	5	6	Total
Wet Weight (gms.)	25.75	24.52	30.63	21.64	24.83	23.50	151.02
Dry Weight (gms.)	15.26	13.68	16.07	11.37	13.86	15.40	85.60
Moisture Content (%)	68.7	79.2	90.6	90.3	79.1	52.6	76.40
Specific Gravity		.58			.59		

AVERAGE MOISTURE CONTENT, OUTER 1/3 - 60.6 %

AVERAGE MOISTURE CONTENT, INNER 2/3 - 84.8%

FIGURE 6. Moisture content and specific gravity determinations.

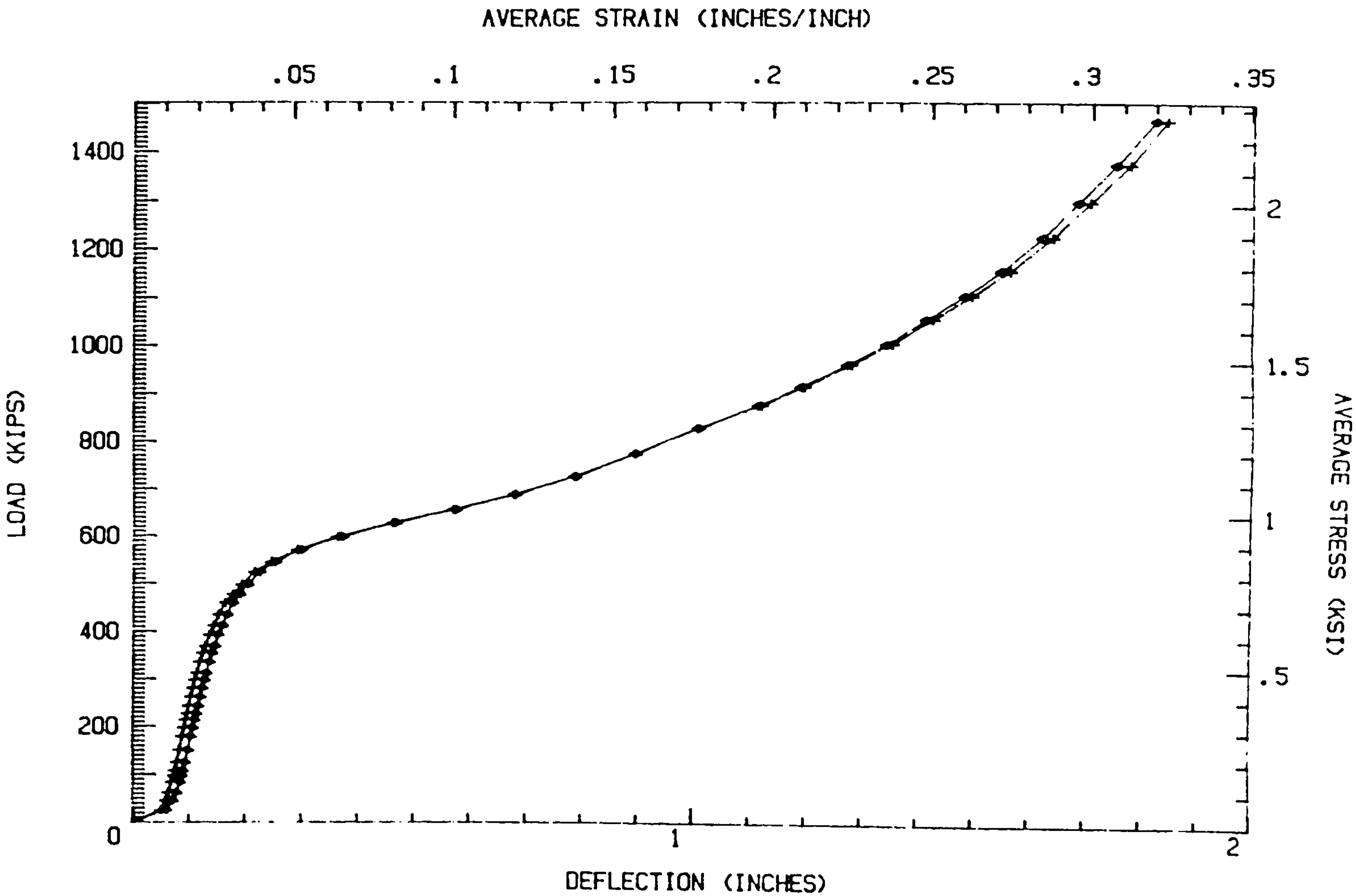


FIGURE 7. Single timber test.

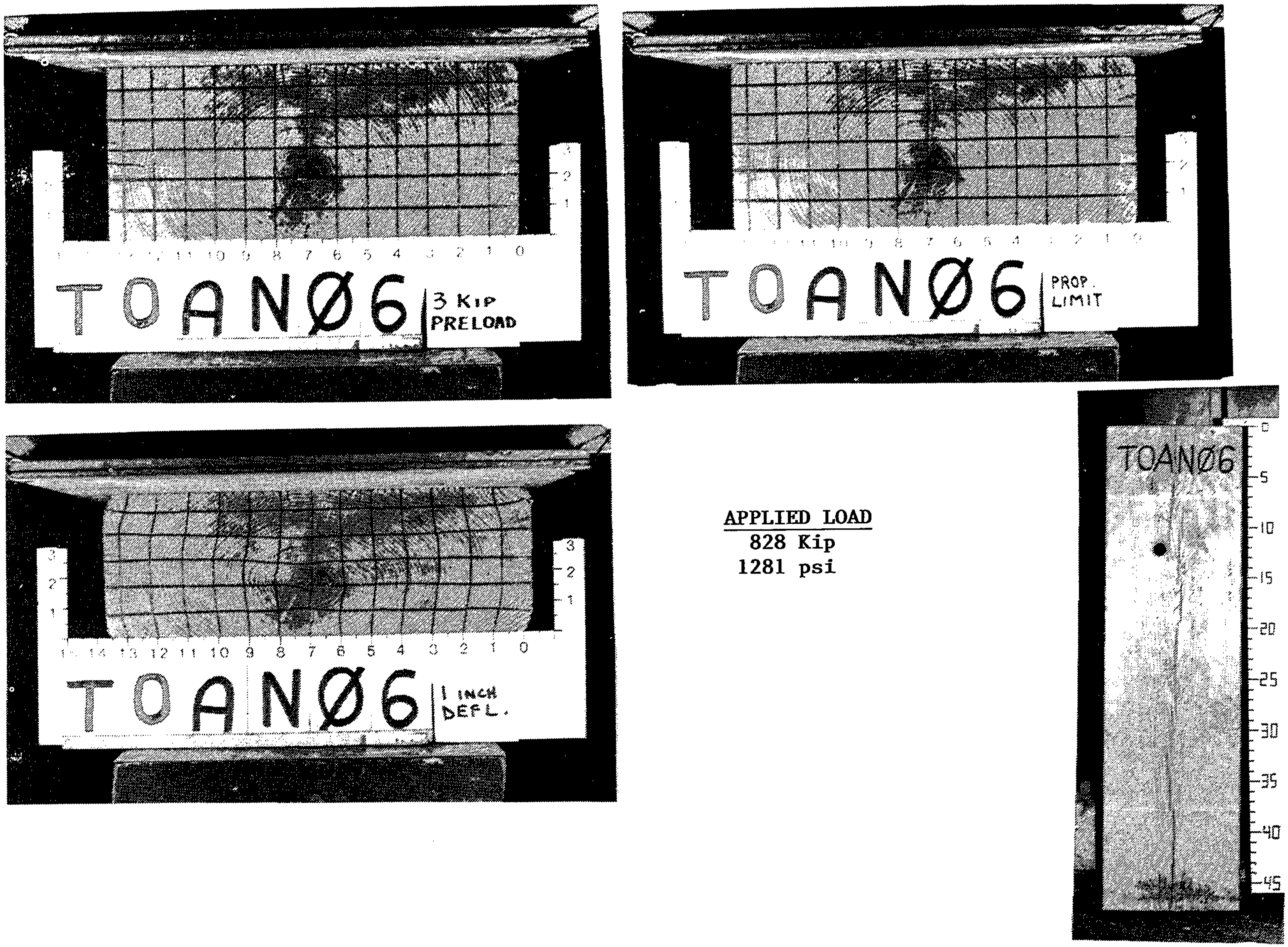
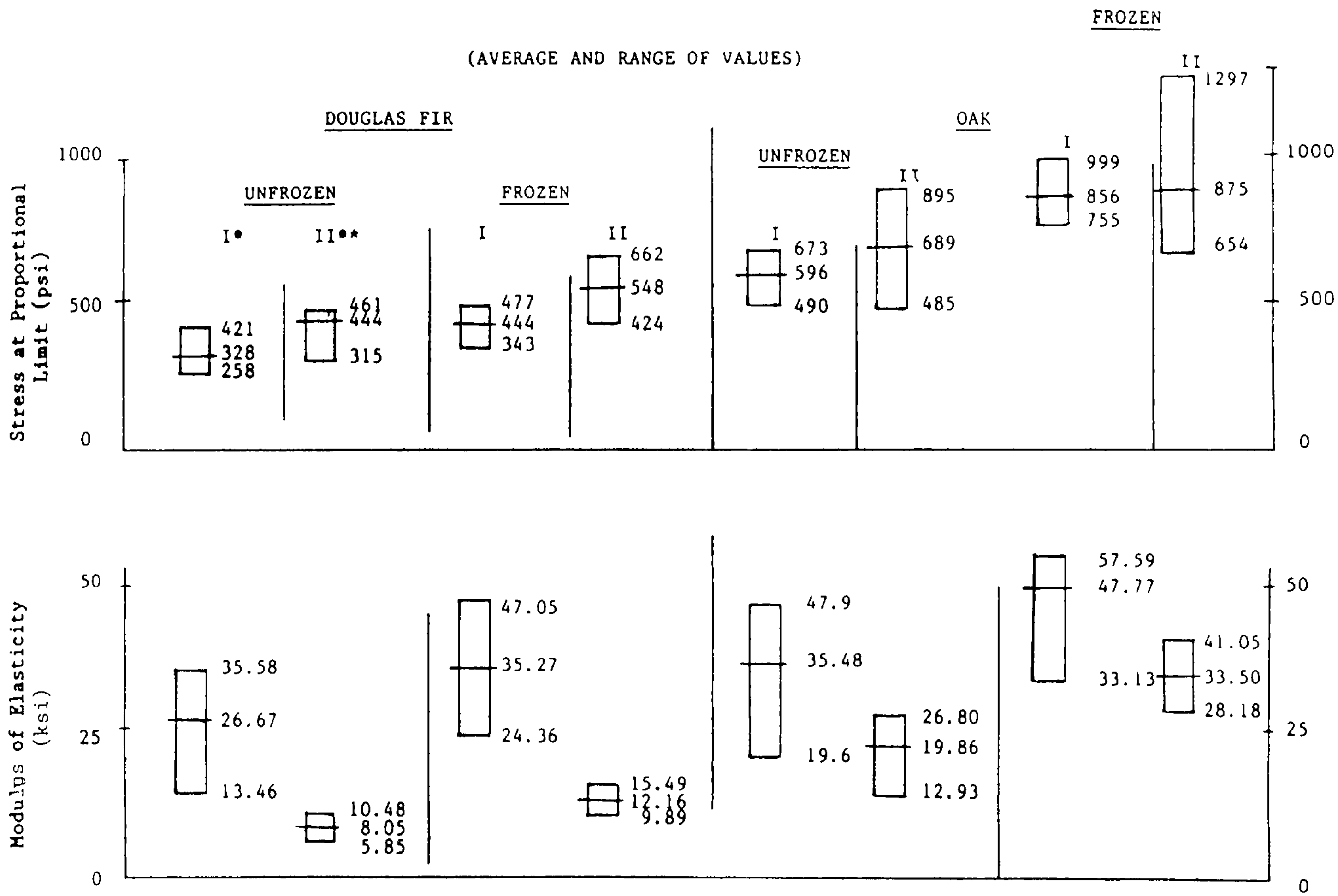


FIGURE 8. Timber photographs



*SERIES I WAS LOADED TO JUST ABOVE THE PROPORTIONAL LIMIT AND THEN THE LOAD RELEASED
**SERIES II WAS LOADED TO DESTRUCTION

FIGURE 9. Compressive test results on matched timbers of frozen and unfrozen Douglas fir and oak (average range of values).

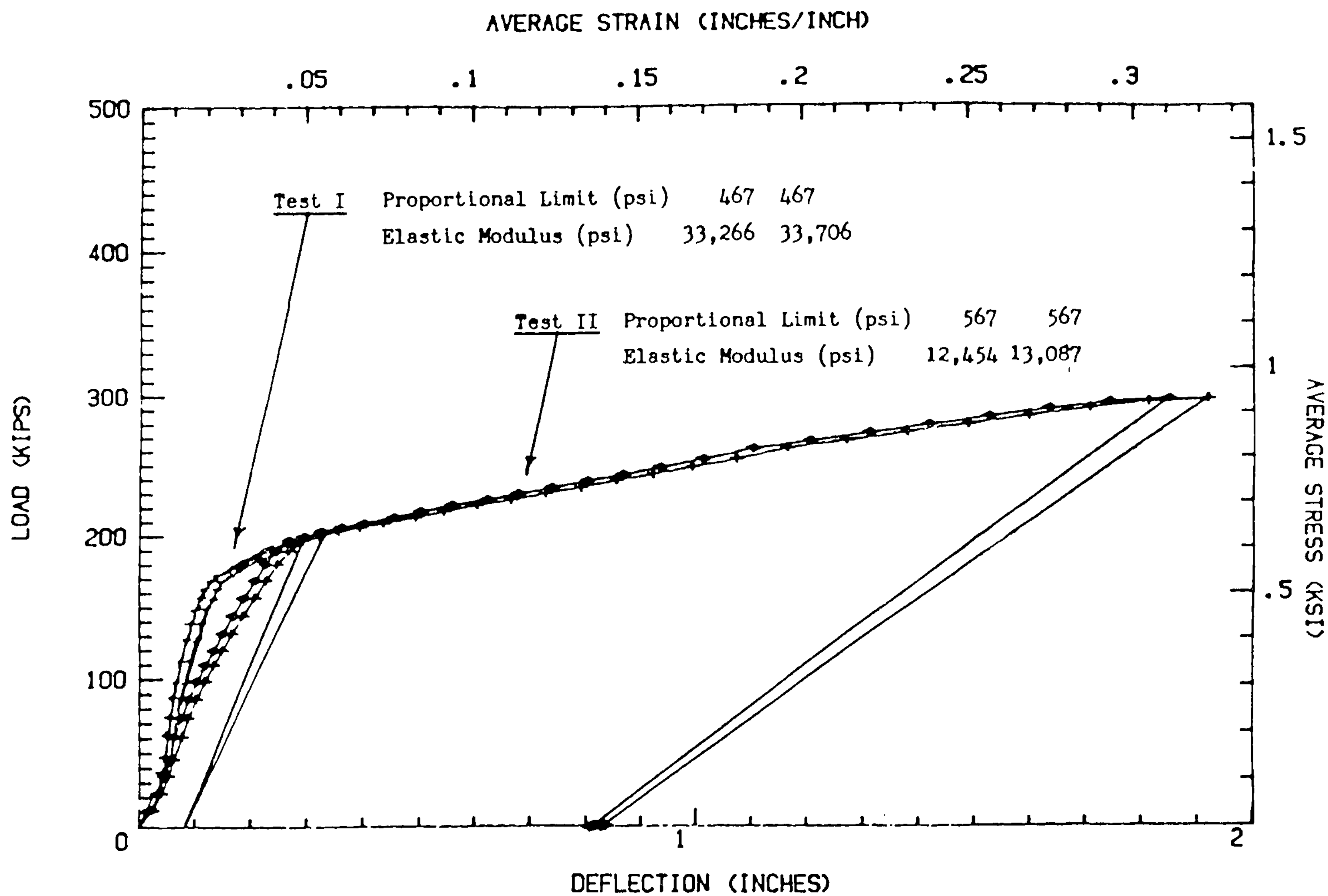


FIGURE 10. Stress-strain diagram.

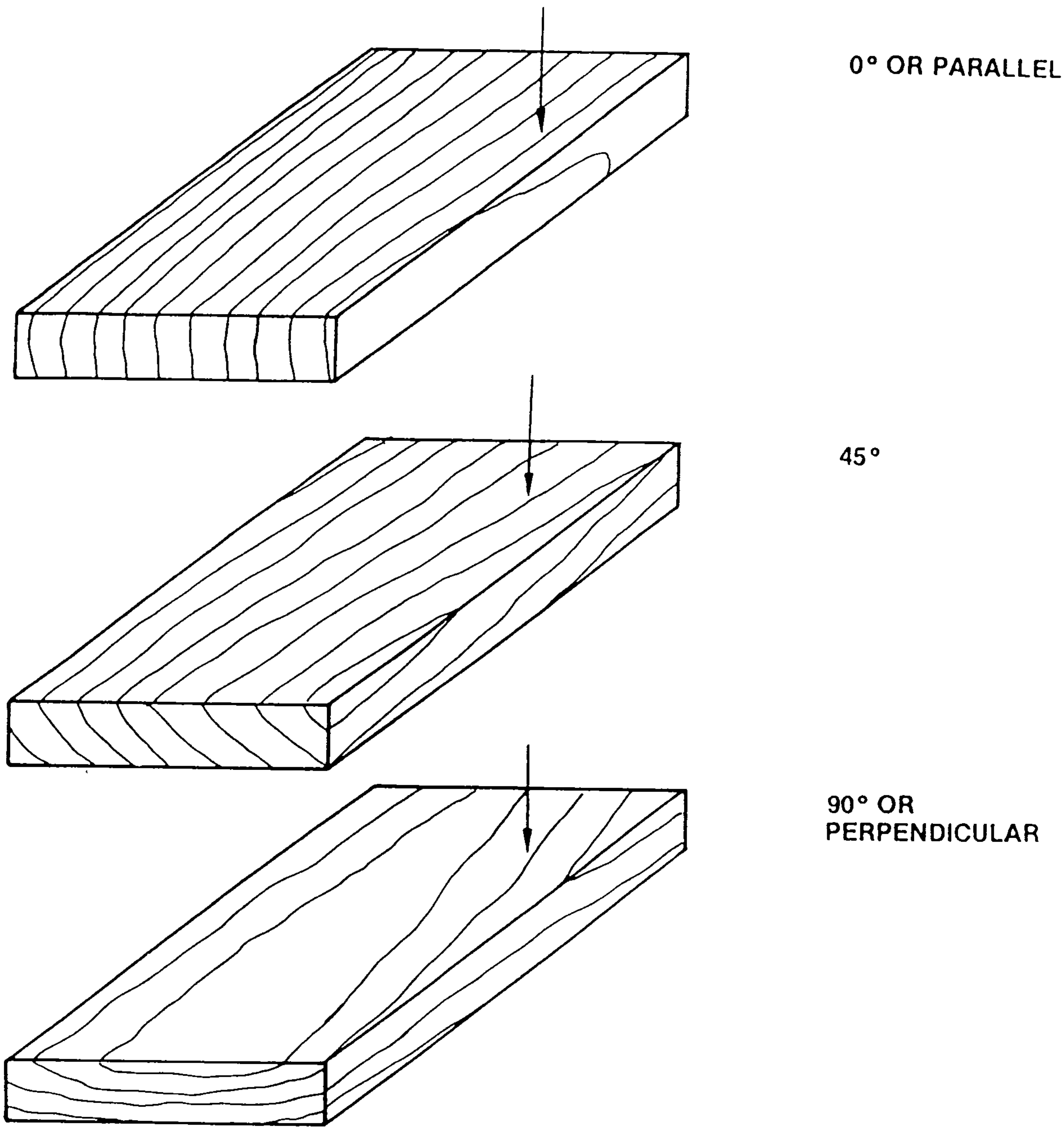


FIGURE 11. *Compressive load direction (4 x 12 inch components).*

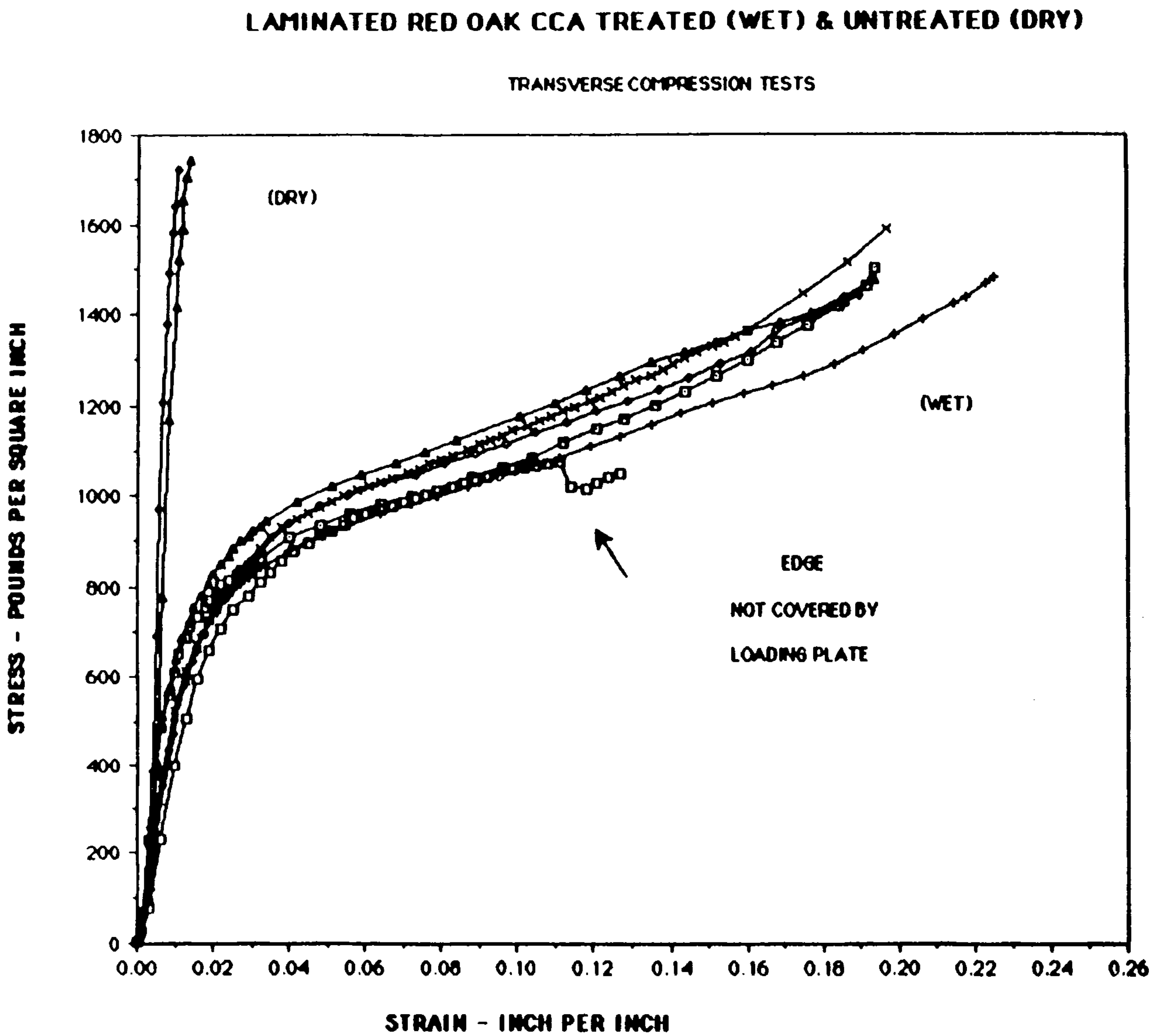


FIGURE 12. *Stress-strain curves for laminated red oak timbers.*

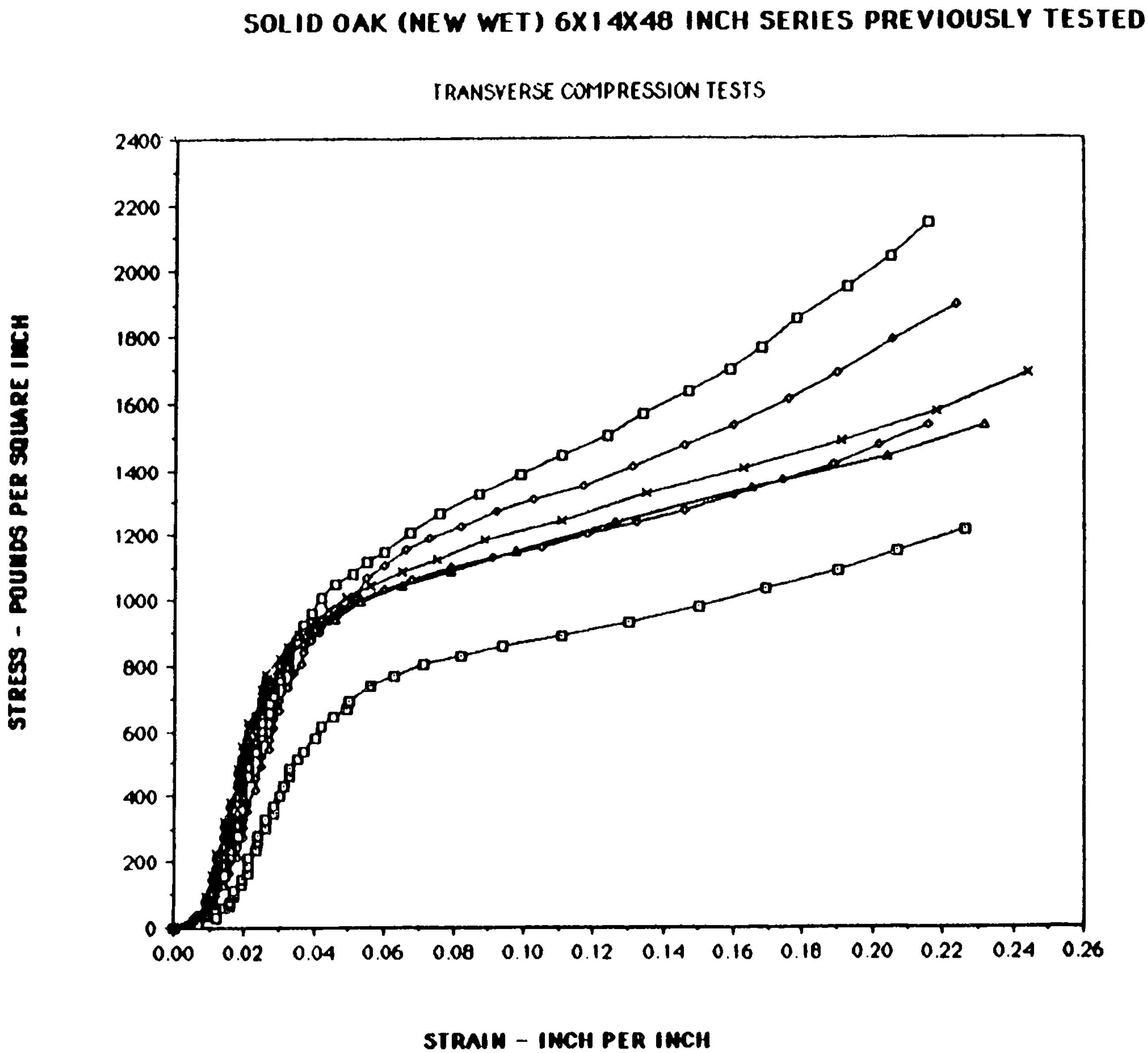


FIGURE 13. *Stress-strain curves for solid sawn oak timbers.*

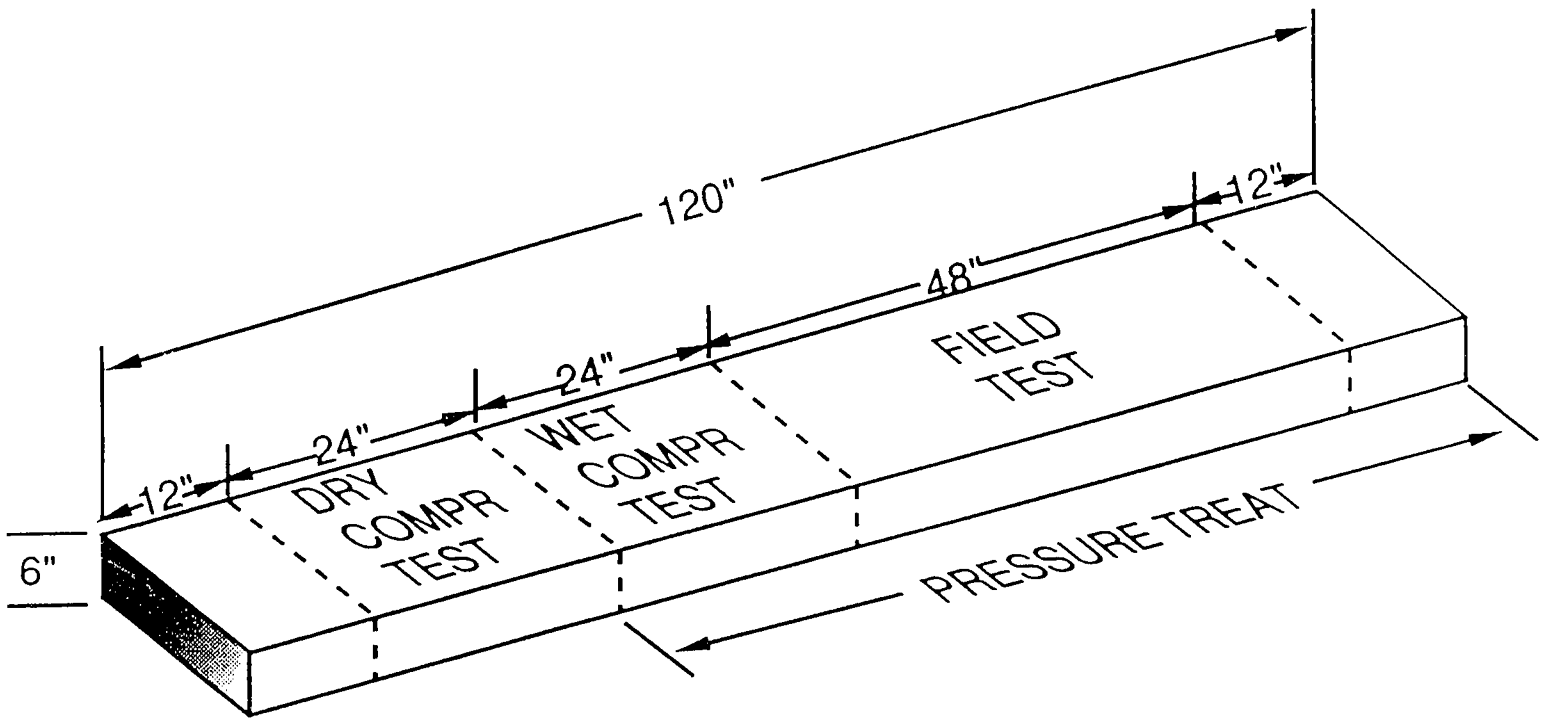


FIGURE 14. Testing pattern for laminated timbers.

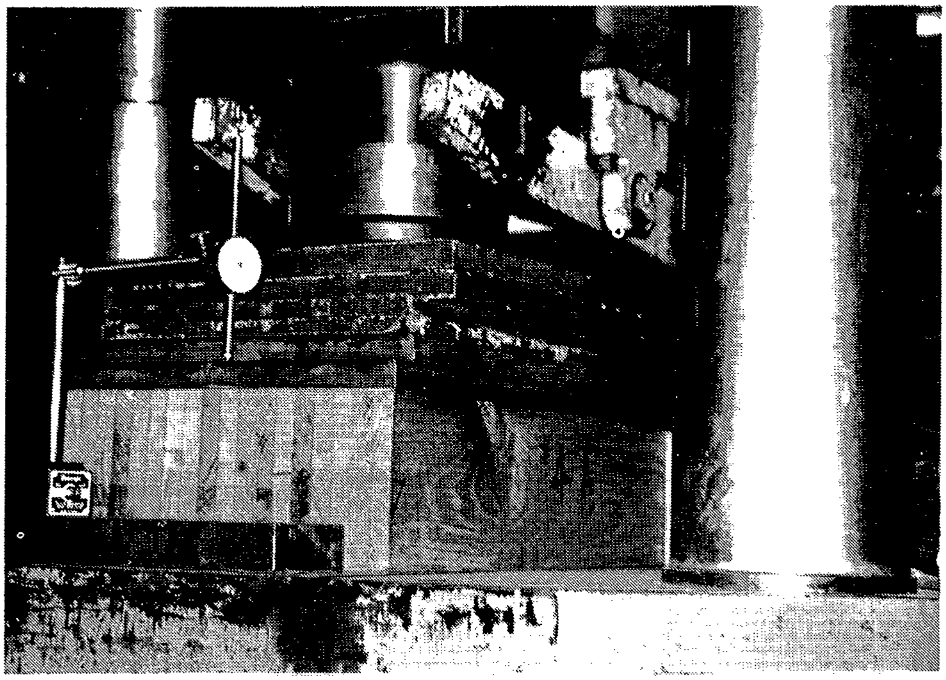


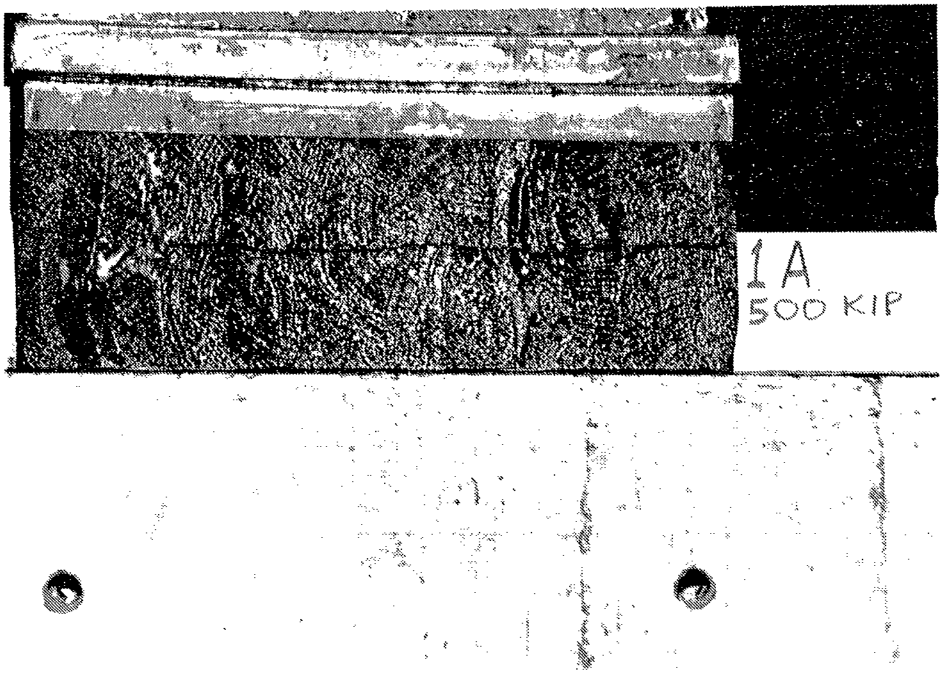
FIGURE 15. *Laminated timber ready for testing in 600,000-lb. Universal testing machine.*

Note: Horizontal line in specimen is a saw mark and is not related to compression test phenomena.

FIGURE 16. *Test specimen under a 2-kip preload.*

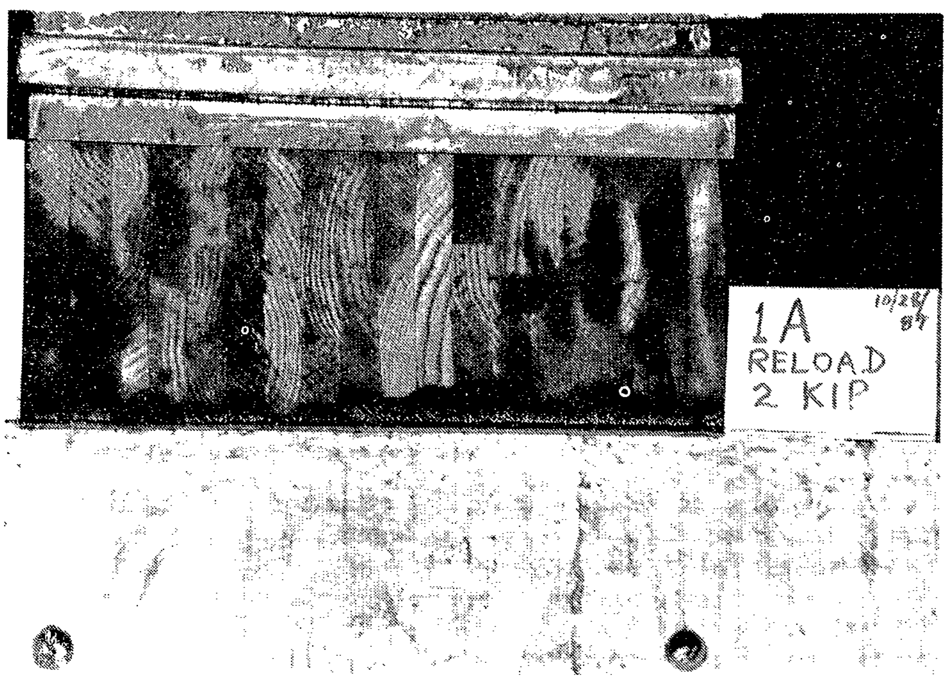
Note: Dark coloring is water and preservative being forced out of wood.

FIGURE 17. *Test specimen at 0.5 in. deflection (1024 lb/in²).*



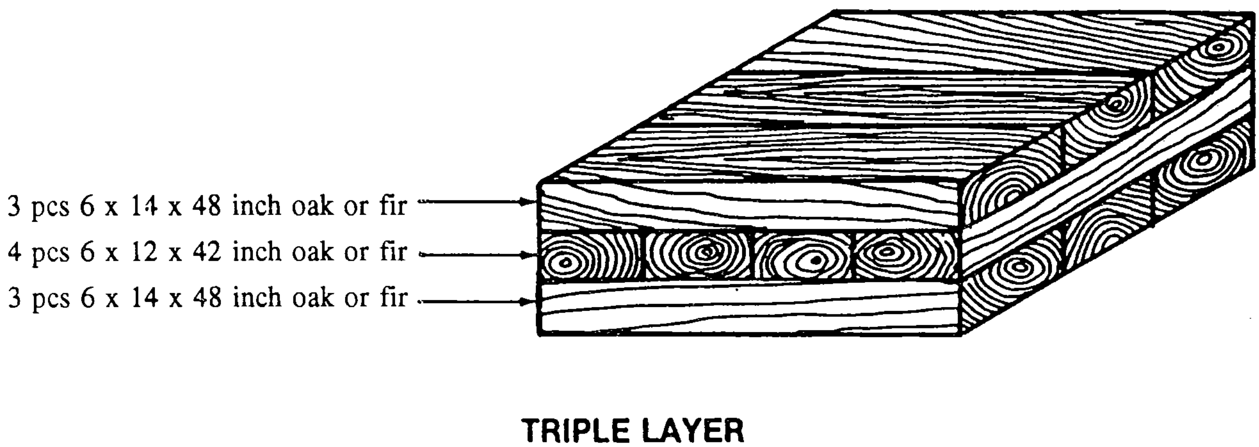
NOTE: Test discontinued at 525 kips with 1.215 in. deflection.

FIGURE 18. *Test specimen under 500 kip load (1431 lb/in²).*



NOTE: Deflection was 0.237 in.

FIGURE 19. *Test specimen reloaded to 2 kips after test.*



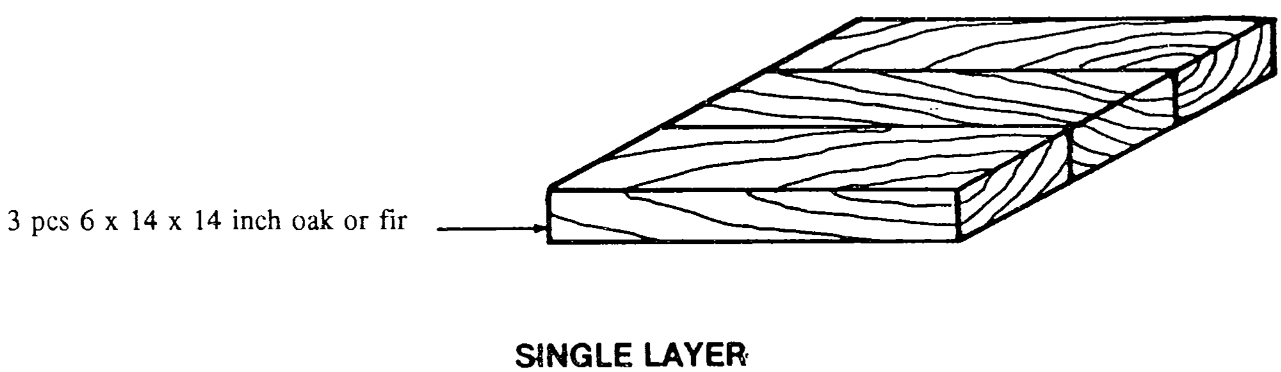


FIGURE 20. *Timber layer tests.*

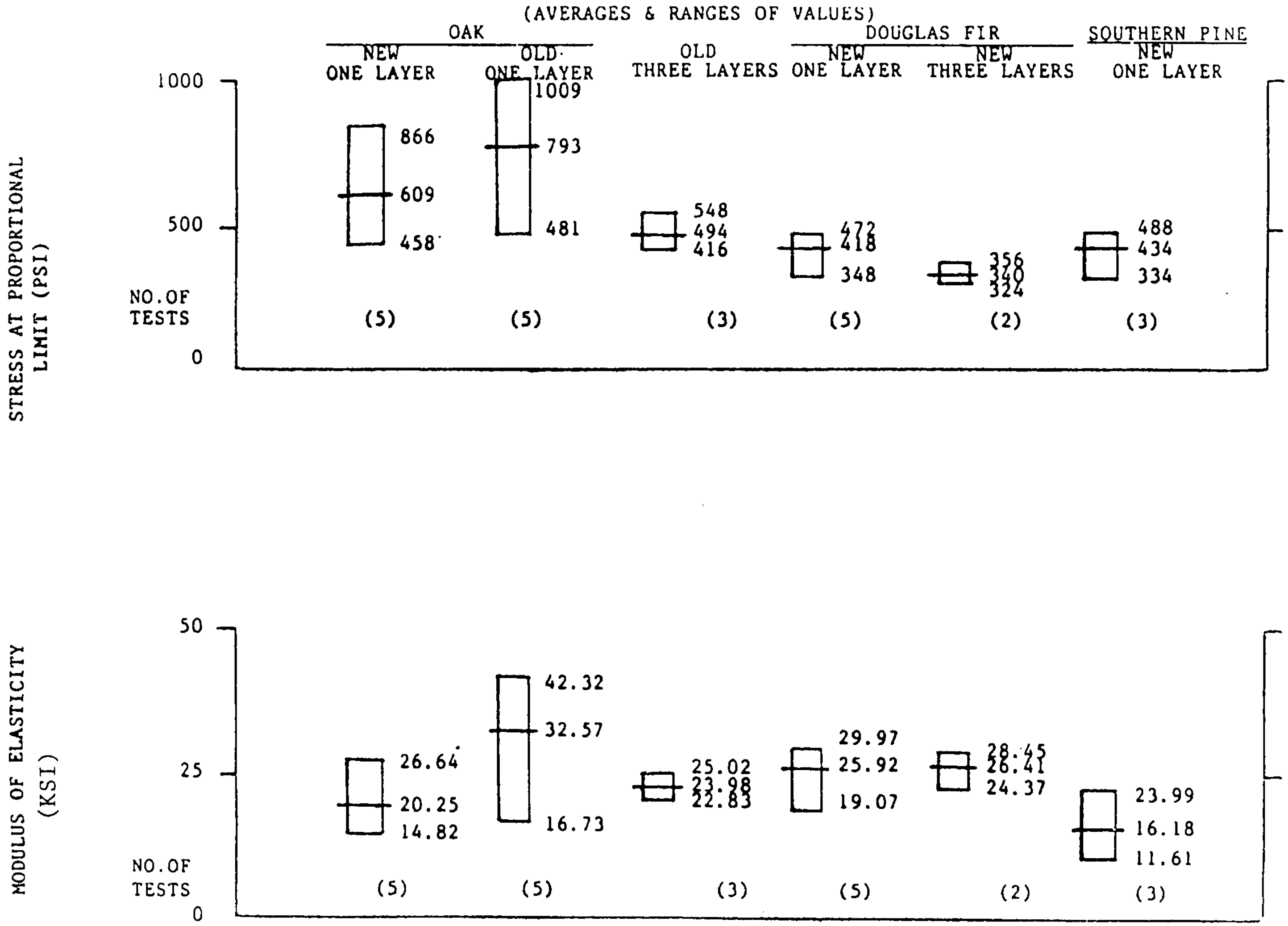
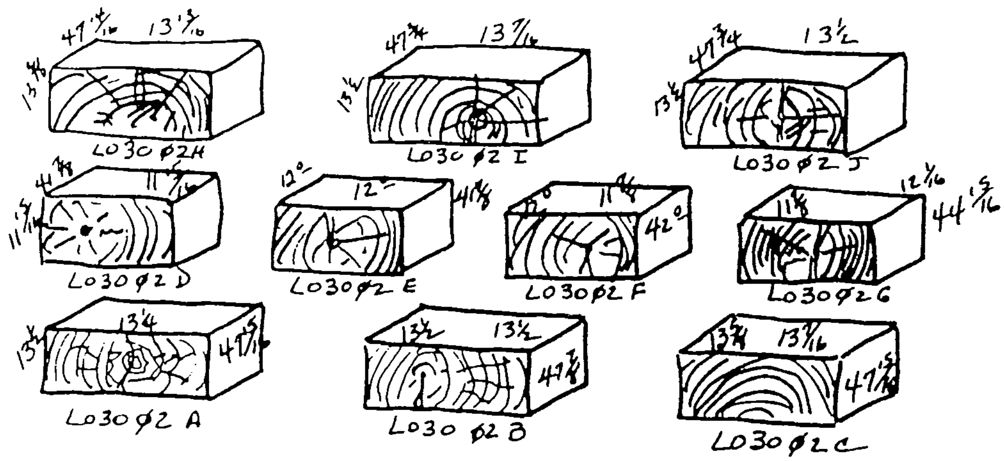


FIGURE 21. Compressive tests on one and three layers of oak, Douglas fir and southern pine timbers.

SPECIES OAK OLD X NEW

DIMENSIONS:



AVERAGE WIDTH TOT 40.56 inch AVERAGE LENGTH 47.85 inches

SURFACE AREA 1940.80 sq.in. AVERAGE HEIGHT

AVHT FOR STRAIN - 15.44 inches

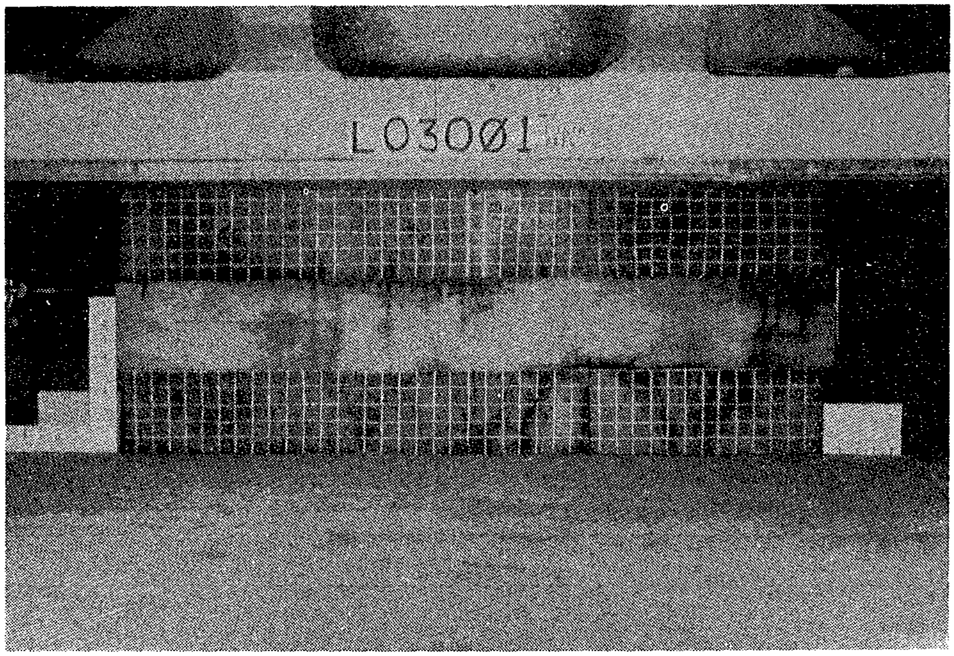
MOISTURE CONTENTS (METER)

DEPTH	0.3 0.5 1.0 inch		0.3 0.5 1.0		0.3 0.5 1.0
	32 38 75 5 to 14 Rings/in.		39 46 70 10 to 23 Rings/in.		28 34 52 9 to 20 Rings/in
	31 46 65 12 to 22 Rings/in	42 80+ 80++ 5 to 8 Rings/in	18 25 37 7 to 19 Rings/in		33 65 80+ 6 to 7 Rings/in.
	80 80++ 80+++ 8 to 15 Rings/in		33 50 80 9 to 18 Rings/in.		60 80+ 80++ 7 to 11 Rings/in

DATE JUNE 18 1985 COMPLETED BY R. England

FIGURE 22. *Three-layer timber identification sheet.*

1 inch deflection



1.5 inch deflection

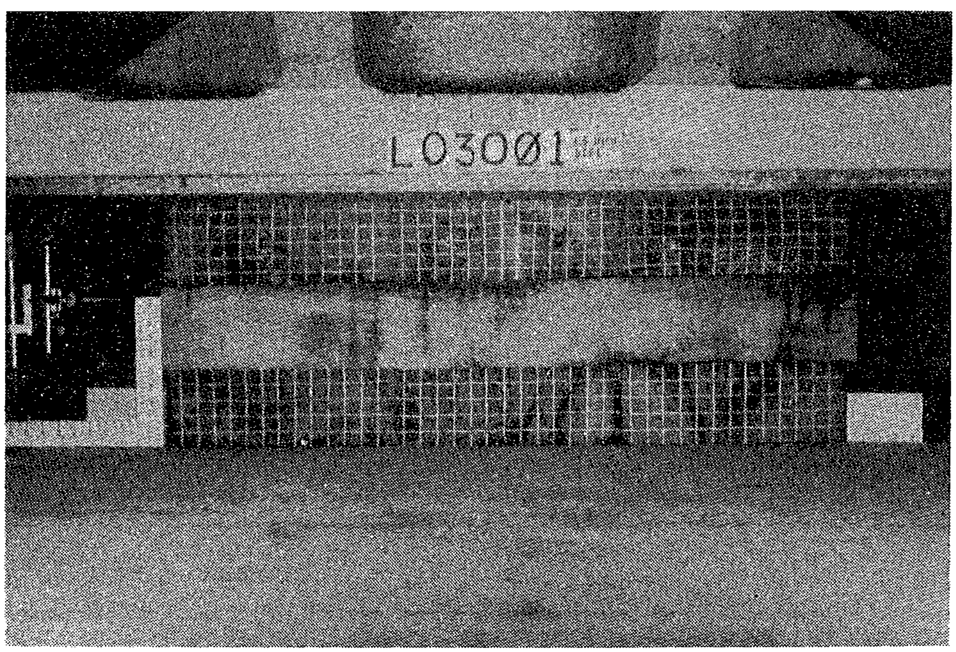


FIGURE 23. *Three-layer test of old oak.*

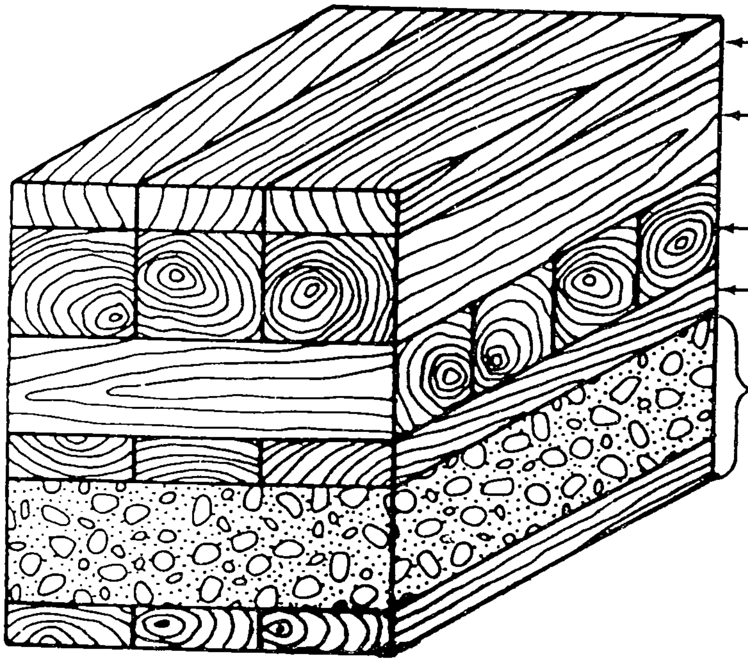


FIGURE 24. *Medium composite block build-up tests.*

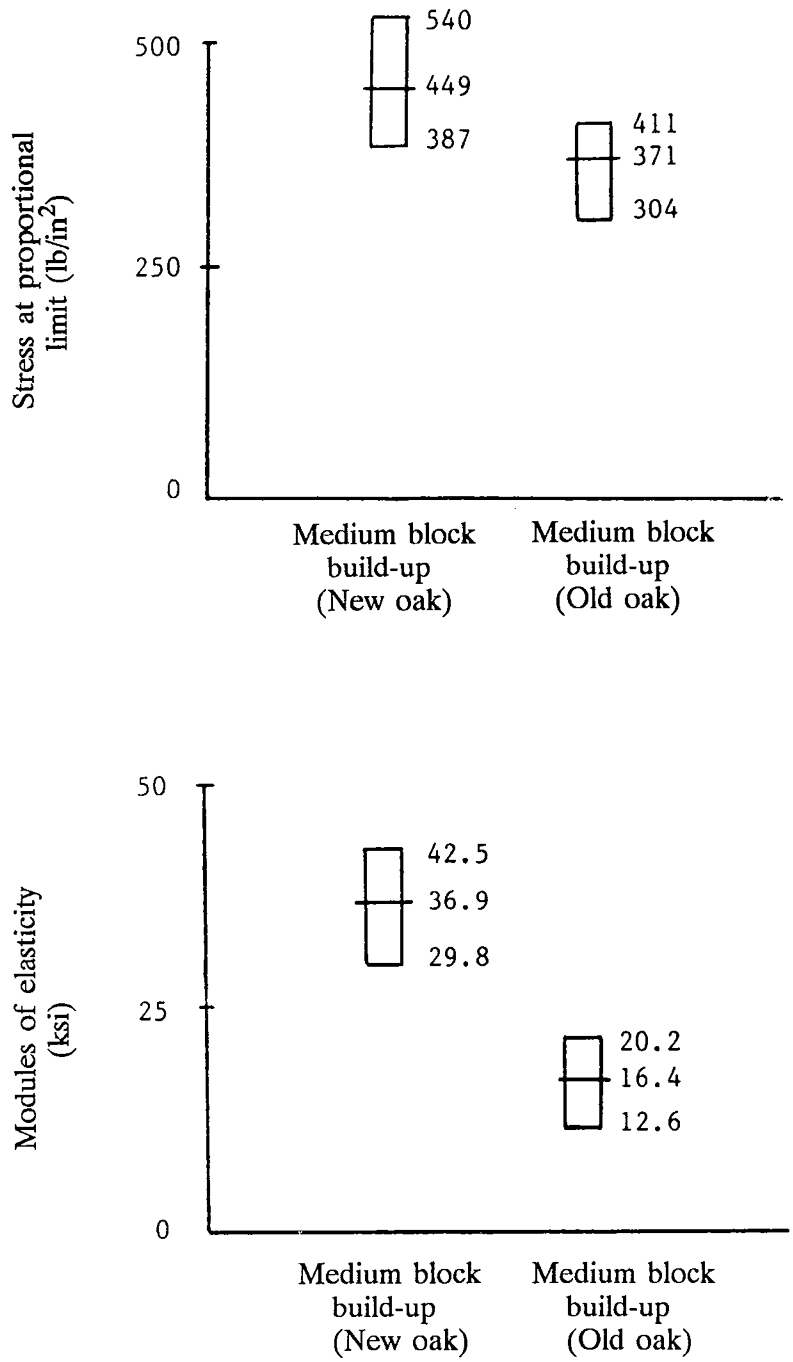
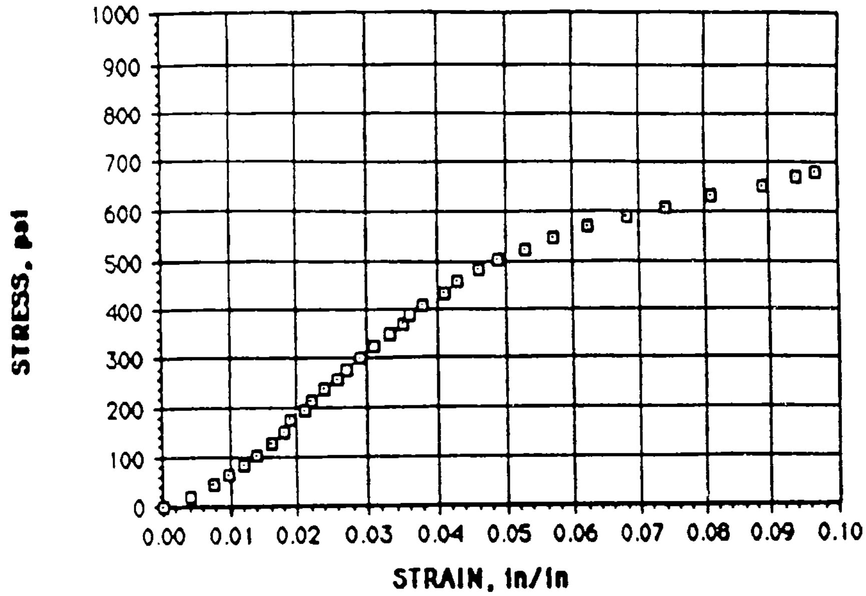


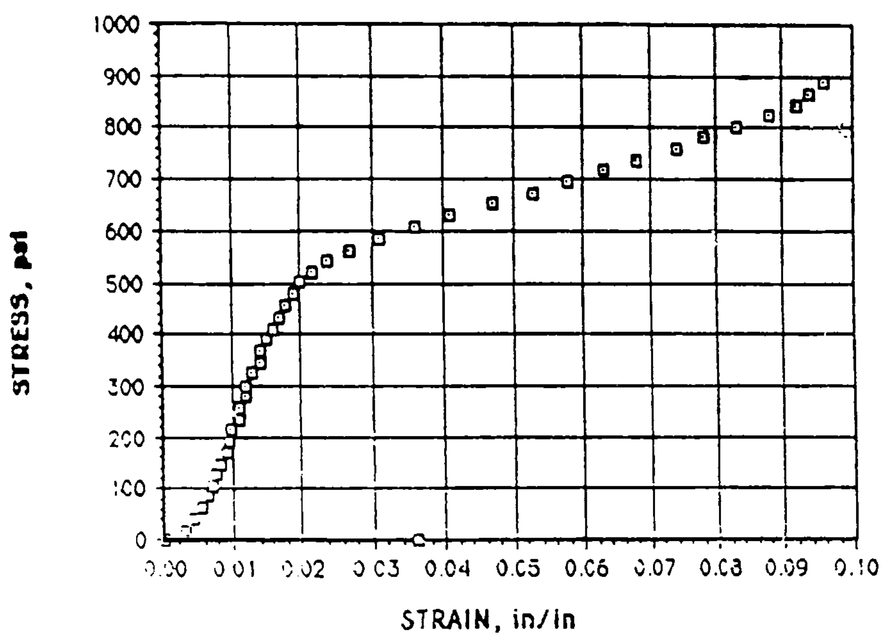
FIGURE 25. *Compressive tests on medium block build-ups.*

Data from old block



AT 500 PSI LB/IN^2
APPARENT
MOE 10492 LB/IN^2
FSPL 411 LB/IN^2
MOE 12945 LB/IN^2

Data from new block



AT 500 LB/IN^2
APPARENT
MOE 25557 LB/IN^2
FSPL 410 LB/IN^2
MOE 36864 LB/IN^2

FIGURE 26. *Comparison of old and new blocks.*

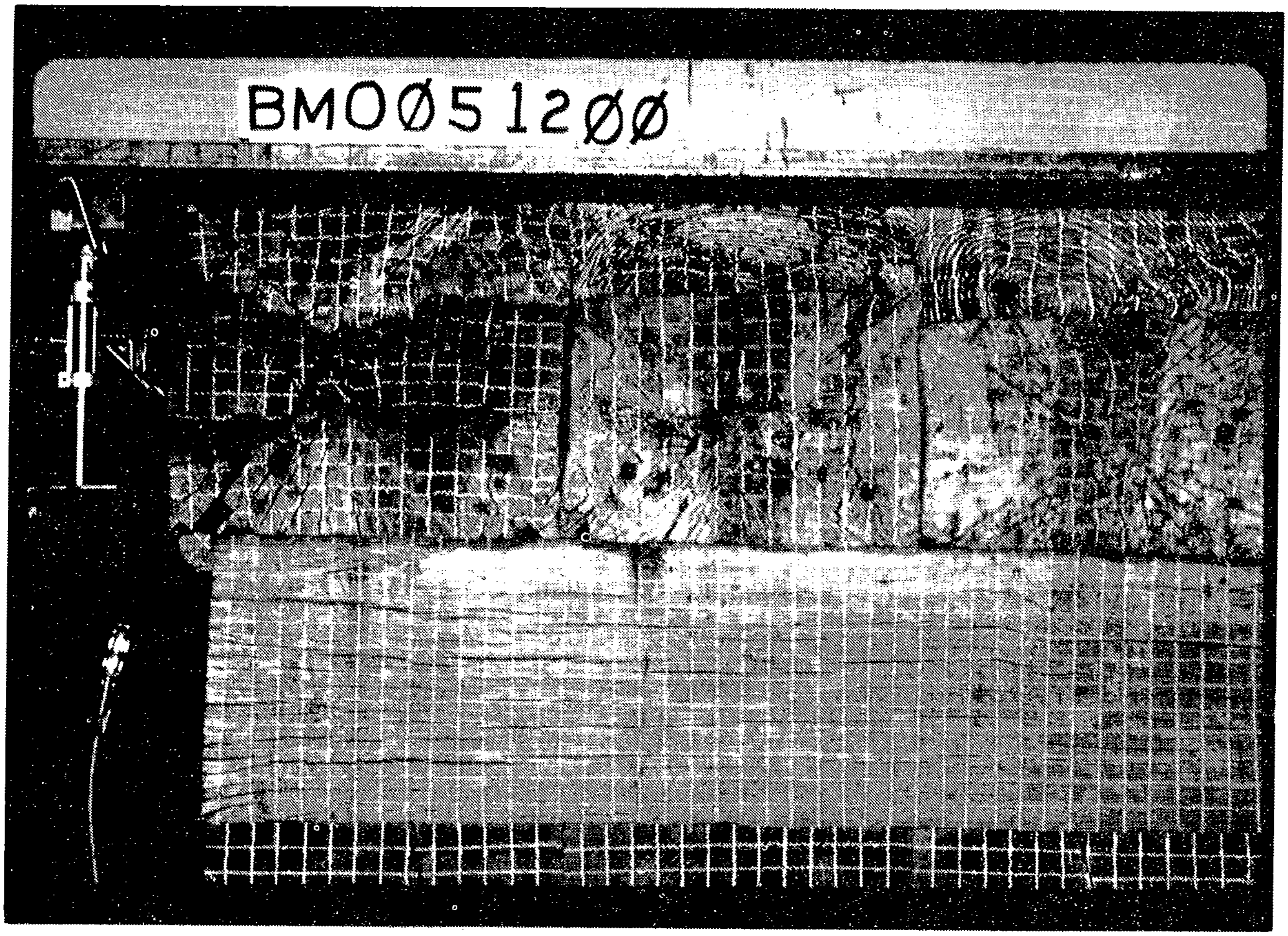


FIGURE 27. *Composite build-up* at 1200 Kipload (657 psi)

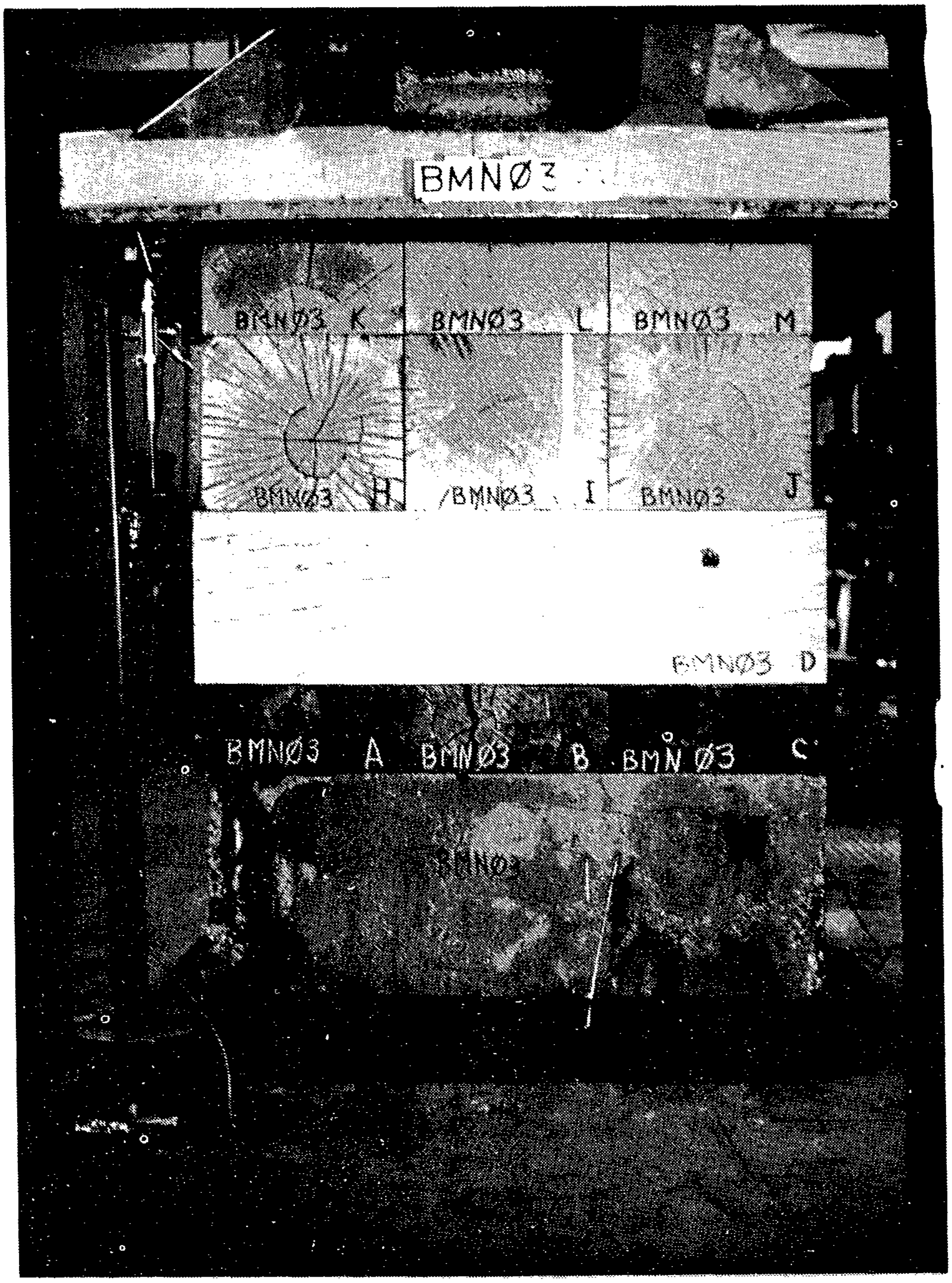


FIGURE 28. *Reference photograph of composite build-up.*

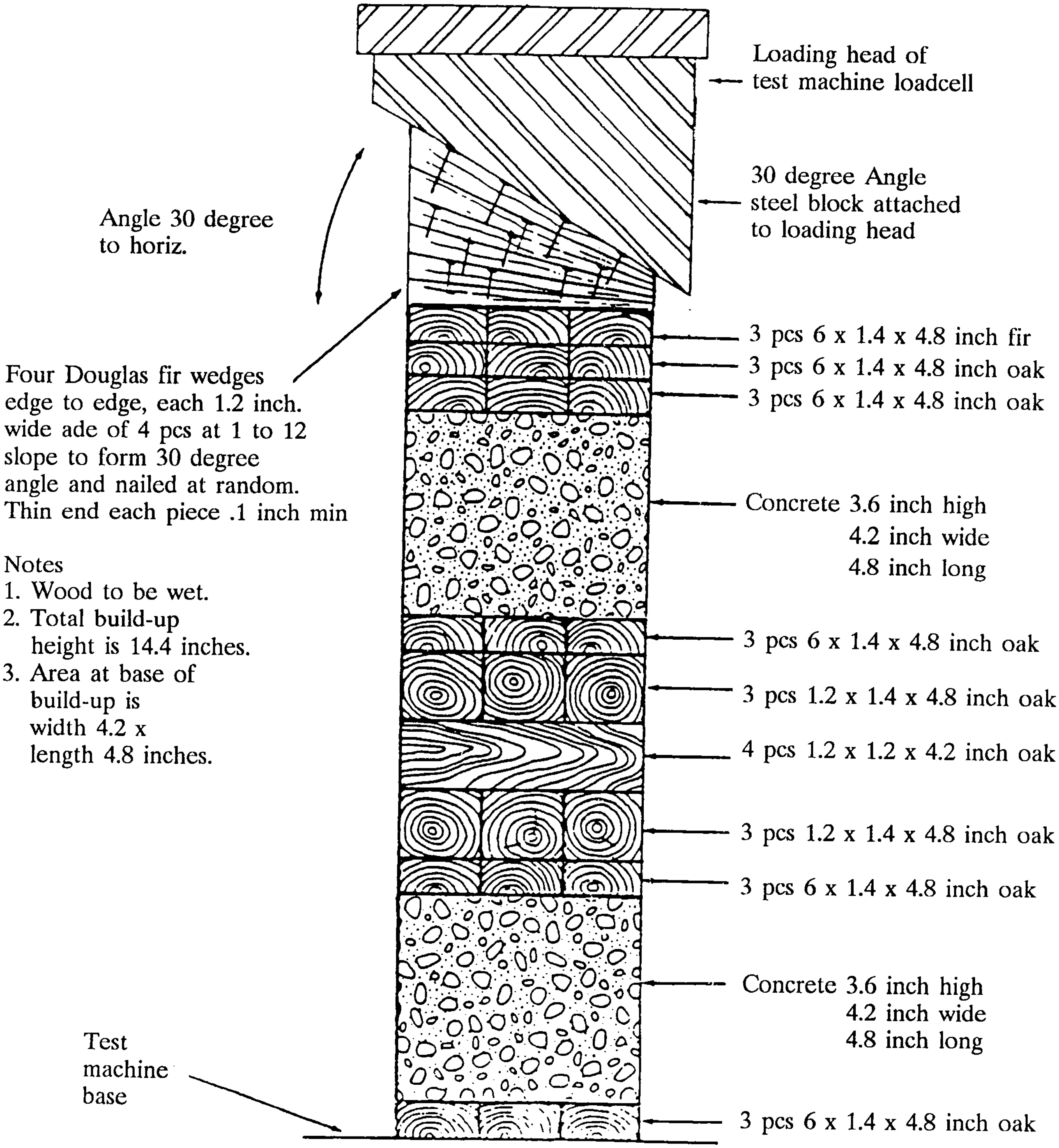


FIGURE 29. *Scale model test of 12-foot high block build-up with 30 degree contact angle loading (scale: 1 inch = 10 inch).*

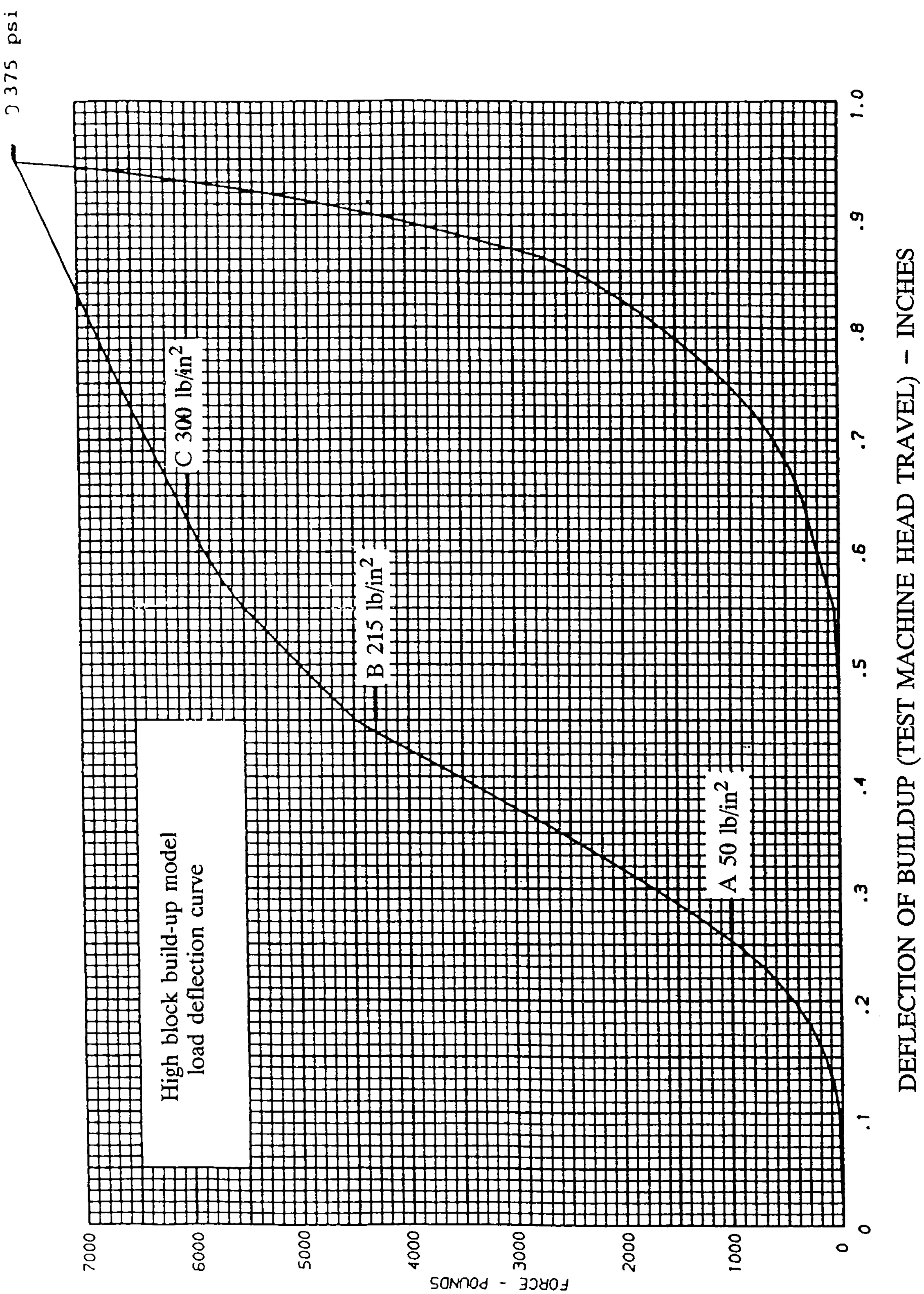


FIGURE 30. *High block build-up model load deflection curve.*

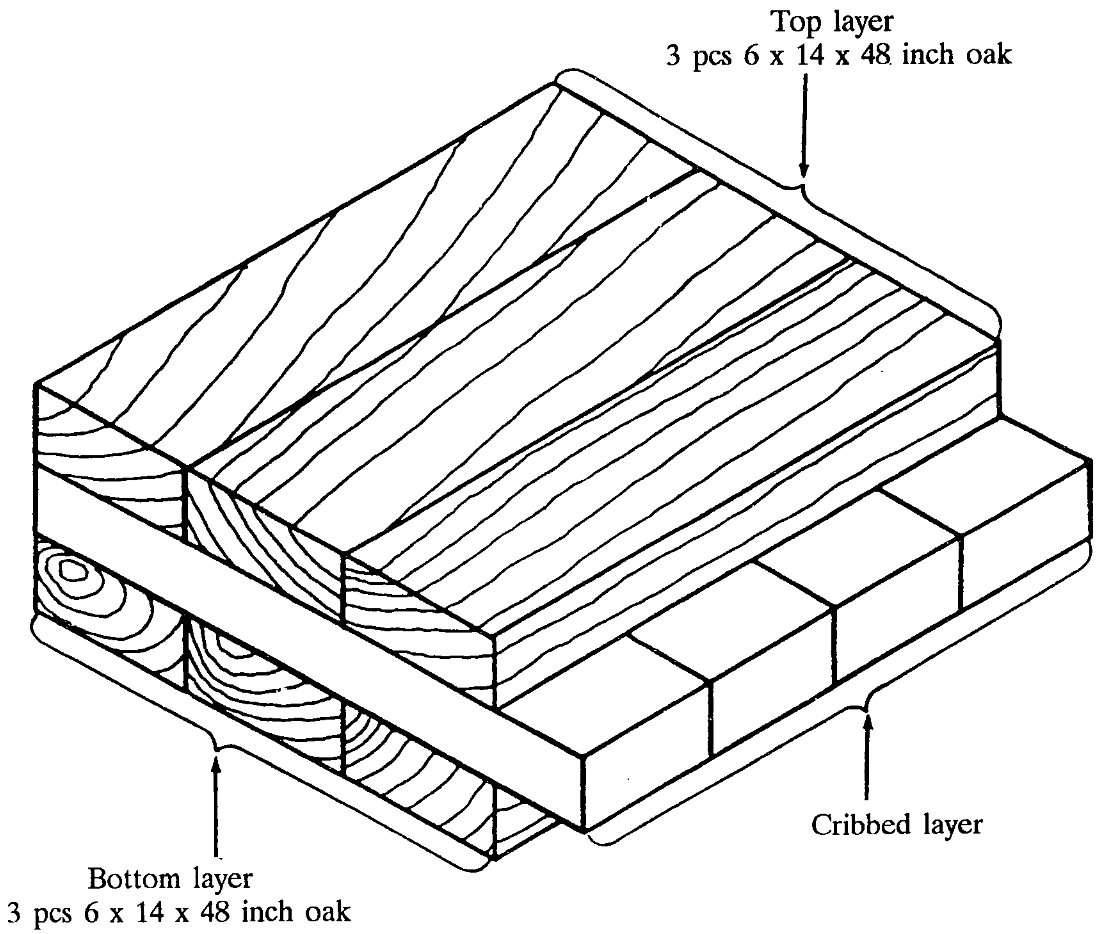
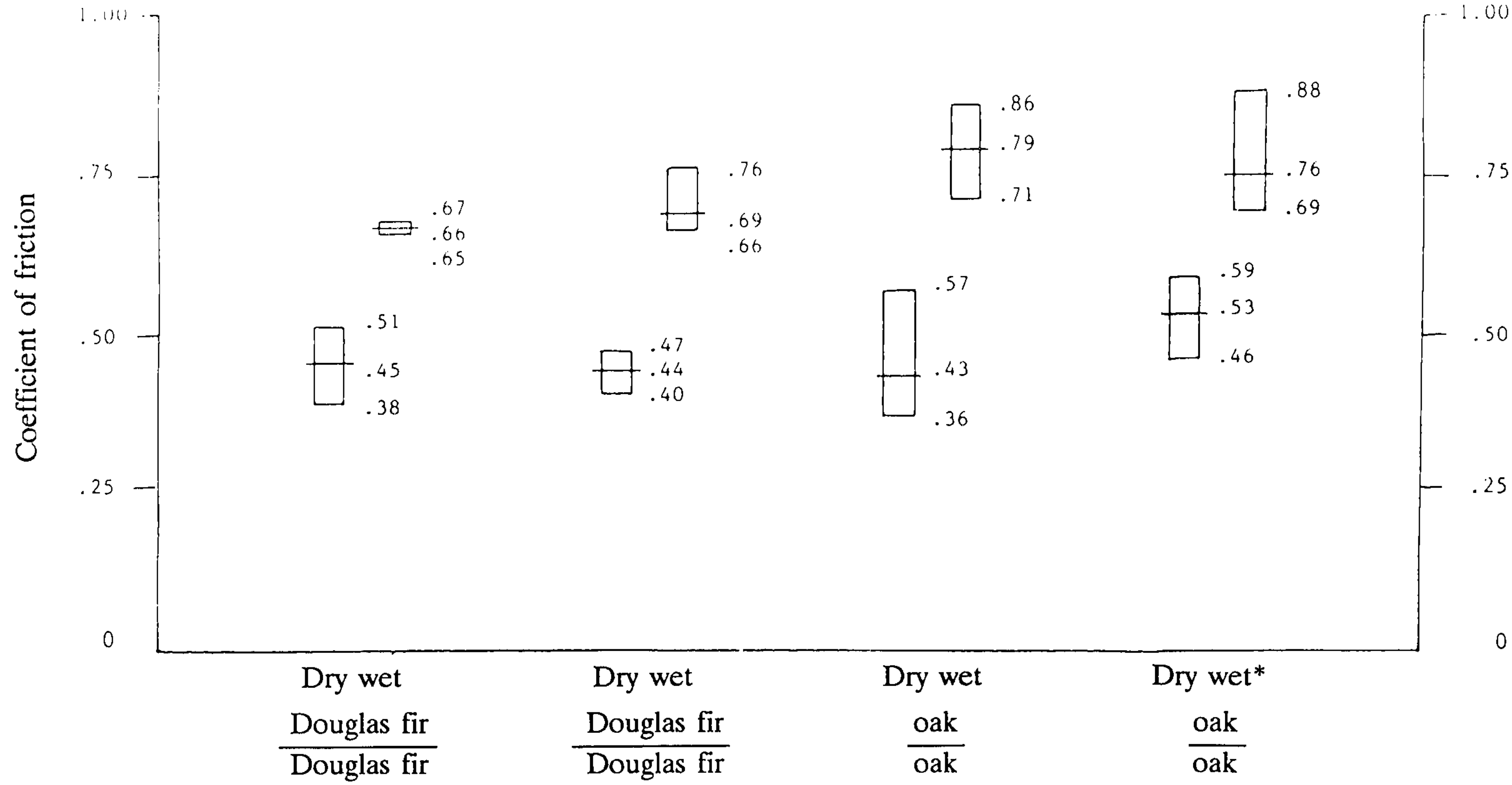


FIGURE 31. *Cribbing friction test arrangement.*



* Two tests only

FIGURE 32. *Laterally-loaded friction tests on four interfaces (averages and ranges for four tests).*

U.S. Navy Dry Dock Block
Compression Test Program

TEST FILE NO. FFOD2

TEST IDENTIFICATION CRIBBING LATERAL FRICTION TEST

SPECIES AND AGE DOUGLAS FIR ON OAK NEW DATE APRIL 5, 1985

MOISTURE CONTENT	Timber	A	B	C	D	E	F	G	H	I
	at surf.	17	17	23	20	16	22	18	17	16
	at .5 in.	24	26	33	23	19	27	23	26	30
	SPECIES	RED OAK	W OAK	RED OAK	DFIR	DFIR	DFIR	RED OAK	W OAK	RED OAK

SURFACE AREA AND HEIGHT OF BLOCKS

Block with Moving Cribbing

Bot Wood: 1628 — Top Wood: 1648 sq in

Corner heights: 17.42, 17.40, 17.42, 17.50

MOVING ← DIRECTION

Braced Block

Bot Wood — Top Wood

Corner heights: 17.48, 17.52, 17.38, 17.38

Deductions for Wane

Block with Moving Cribbing:

	Bot	Top		Bot	Top
A			G		
B		-7 chocks	H		
C		-11 wane	I	-4	-5
Total	0	-18	Total	-4	-5

Braced Block:

	Bot	Top		Bot	Top
A			G		
B			H		
C			I		

Net Area 1600 1643 AVE 1621 sq. in. 1664 1661 AVE 1663 sq

VERTICAL HEIGHT OF BLOCKS AVE of 8 corners 17.44 Inches Total Net Area 3284 sq.in.

VERTICAL LOAD 150 P.S.I. TEST MACHINE LOAD 492600 lbs
493 Kips

CONTENTS ON LATERAL LOAD FRICTION SURFACES

	41.2	
39.9		40.2
	41.1	

NET AREA 1643 sq. in.

MOVING ← DIRECTION

	40.4	
40.1		40.3
	40.6	

NET AREA 1610 sq. in.
TOTAL AREA 3253 sq. in.

FIGURE 33. Test identification sheet.

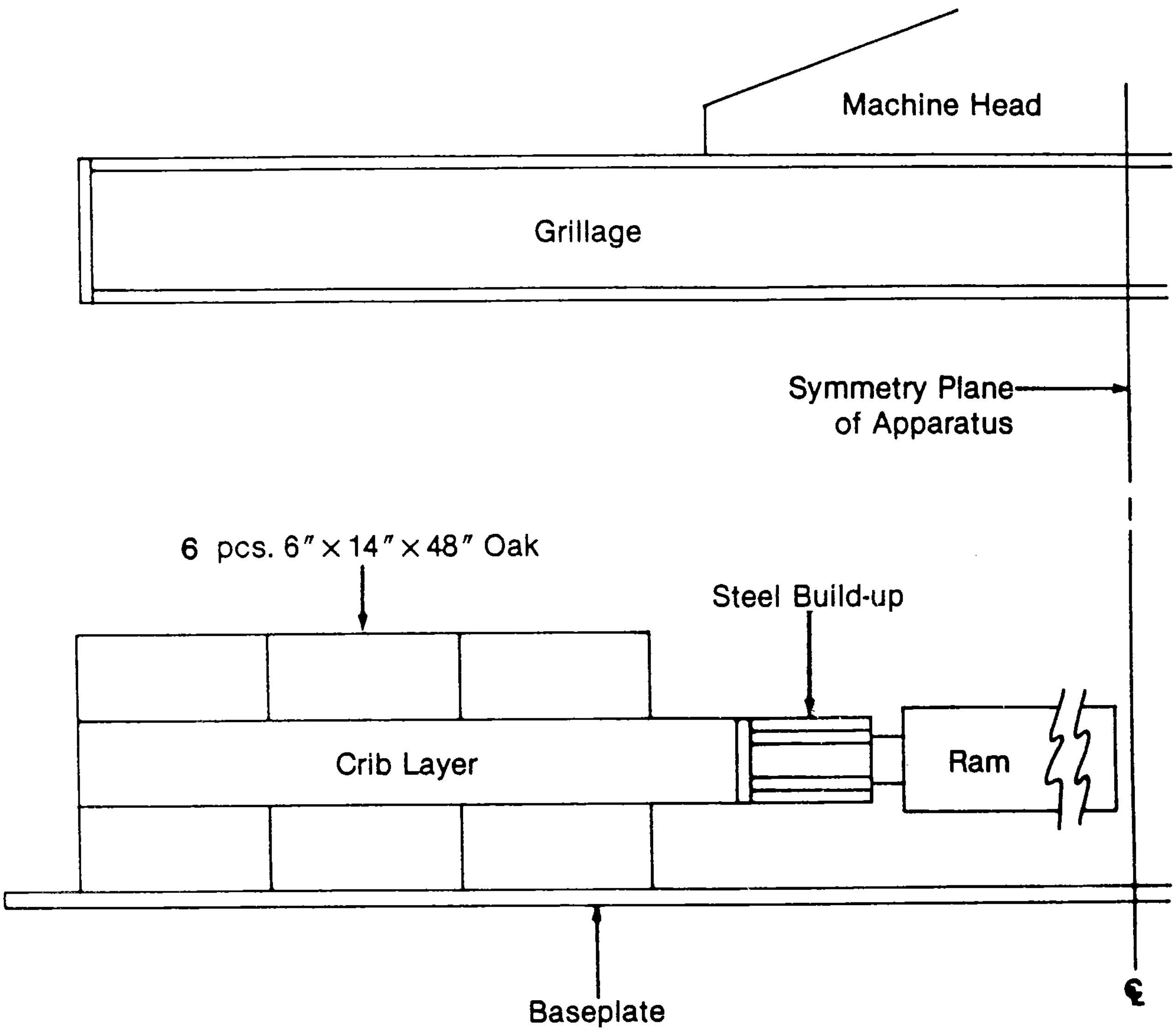
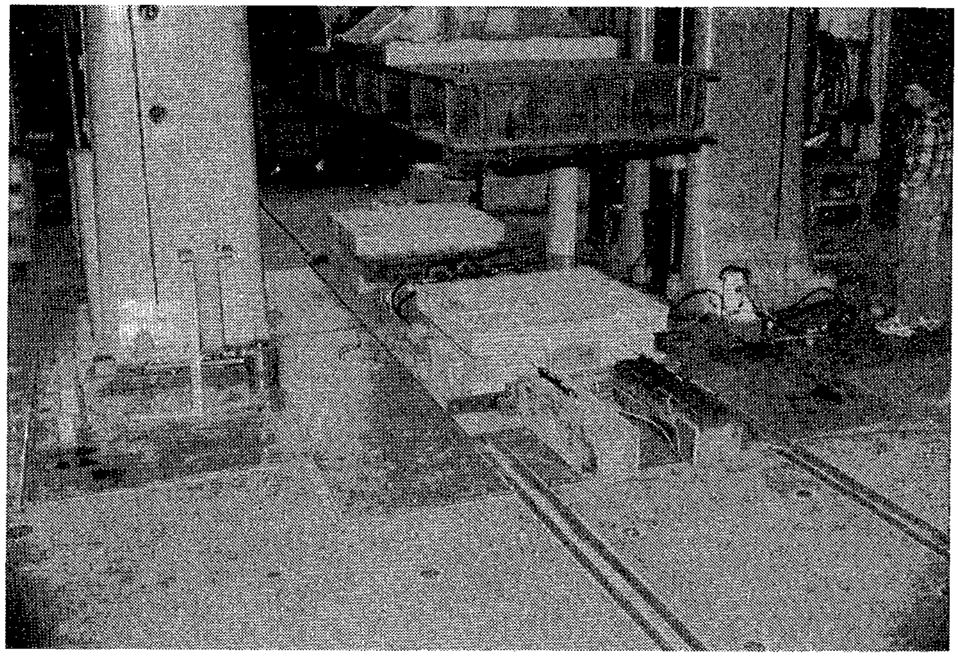
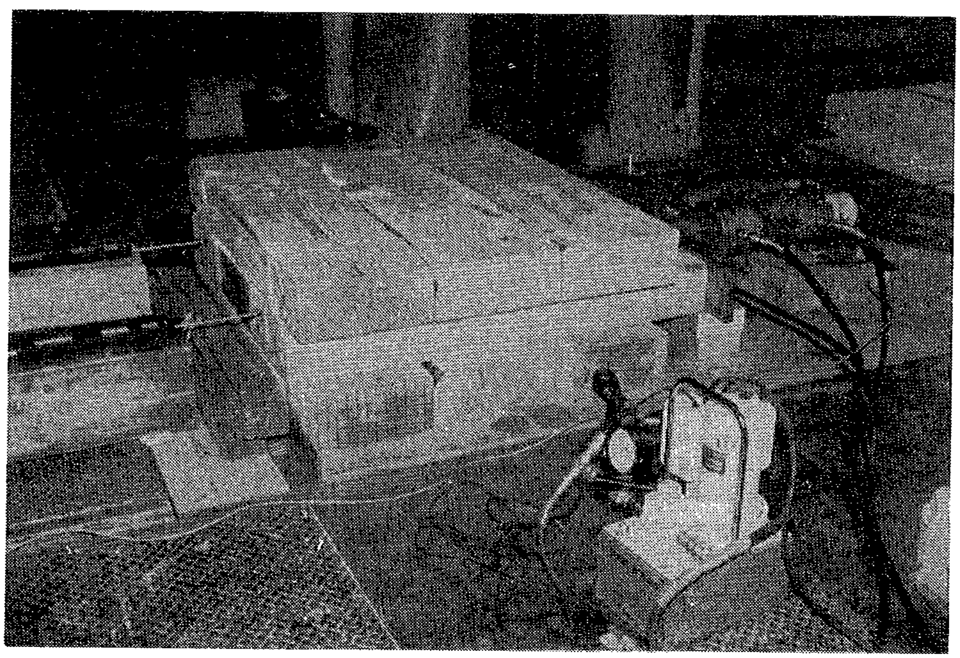


FIGURE 34. *Frictional resistance test – test machine arrangement.*





(Note the potentiometers at left and hydraulic rams at right)

FIGURE 35. *Friction test set-up.*

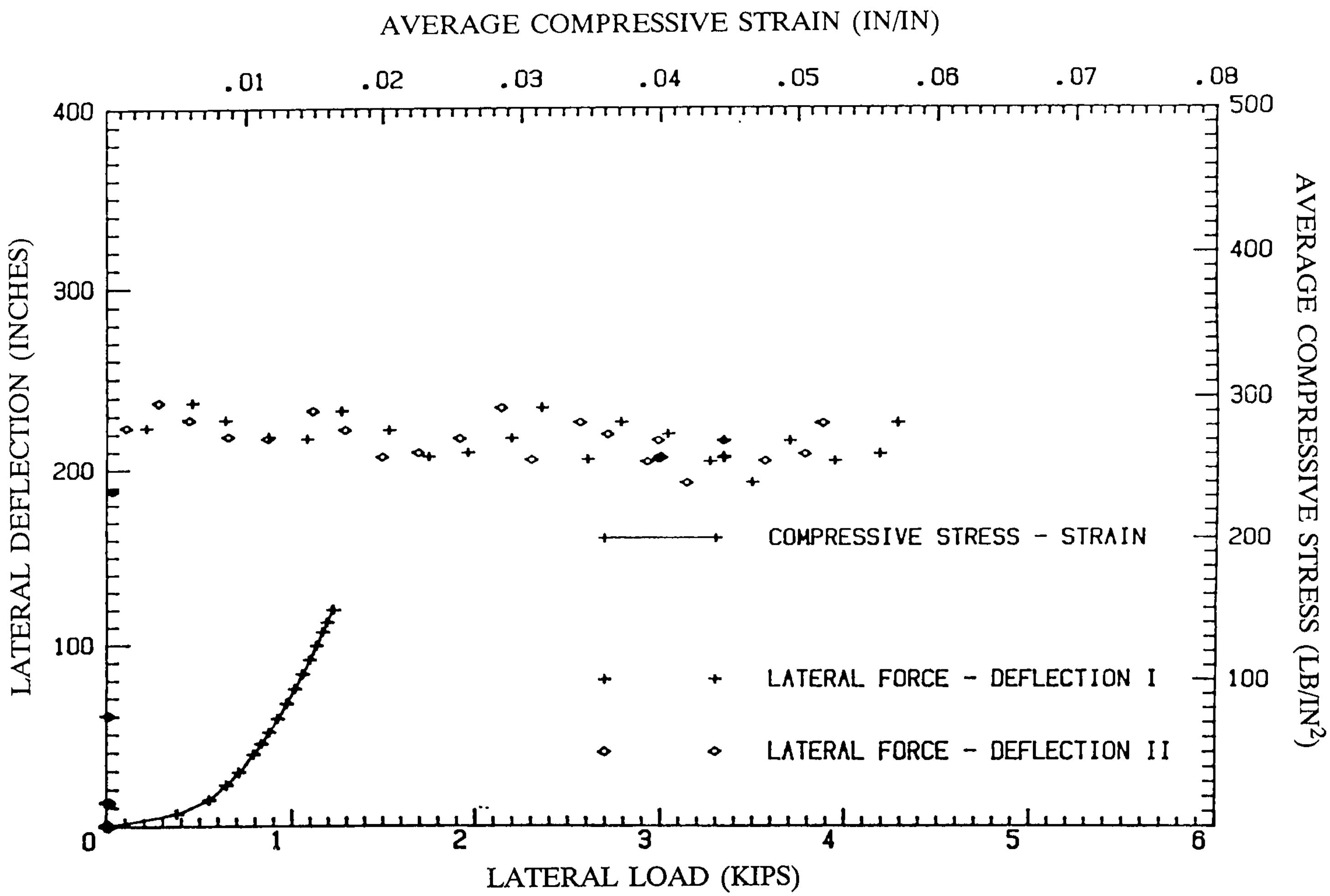


FIGURE 36. *Stress-strain and lateral deflection diagram.*