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WEPO - WIND ENERGY PROJECT OFFICE

PIR No. 62

PROJECT INFORMATION REQUEST/RELEASE

FROM		TO
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DATE SENT	**DATE INFO. REQUIRED**	**REFERENCES**
May 24, 1978		

SUBJECT

Wood Blade Bolt-Epoxy Bond Tests

INFORMATION REQUESTED/RELEASED

A series of tests were conducted to determine the strength of an epoxy bond between a threaded steel rod (bolt or stud) and a laminated wood specimen. Results from these tests will be used to determine a satisfactory method for transfering loads from a wood wind turbine blade to the rotor shaft of the turbine. A reason for investigating this facet of a wood blade is the fact that an area with high stress is created where the root end of the blade (see figure 1) is bolted to the rotor hub due to the bending moment applied to the rotating blade and the bolts. The bond between the wood and bolts, therefore, must be able to hold the bolts in place and withstand the expected bolt operating loads of approximately 10,000 ± 5,000 pounds and one time gust load of 38,000 pounds. Laminated wood specimens with a 4-inch by 4-inch cross section (typical of the section thickness of the blade) and 24 inches in length were manufactured for testing by the Gougeon Brothers of Bay City, Michigan. After wood lamination was complete a stud hole of the proper depth was drilled, filled with thickened epoxy, and the stud was inserted. These specimens were then sent to Lewis Research Center where the wood model shop epoxyed and bolted two ½-inch thick heat treated steel plates to the side of each specimen (for complete assembly see figure 2). The specimens were each suspended in a Gilmore multiaxial test machine in the Special Projects Laboratory and loaded in tension until failure occurred or cycled between upper load and lower load values until they failed. As the test progressed, techniques were improved and the fatigue life of the specimens was increased through modifications made to the wood specimens and the bond between the wood and the stud.

Three different types of wood/stud specimens were tested: 1) fir block specimens which were made of 3/4 to 1 inch thick pieces of fir bonded together, 2) fir block specimens with a ½ inch thick plywood core approximately in the center of the specimen simulating a proposed shear web, and 3) fir laminated (veneer) specimens which were 1/8 inch thick layers of fir bonded together. Three ash block specimens (one with a 7/16 inch thick ply core) were also tested.

TEST RESULTS

Tensile pull tests and cyclic fatigue tests of the above described wood specimens indicate that:

1) Due to the fact that the stud transfers load to the wood through shear in the epoxy resin, high shear stresses develop at the point of entry of the stud into the wood block. These shear stresses cause significant cross grain tensile stresses

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to develop at the end of the wood block. Since the cross grain tensile capacity of the wood is less than 500 pounds per square inch, the result is a splitting failure of the wood with a premature pull out of the stud (see figure 3). It was found that bonding a thin layer of birch plywood to the end of the specimen would aleviate this problem. Plates clamped to the top of the specimen and fiberglass wrapping of the top were also tried but with less success. The effect of the birch ply can be seen in figure 4 where comparative tensile load capacities are presented.

2) Fir block with plywood core specimens are inferior to fir block or laminated fir in load carrying capacity. The specimens have a tendency to split within the plywood, as shown in figure 5, resulting in a premature failure of the specimen.

3) Fir block specimens are comparable with fir laminated specimens in axial tensile pull loading capacity (see figure 4) but are inferior to the laminated specimens when loaded in a cyclic manner.

4) Fir laminated (veneer) specimens show the greatest fatigue life in cyclic tests and can resist stud "pull-out" at high tensile loads.

5) 15-inch stud depths increase both the tensile load and cyclic fatigue life of all specimens when compared with 12" and 9" stud depths (see figure 4).

6) A step-tapered hole is a method that can be used to increase the load carrying ability of the wood/stud bond. Fir veneer specimens with fifteen-inch stud depths increased in tensile load capacity from about 67,000 pounds load to 75,000 pounds load, through application of this concept (load values are an average of two specimens in both cases). The step-tapered hole causes more tearing to occur during failure (see figure 6) than does the continuous diameter hole which generally fails by splitting or shearing the wood. The stud hole configuration has still not been optimized but based on test results a step-tapered hole will be used in the 20-foot wood blade root section being fabricated by the Gougeon Brothers.

7) Results of the ash block specimen tests are inconclusive. Two of the specimens were of poor quality. The third was assembled differently from other block specimens but gave the highest tensile load value recorded (89,565 pounds load). More testing of ash specimens is suggested.

8) The mean value for all 15-inch stud depth, laminated fir (veneer) specimens was 64,800 pounds load. This is well in excess of the 38,000 pounds maximum load expected on the blade. Cyclic loads at 10,000 $\pm$ 10,000 pounds load (compared to the 10,000 $\pm$ 5,000 pounds expected in the blade) did not cause bond failure at 1×10^6 cycles. 15" fir laminated specimens are projected to have a fatigue capability in excess of 10^8 cycles at 20,000 $\pm$ 15,000 as shown in figure 7C. (Plots of other stud depth cyclic fatigue tests are shown in figures 7A and 7B.)

CONCLUSION

Our tests indicate that a stud epoxy bonded to the wood blade root end should have an adequate load carrying capacity. Cyclic fatigue and tensile pull strengths are improved as stud length increases to 15 inches. Strength in tensile and cyclic loading is also enhanced by use of birch plywood and step-tapered stud holes. Therefore, the fabrication of the 20-foot wood blade test section will include 15-inch stud depths, birch plys surrounding the studs, and step-tapered stud holes. Cyclic tests of wood specimens indicate that the life of the root end of a wood blade with the bonded stud arrangement should be in excess of that expected for wind turbine blades.

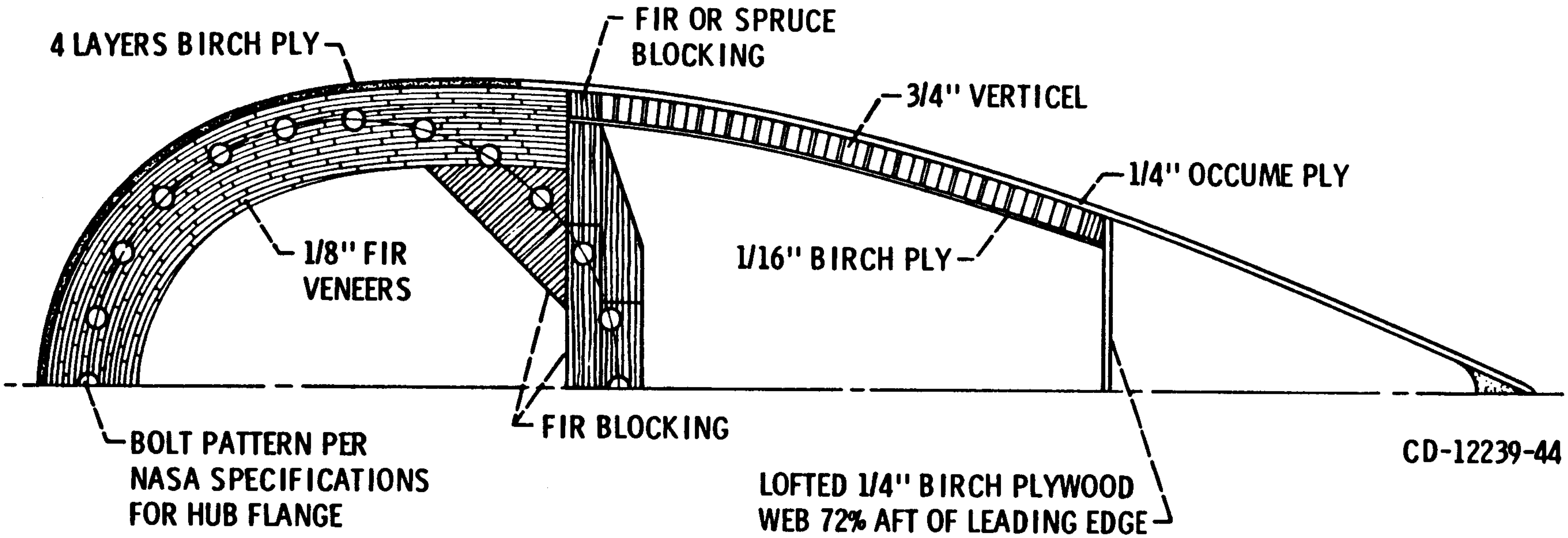
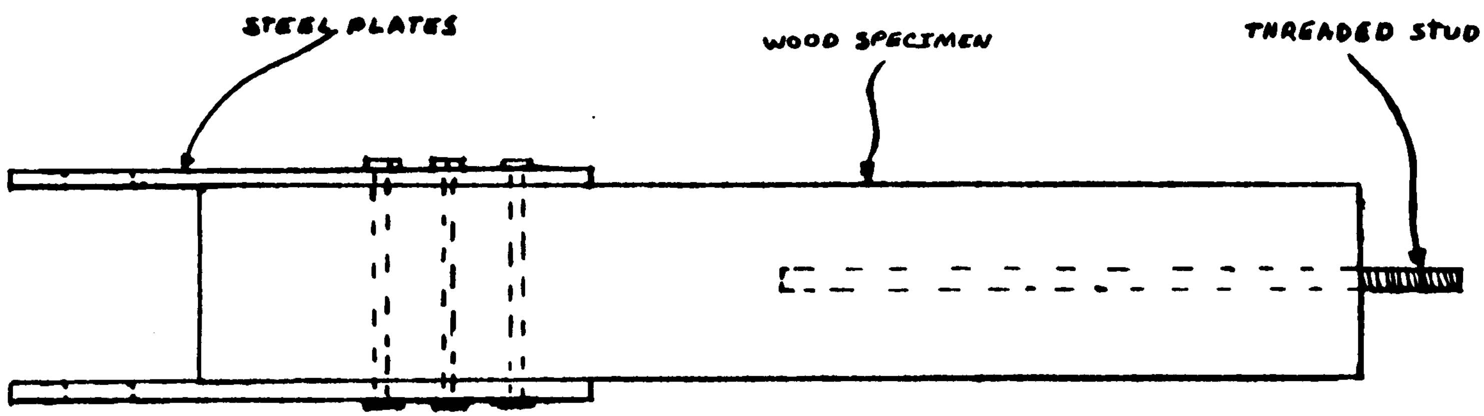


FIGURE 1

WOOD BLADE ROOT END CROSS SECTION

WOOD TEST SPECIMEN SCHEMATIC



1/4" = 1"

FIGURE 2

SKETCH 051578
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SPECIMEN WITHOUT BIRCH PLY -
CROSS GRAIN FAILURE.

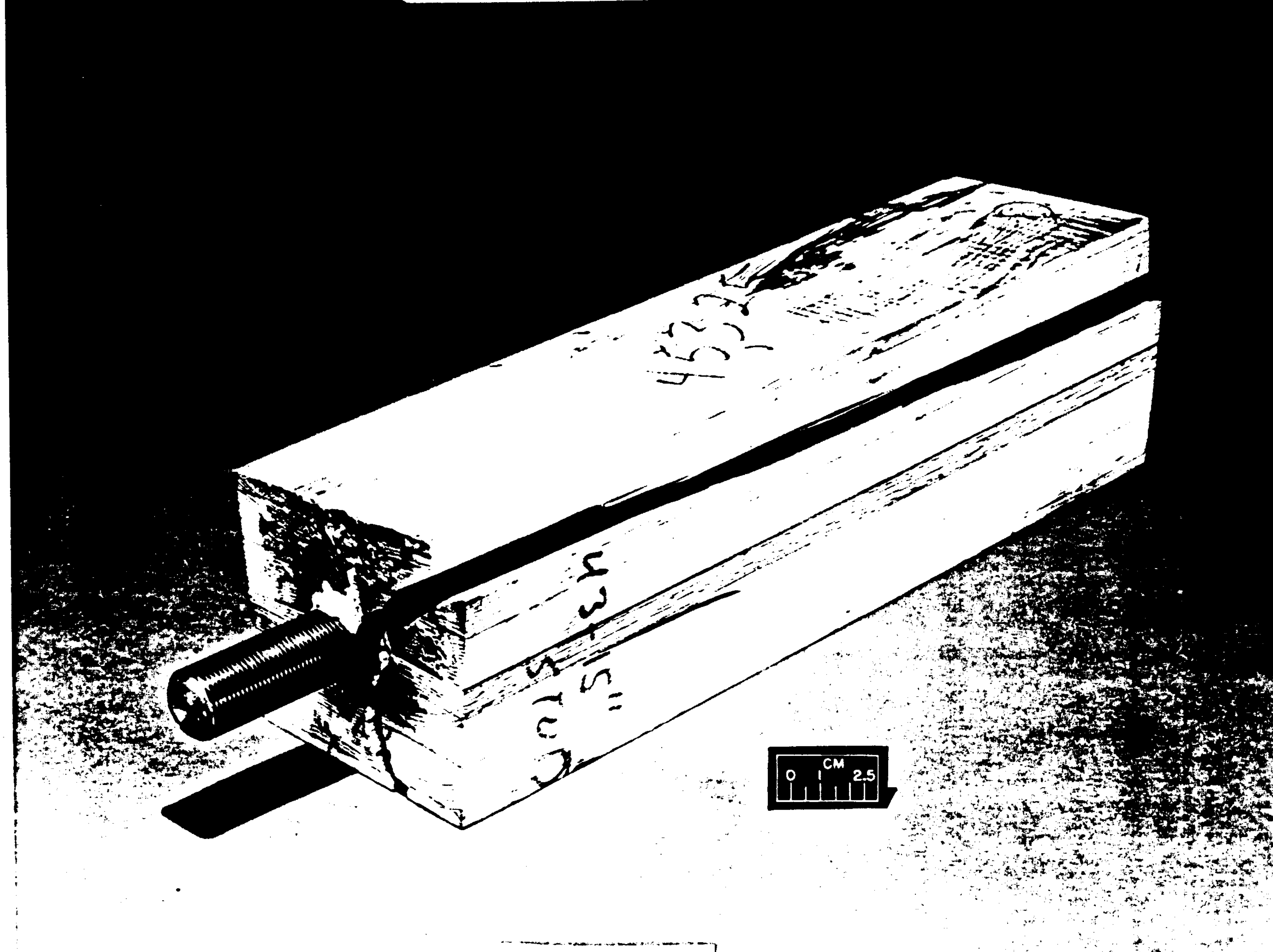

FIGURE 3

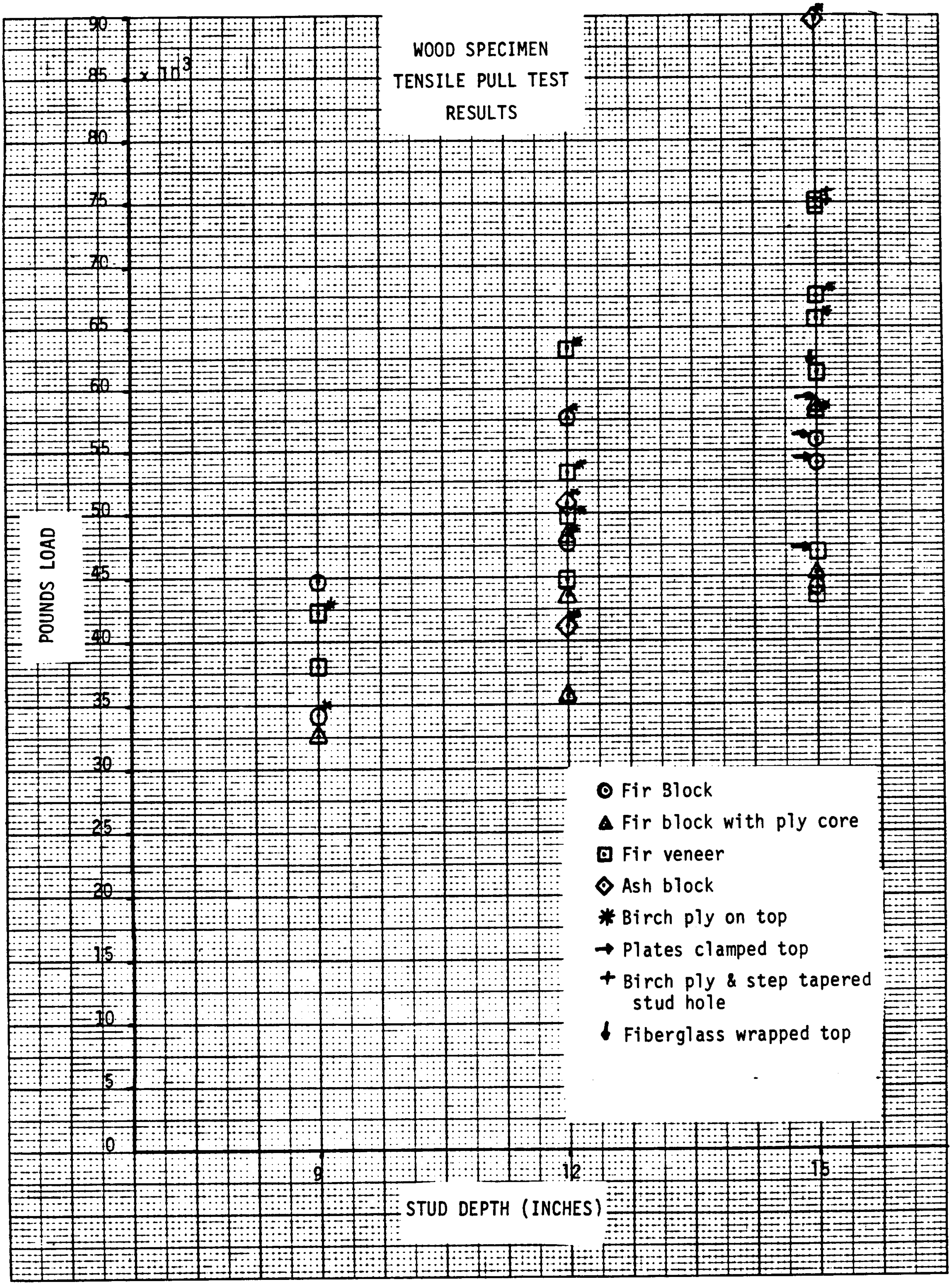
WOOD SPECIMEN
TENSILE PULL TEST
RESULTS
x 10^3
POUNDS LOAD
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
9
12
15
STUD DEPTH (INCHES)
Fir Block
Fir block with ply core
Fir veneer
Ash block
Birch ply on top
Plates clamped top
Birch ply & step tapered stud hole
Fiberglass wrapped top

FIGURE 4

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FIR BLOCK WITH PLY CORE
FAILURE MODE

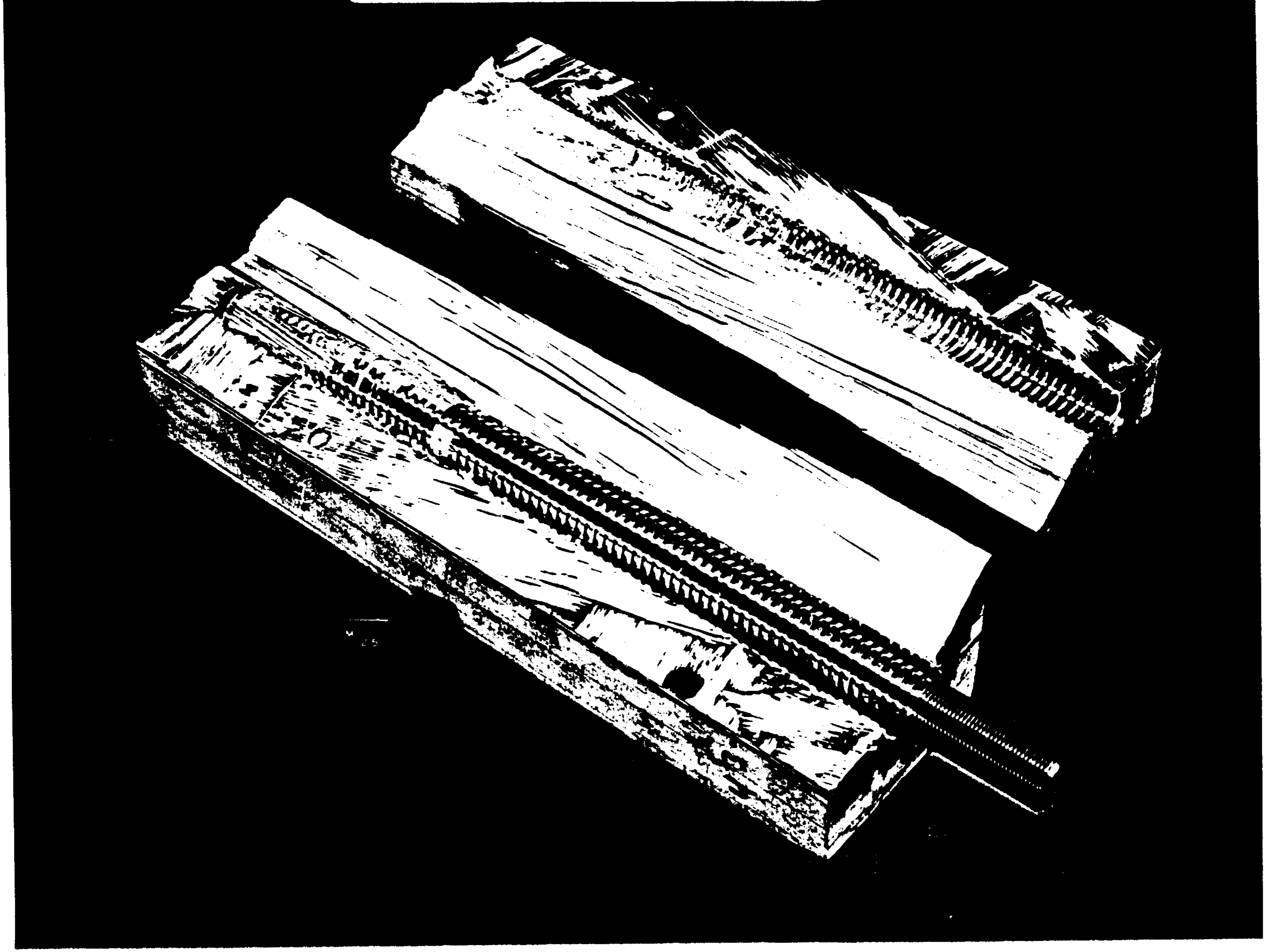

FIGURE 5

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STEP-TAPERED STUD HOLE
FAILURE MODE

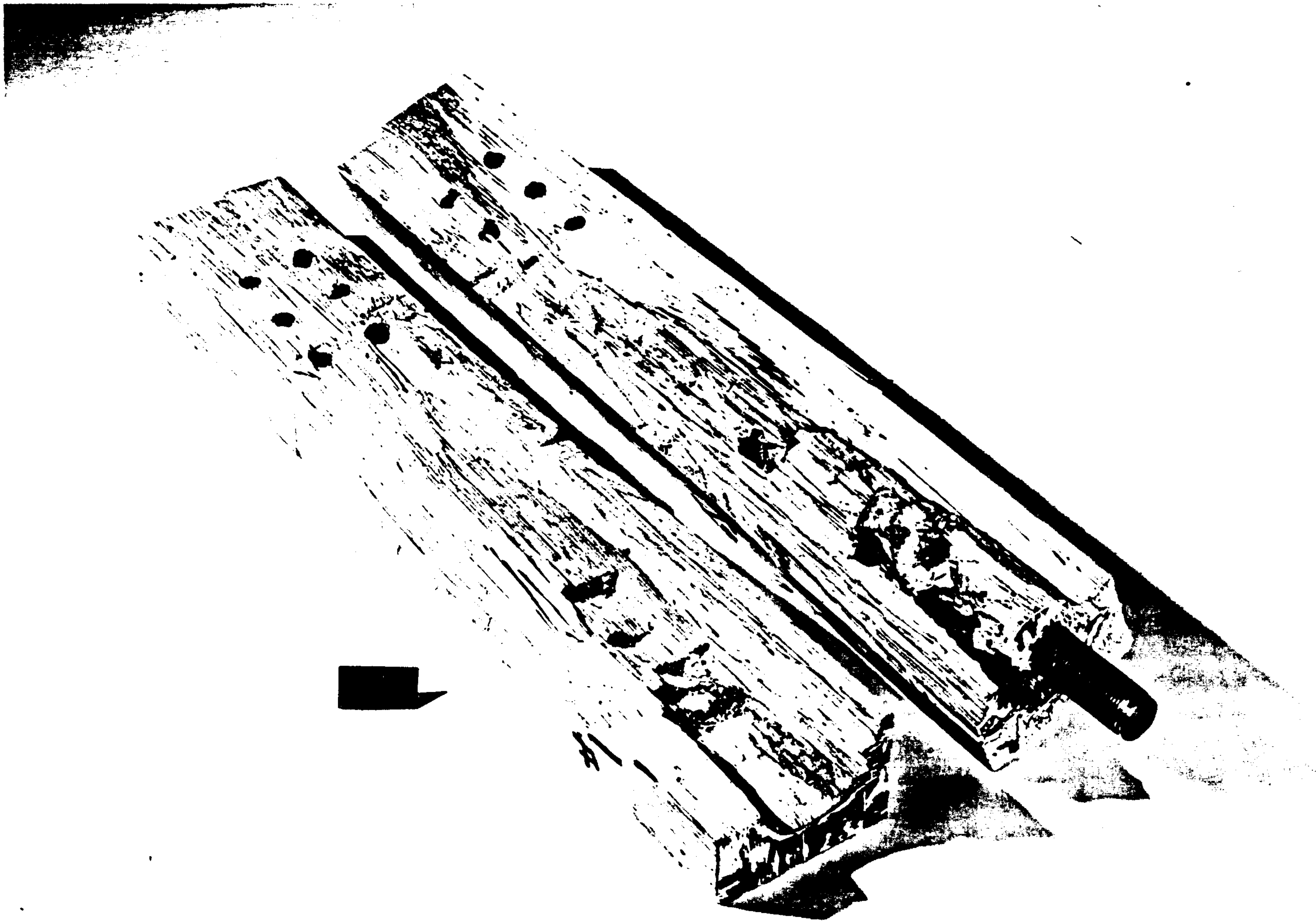

FIGURE 6

WOOD SPECIMEN CYCLIC FATIGUE

TEST RESULTS

9" STUD DEPTH

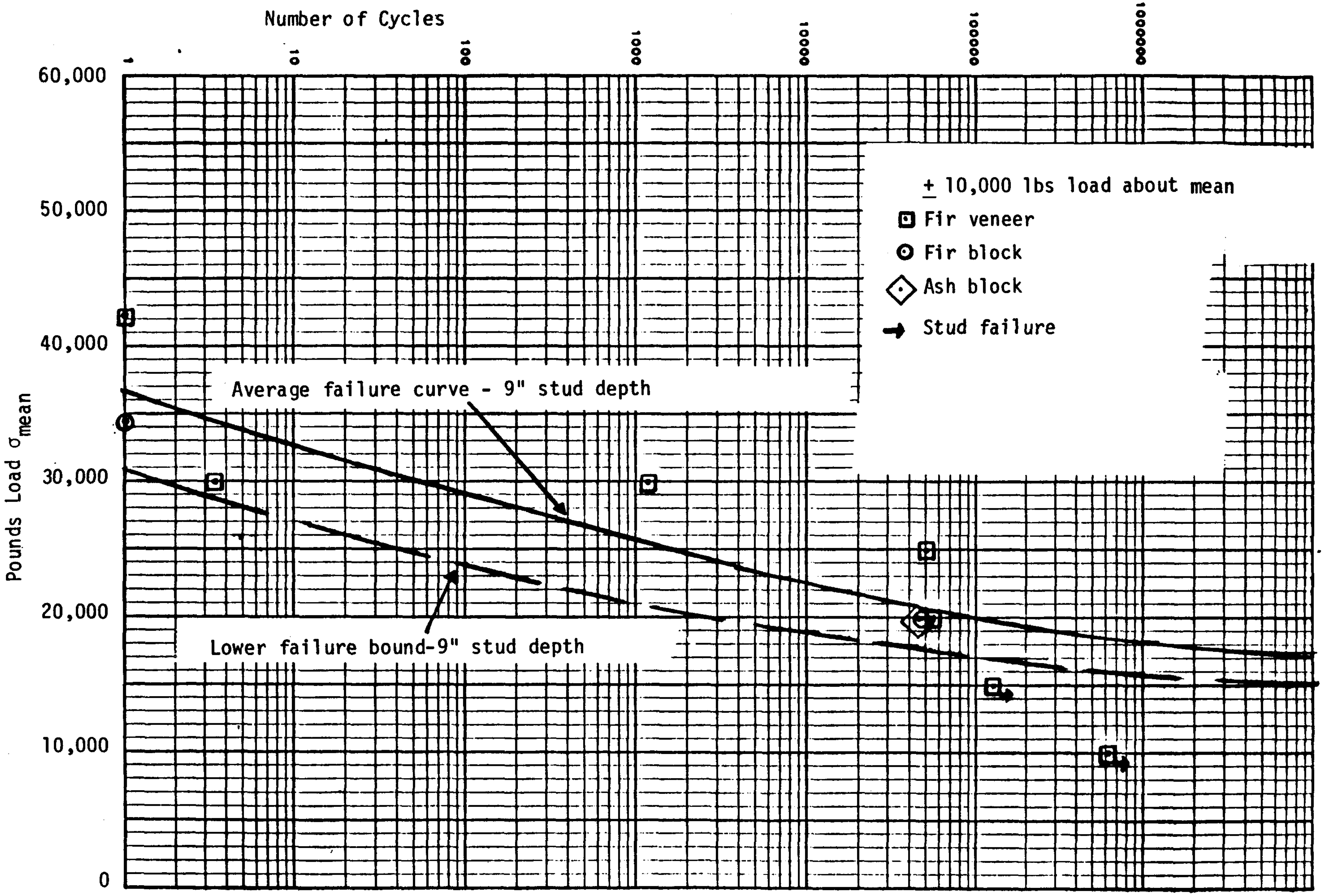

FIGURE 7A

D.P.C. 5/19

WOOD SPECI[illegible] CYCLIC FATIGUE
TES[illegible] RESULTS
12" STUD DEPTH

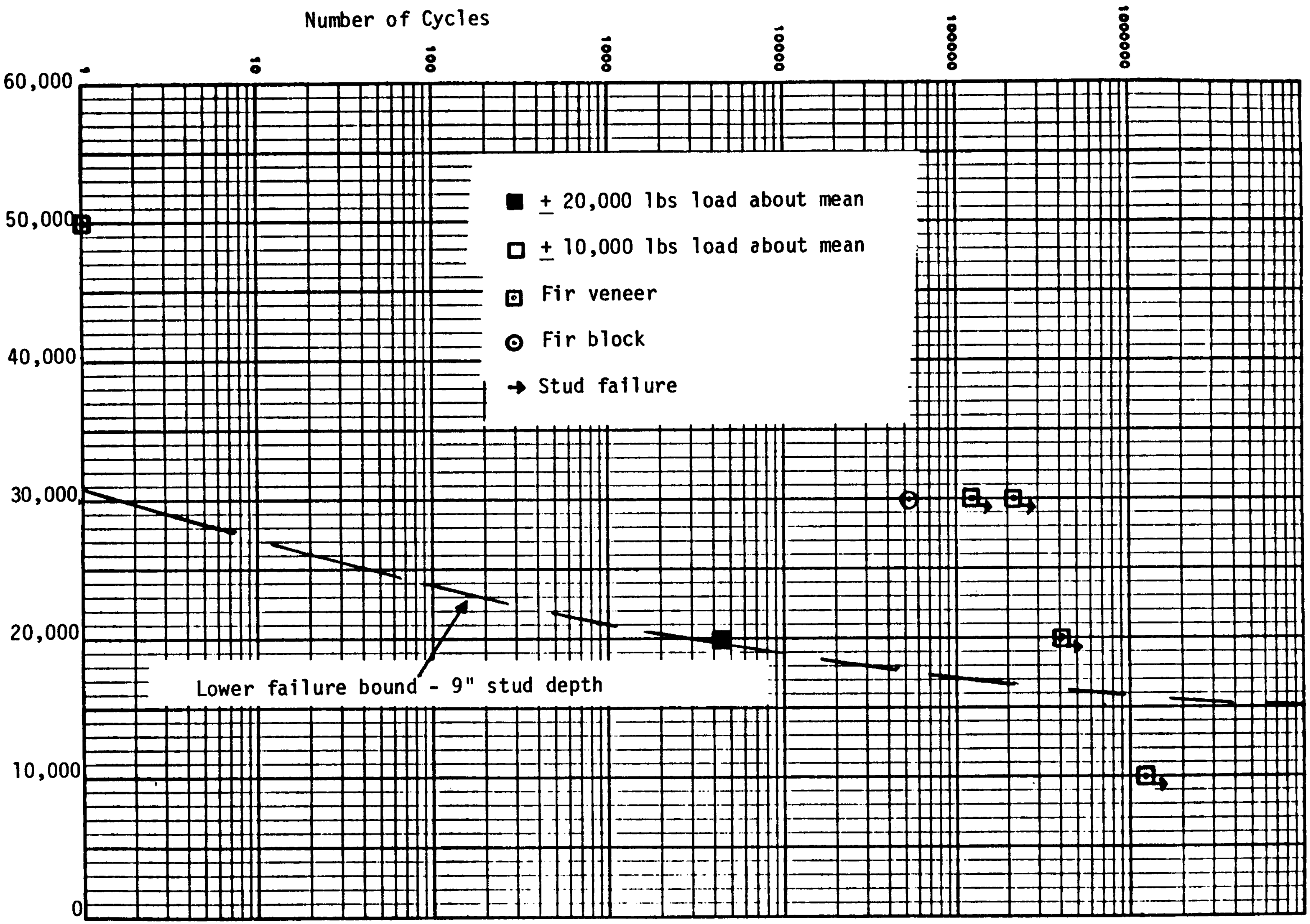

FIGURE 7B

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WOOD SPECIMEN CYCLIC FATIGUE
TEST RESULTS
15" STUD DEPTH

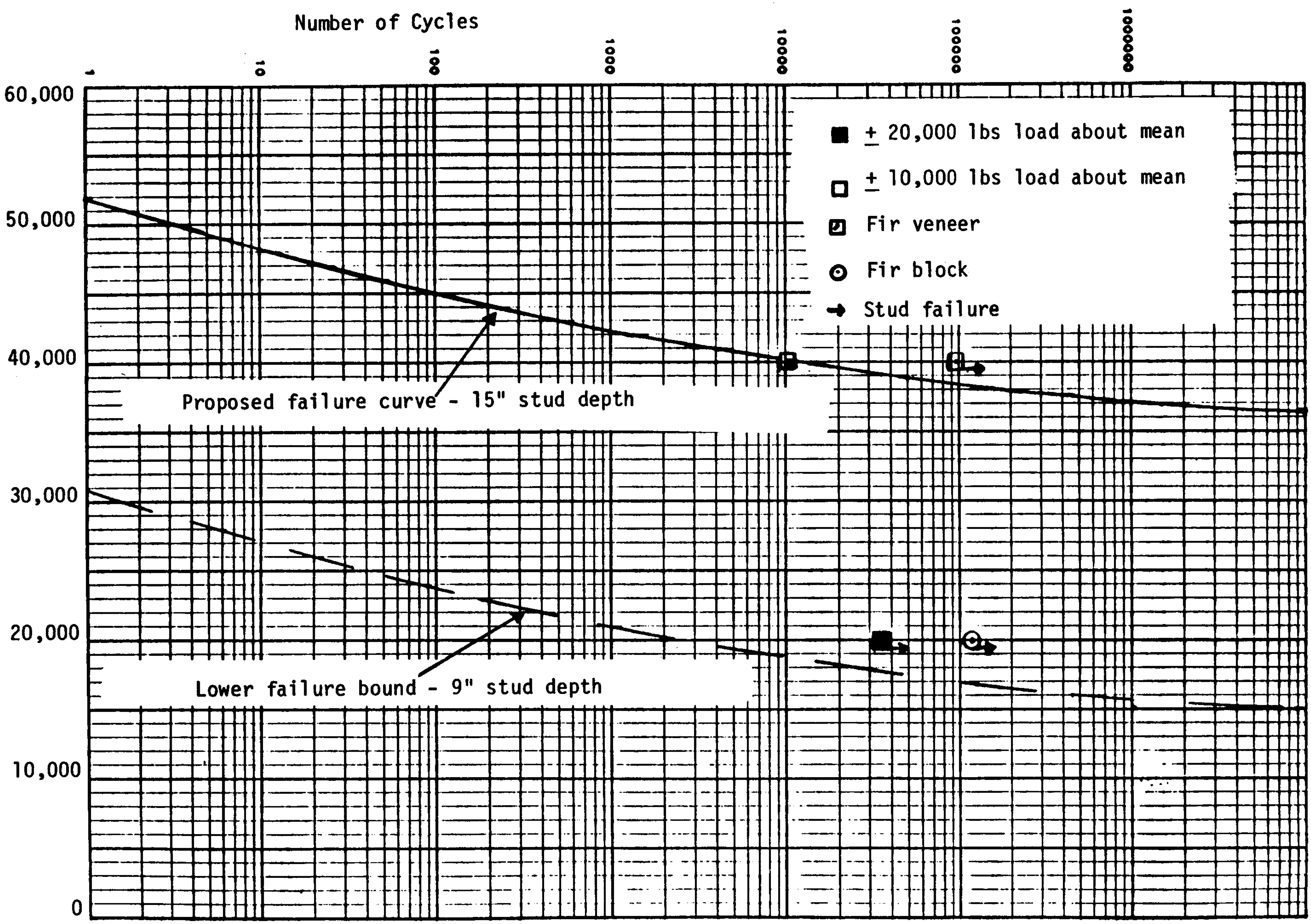

FIGURE 7C