

EVALUATION OF TIMBER CAISSON US 25 BRIDGE OVER OHIO RIVER

Jas. H. Havens, Director of Research
and
Assaf Rahal, Research Engineer
Kentucky Department of Highways

INTRODUCTION

Timber foundations under masonry structures have been employed throughout recorded history. Wood buried below the oxygen-diffusion zone is preserved through oxygen starvation of fungi and bacteria. Decay may proceed for a short time. Anaerobic bacteria have an implied capability of regenerating and utilizing oxygen from host organic matter; however, the digestive cycle is likely to become unbalanced, poisoned, or at least arrested. Obviously, buried woods do not persist forever. Some commentaries indicate that wood pilings suffice for 80 to 100 years; others suggest hundreds of years. However, the tenure of structures in this country rarely exceeds a hundred or more years. American engineers do not usually build to withstand the ages. Obsolescence limits tenure. European engineers strive for greater tenure.

Pier No. 2 of the former C&O Bridge at Covington is off-shore from the Kentucky side of the Ohio River. It was built in 1887. In 1927, this pier was extended downstream to support a new railroad bridge. The other three piers remained independent. The original structure was then converted to highway use and was purchased by the Commonwealth of Kentucky in 1937. In 1968, an engineering analysis of the superstructure indicated critical deficiencies in terms of "safety factors", and the bridge was closed to all traffic. Subsequently, various plans for reconstruction came under consideration. Of greatest significance here is the consideration toward re-use

of Pier No. 2 -- jointly with a new highway bridge and the existing railroad bridge. Cost estimates appeared persuasive; the structural feasibility remained dependent upon the integrity of the pier -- more specifically, the worthiness of the masonry, concrete, and the underlying timber caisson.

Prior to removal of the steel superstructure (fall of 1970), vertical cores were extracted from Pier No. 2 for evaluation. This report concerns the evaluation of specimens of wood from the timber caisson.

Consideration of use of Pier No. 2 in the new structure afforded a rare opportunity for historical but purposeful inspection of the existing condition of the wood. Discovery of decay or rot would probably have led to immediate rejection of the alternative. Upon recovery, the cores appeared frayed and severely damaged. Later, when sawed along their diameters, bright wood appeared. A slightly acrid odor was detectable; but there was also a distinctive scent of newly-cut wood. Specimens of pine were distinctly odorous. A specimen of poplar was recovered but was examined only by the Forest Products Laboratory. In the main, the cores consisted of white oak. Not all of the specimens were bright (yellowish); some were dark -- approaching gun-metal blue or dark gray. Miniature specimens were cut from the cores and subjected to compressive loading. Stress-strain curves are presented here. Comparative stress-strain curves obtained from new white oak wood are also provided.

The substructure construction was described by Wm. H. Burr (1). Plate XIII, therein, is most pertinent and is reproduced herein as Figure 1. The

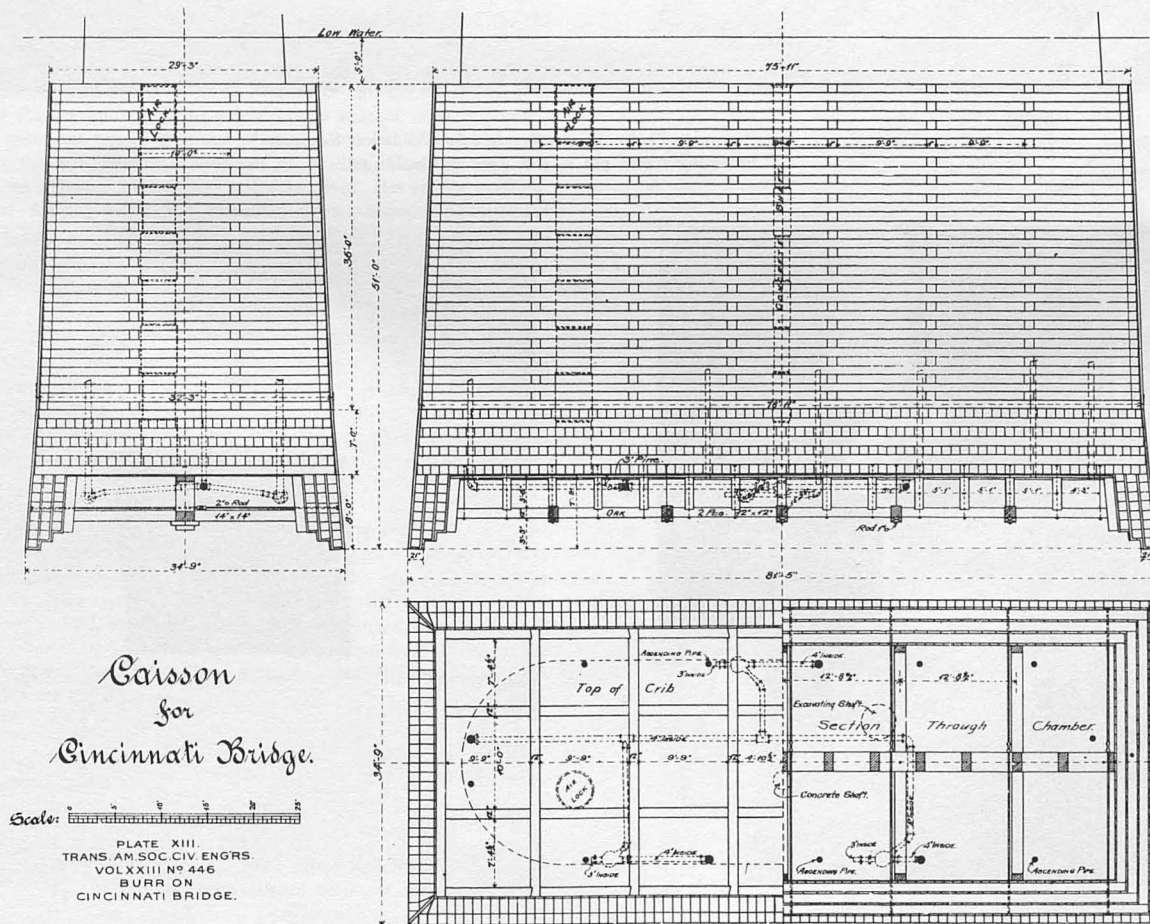


Figure 1. Caisson for Cincinnati Bridge (1).

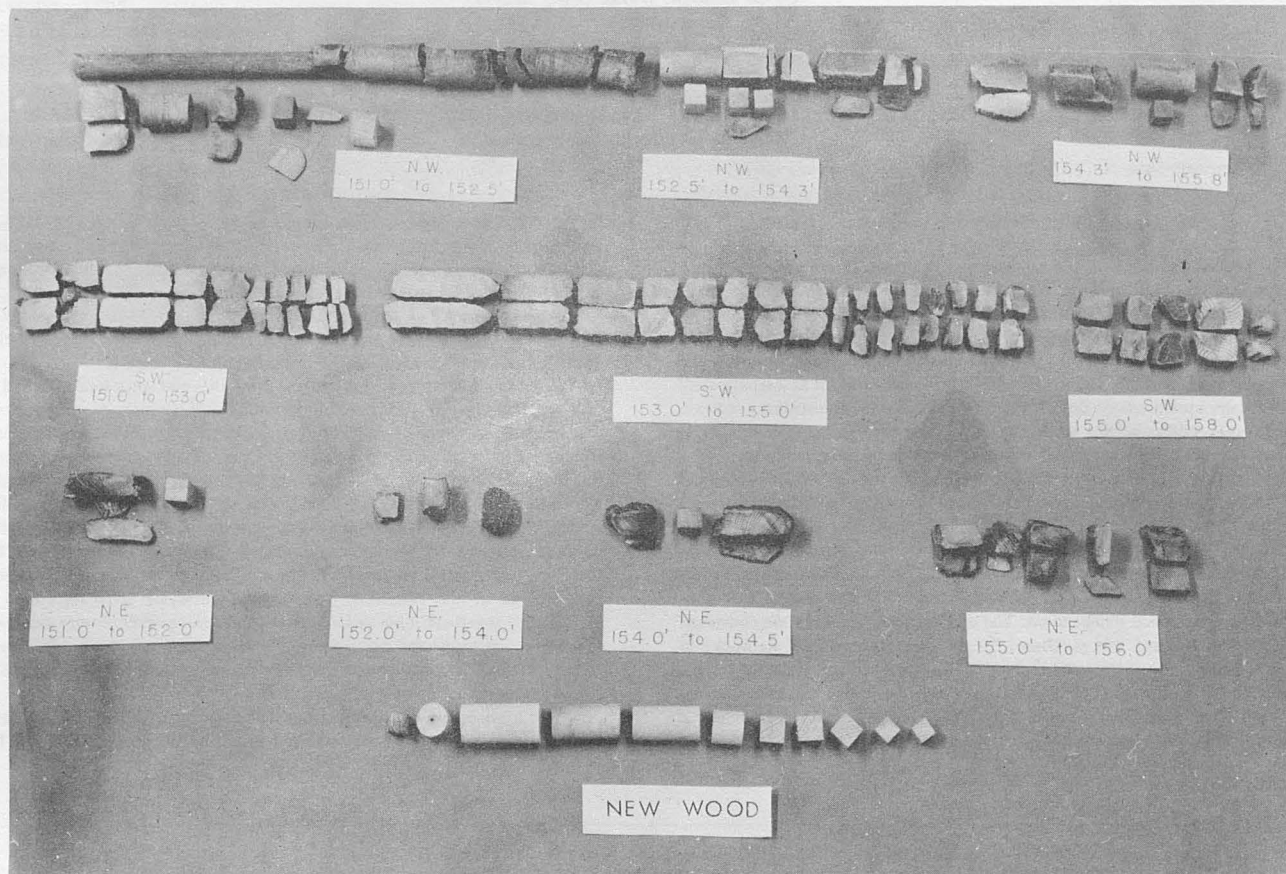


Figure 2. Composite Photo of Cores Received for Evaluation. Recovery of wrought iron pin in NW core was incidental.

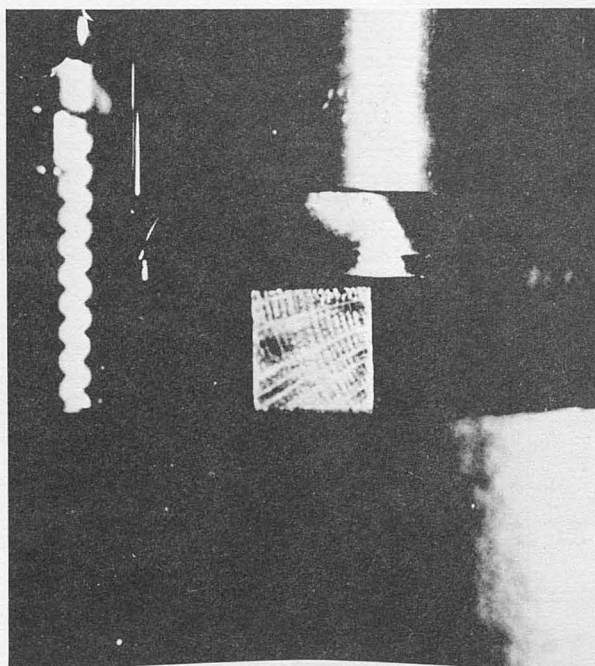


Figure 3. Specimen of Bright White Oak in Compression. Note weeping from pores near base of specimen.

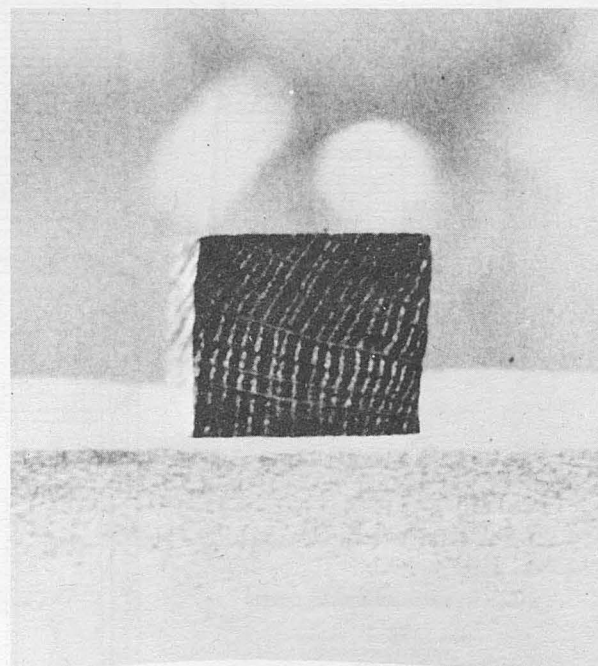


Figure 4. Dark White Oak Specimen Showing Residual Distortion Following Severe Compression.

main piers of the Roebling suspension bridge immediately upstream from the C&O site, was begun in 1857; the piers are founded on hewed log mats set on gravel 10-12 feet above bedrock. The bridge was opened to traffic January 1, 1867 (2).

Figure 2 is a composite photograph of the three cores received for evaluation. Attention is directed to the incidental recovery of a wrought iron pin in the upper portion of the NW core.

COMPRESSION TESTS

Small cubical specimens, ranging from 0.7 inch to 1.2 inches in size, were cut from the cylindrical cores. Except for slight surface drying during fine shaping, the specimens were maintained in a wet condition until the compression tests were completed. A specimen of bright wood in test is shown in Figure 3. All compression tests were made perpendicular to the grain. There was noticeable weeping of water from the pores.

Figure 4 shows a specimen of dark wood distorted (residual) by compression. None of the specimens ruptured, split, or tore; all specimens, including new wood, exhibited a yield point followed by strain hardening. The resulting stress-strain relationships are shown in Figure 5. The minimum yield point occurred at about 350 psi; the yield stress of new wood was in the order of 2 to 2.5 times that of old wood. The handbook yield point for white oak, at 70 percent moisture (green and unseasoned), is 850 psi. New wood specimens were soaked in water for five days before testing.

Differences (between new and old wood) in the number of annual rings per inch are also shown in Figure 5. Because of these differences, the woods are not directly comparable in terms of strength. The new wood specimens contain a significantly greater proportion of late wood growth and are thereby adjudged to be superior in strength. Due to an assumed improbability of finding new wood comparable in anatomical attributes to the old wood, it was decided to air dry specimens of old wood and to make strength tests in that condition and to compare those strengths with handbook values for new wood. The average handbook value for white oak in this condition is 1410 psi. The strengths of the two specimens selected (one bright wood and one dark wood) are shown in Figure 6. By this comparison, the old wood would necessarily be adjudged equal to average new wood. This interpretation minimizes any effects otherwise attributable to decay. It does not suffice to explain the low, wet strength of the old wood (3). It is suggested that moisture contents approaching a state of supersaturation -- possibly somewhat greater than that of green wood and of osmotic origin -- affects the wet strength. The effect of swelling, attending unloading (coring), on moisture content was not determined. However, a small but significant swell pressure was measured upon reimmersion (discussed subsequently).

SWELL AND RELAXATION TESTS (TRIAxIAL)

A cylindrical specimen of dark wood, 2.72 inches x 1.30 inches, was placed in a triaxial test chamber and surrounded by water under 20 psi pressure; the specimen was restrained in the axial direction by a nominal preload of 1 pound and a load cell. After 24 hours, the swell pressure was 6.1 pounds. The load was increased to 50 pounds; and under constant strain, the specimen was allowed to relax for 1 to 6 hours; the residual load then was recorded. Then the load was removed and the residual strain recorded (usually 20 to 30 minutes after unloading). This procedure was repeated with five additional, 50-pound increments of loads; the maximum load was 300 pounds. The resulting strain-hysteresis data were plotted as shown in Figure 7. The relaxation loads after a time (1 to 6 hours) are shown plotted against applied load, in Figure 8. There, the deviations from the line of equality indicate the relative creep-relaxation of load with respect to the applied load and time. From these data, the relaxation modulus, G , was calculated from the equation:

$$G = P/3 A e_1,$$

in which: P = Applied Load
 A = Area of Specimen (after straining)
 e_1 = Strain (from original height of specimen)

The respective moduli for old and new wood are:

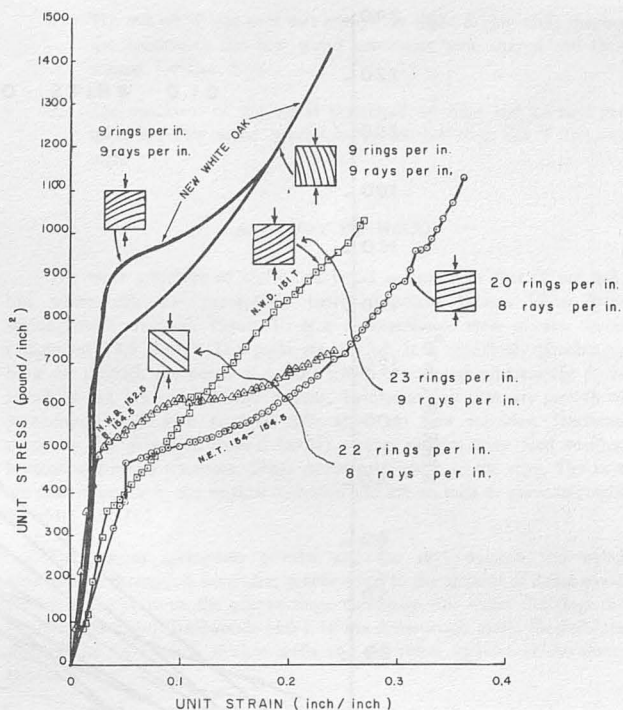


Figure 5. Stress-Strain Relationships Obtained from Old Wood and New Wood (Saturated).

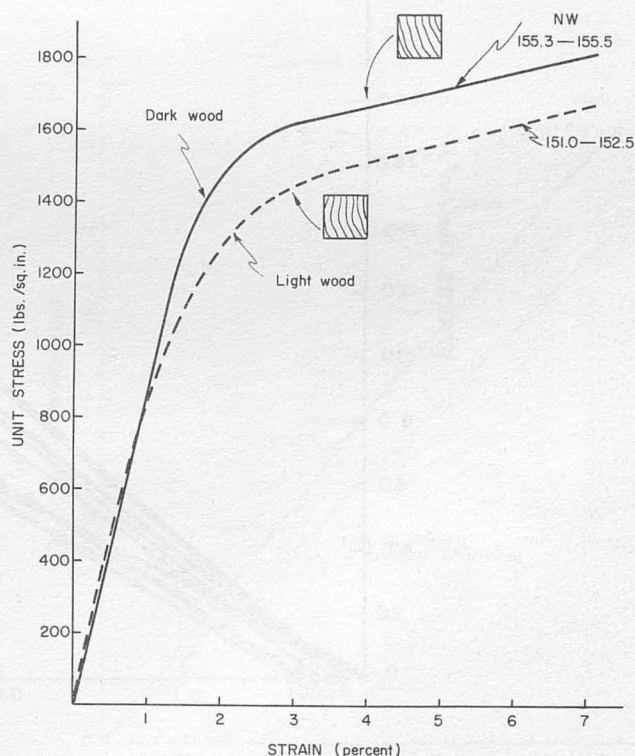


Figure 6. Stress-Strain Relationship Obtained from Air-Dry Specimens of Old Wood.

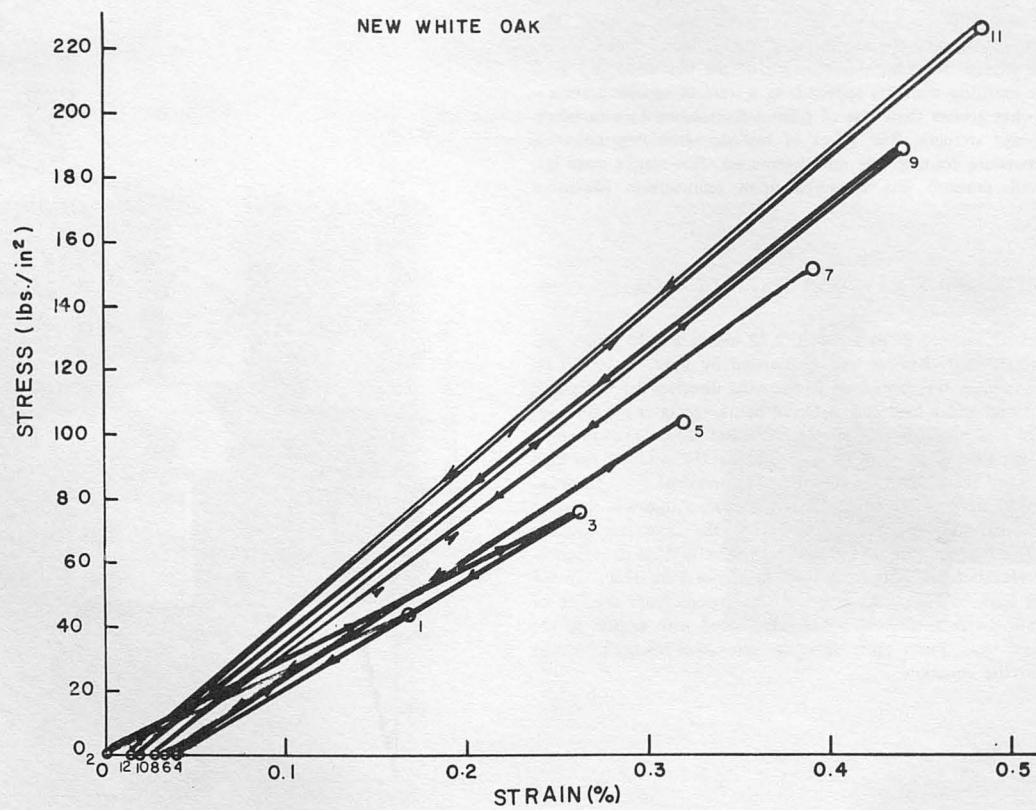
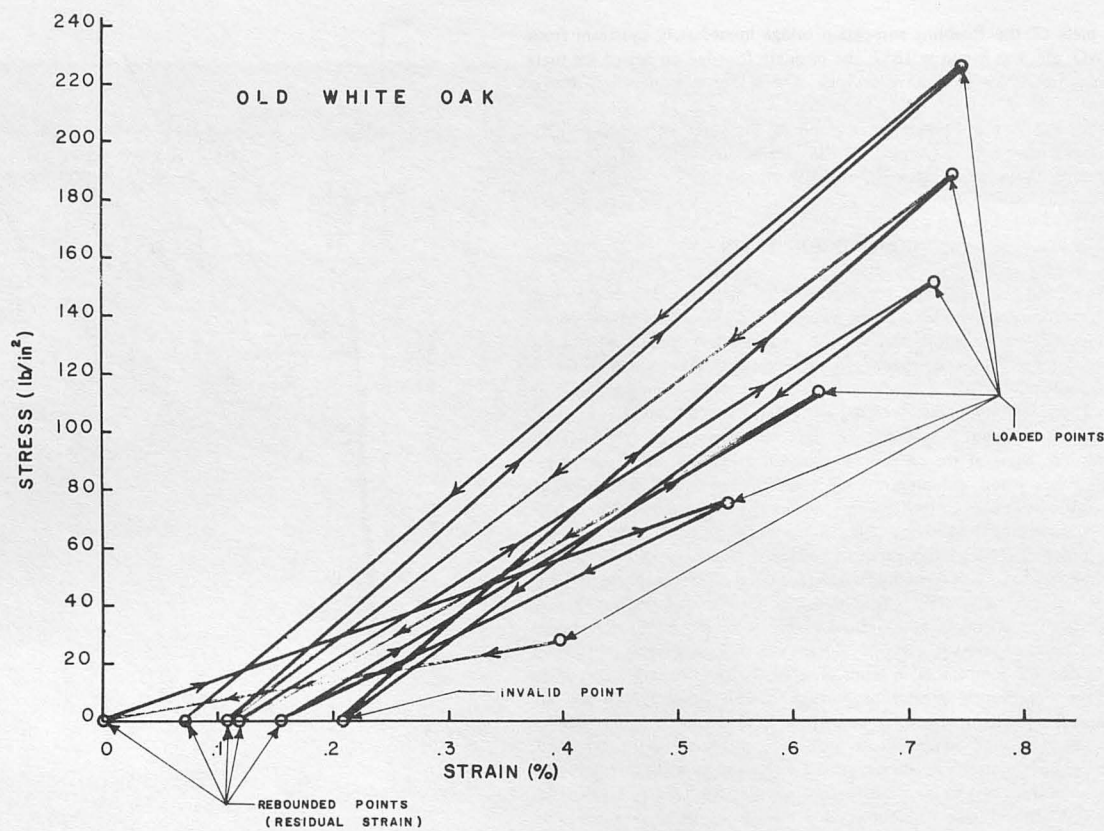


Figure 7.

Strain-Hysteresis Tests: Old and New Wood. Arrows show cycling of loads; points show total strains with respect to original height of specimen. Residual strain points show the unrecovered strains from each load-rebound cycle.

LOAD (lbs)	MODULUS (psi)	TIME (min)
Old White Oak (From Cores)		
50	2,398	60
100	2,856	164
150	3,834	110
200	4,668	75
250	5,596	360
300	6,348	70
New White Oak		
58	7,145	62
100	7,903	60
150	9,371	60
200	10,501	61
250	11,572	68
300	13,096	65

Finally, after a period of rest, the specimen was loaded at a constant rate of strain (1/1000 inch per minute) while monitoring the load. The resulting stress-strain graph is shown in Figure 9. The effects of the previous strain history of the specimen are evident in the lower portion of the curve; some collapse of internal fibers undoubtedly occurred during previous loadings; thereafter, near-linearity is resumed. Also shown there is the stress-strain curve obtained from successive, quick applications of 50 pound increments of load (from Figure 7).

Comparative compression graphs obtained from similar tests on a specimen of new white oak are provided for each of the test situations. Significant differences between the old and new wood are:

1. The old wood was kept wet except for slight drying while shaping the specimens; the new wood specimens were shaped and then soaked for five days.
2. The specimen of old wood contained 19 rings and 13 rays per inch; the new wood specimen contained 9 rings and 9 rays per inch.

ANATOMY OF WOOD

The inner structure of white oak wood is similar to that of red oak, but white oak has perceptibly more abundant tyloses filling large spring-growth tracheid. Figure 10 is a cross-sectional view of new wood (magnified 13.5 times). The parts are labeled. It is reportedly possible to blow air through the pores of a short length of red oak whereas the pores in white oak are plugged with tyloses. Tyloses are an intrusive growth of parenchyma cells into tracheid cells after sap flow subsides. Tracheids comprise the principal vertical (axial) piping system; they feed smaller, horizontal (radial) tracheids. These occur principally in the rays. The rays are discontinuous in the vertical direction and are an inch or more in height in white oak (4).

The porous springtime growth and the rays weaken the wood structurally. Strength is somewhat proportional to the amount of dense-wood (late growth) between the porous rings. Generally, the wider the rings the stronger the wood (hardwoods only). In the dense-wood areas, the cells are smaller and have much thicker walls and are richer in intercellular resins (glues).

Figure 11 is a companion to Figure 10 and shows a side view of the same specimen. Figures 12 and 13 illustrate dark wood core specimens. Figure 14 is a bright wood from Pier No. 2 and is comparative to Figure 13. Figure 15 illustrates the pine in cross-section.

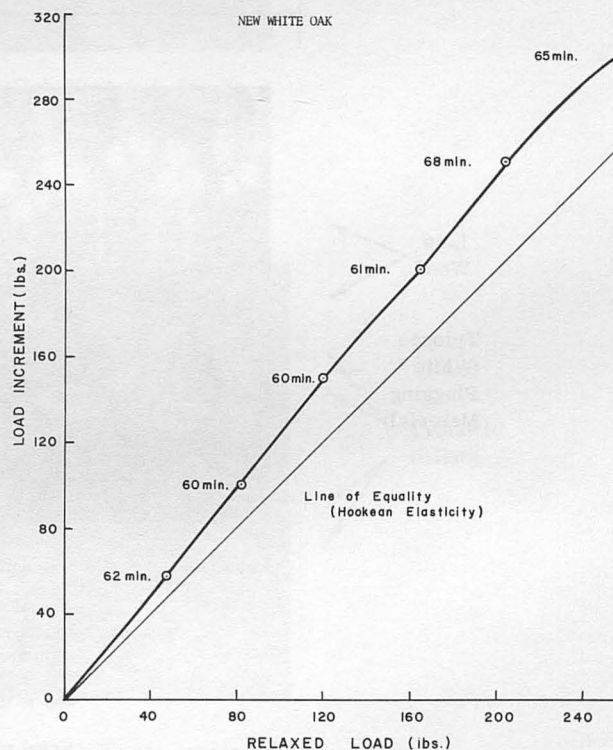
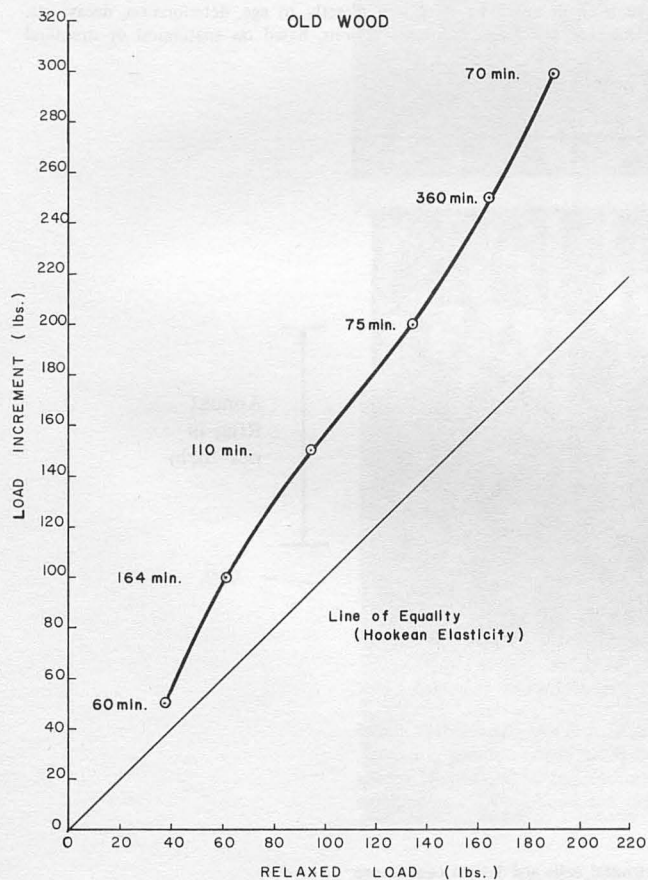


Figure 8. Relaxation or Subsidence of Load Due to Creep.

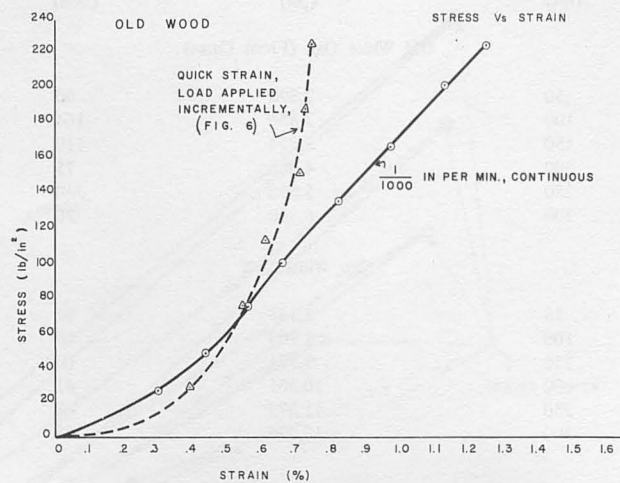
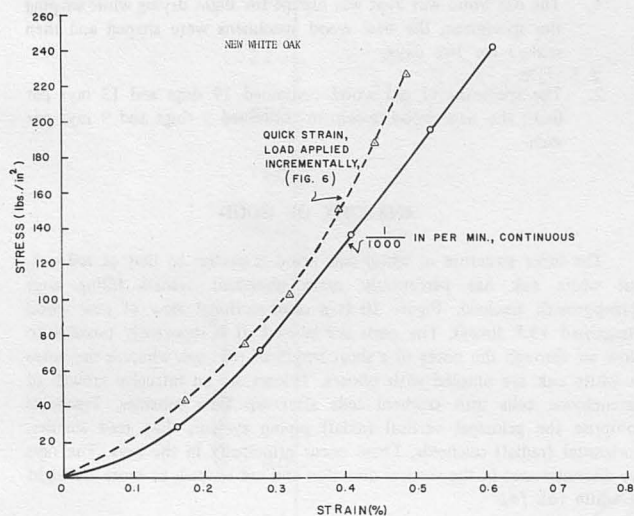


Figure 9. Stress-Strain Curves Obtained in Triaxial Test Apparatus (20 psi Lateral Pressure) Following Creep-Relaxation Tests.

DISCUSSION

The wood specimens tested were necessarily selected from portions within the cores which were recovered intact - that is, showing the least internal damage (fraying, etc.) from the cutting bit. It should be recognized that there was not complete recovery; the possibility remains that the recovered portion of the cores, and thereby the specimens tested, represent only the best wood. This situation seems unrecognizable unless, through insight or conjecture, the imperfect recovery is attributed altogether to the coring equipment.

The only specimen of pine available in cores as received (specimens submitted to Forest Products Laboratory were selected from cores beforehand) contained a large knot and was not suitable for physical tests.

No specimens of yellow poplar were available. The tests were, therefore, limited to the white oak wood.

The simple compression tests and the relaxation moduli indicated an apparent loss of strength in comparison to new wood. If it were assumed that the old wood was originally as strong as the new wood, the differences in strength might be attributed directly to age, deterioration, decay, etc. However, there are significant reasons, based on anatomical or structural

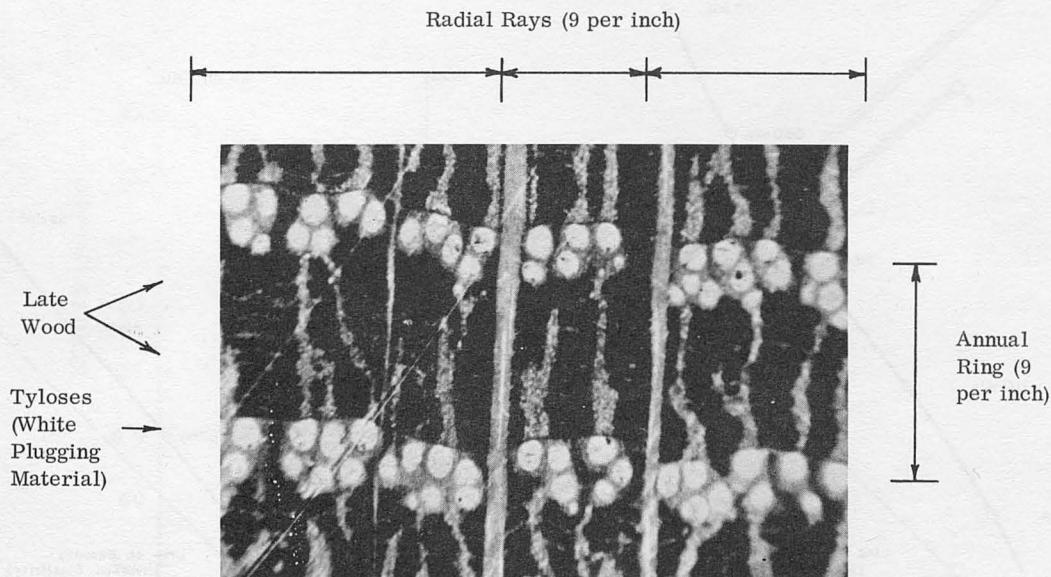


Figure 10. Cross-Sectional View of New White Oak Magnified 13.5X.

1. Annual rings are large vertical pores (tracheid) produced by early spring growth; as growing season progresses, additional pores form but become successively smaller and farther apart. The late wood growth is more dense and is stronger.
2. Radial rays are horizontal cells and lateral conductors of sap; they act as a lateral (radial) piping system. Rays are discontinuous in the vertical direction; each bundle is about one inch in height.

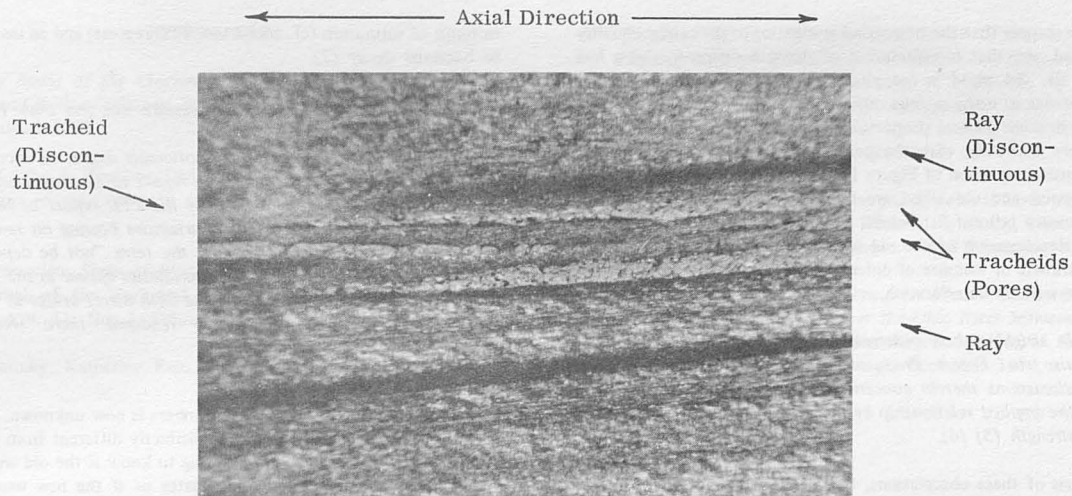


Figure 11. Side View of New White Oak, Magnified 13.5X.



Figure 12. Cross Sectional View of Dark Wood from Pier No. 2, Magnified 17.5X. Note greater abundance of large pores; specimen contains 17.5 rings per inch and 10 rays per inch.

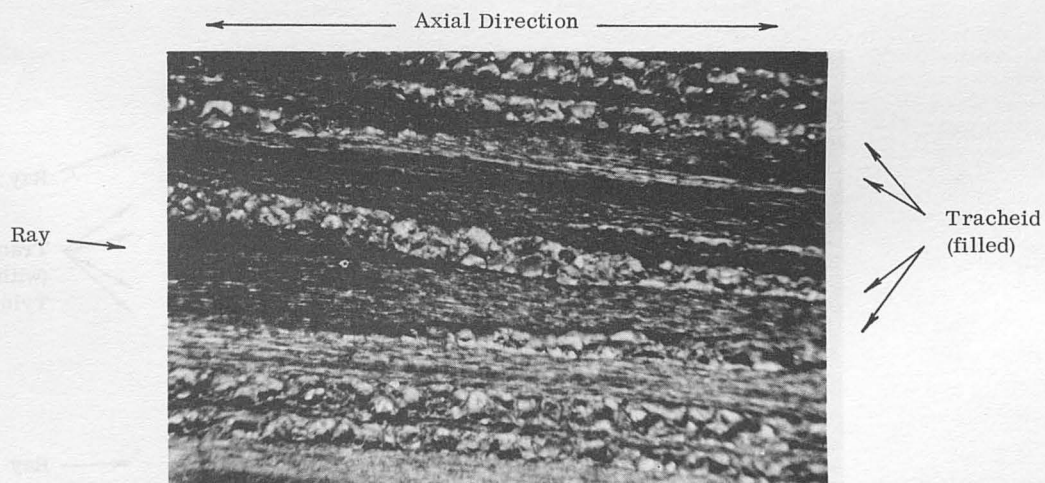


Figure 13. Side View of Dark Wood from Pier No. 2, Magnified 17.5X. Greater abundance of large pores are evident here also.

comparisons, to suspect that the new wood is superior to the original quality of the old wood and that interpretation of strength differences as a loss in strength of the old wood is not altogether justifiable. The old wood contains about twice as many porous rings per lineal inch as the new wood. Strength varies in some inverse proportion to the number of rings per inch -- probably more discretely with the percentage of the area occupied by large pores. Visual comparison of Figure 10 with Figure 12 suffices to show that the new wood and old wood are not identical in these dimensional attributes. A cursory ratio of 2:1 would, indeed, minimize the strength loss attributable to deterioration of the old wood -- that is, if wet-strength loss is used as an estimate or measure of deterioration. Air-dry strengths further minimize the extent of deterioration.

NOTE 1: In weighing these observations, attention should be directed also to Forest Products Laboratory's report and the discussions therein concerning losses in acetyl content and the implied relationship between these chemical changes and strength (5) (6).

On the basis of these observations, the loss in wet strength with time might be in the order of 25 percent -- part of which may be accountable

in terms of saturation (cf. acetyl loss, FPL reports) and an undefined portion to bacterial decay (7).

NOTE 2: The design bearing pressure was less than 100 psi (cf. 1).

NOTE 3: There seems to be a noticeable degree of uncertainty implied in the FPL reports in regard to strength loss. "Inadvisable" was the word used in the FPL report of September 1970 to summarize all uncertainties bearing on re-use of the pier. In the earlier report, the term "not be depended on" was used. These same uncertainties appear in the FPL evaluation of pine piles under the 14th Street bridge in Washington, D. C. The judgements rendered there were doubtlessly precedential.

The source of the white oak timbers is now unknown. Obviously, the new wood grew in an environment distinctly different from that where the old wood grew. It would be interesting to know if the old wood came from virgin forests in more northern climates or if the new wood specimen is merely typical of second-growth timbers.

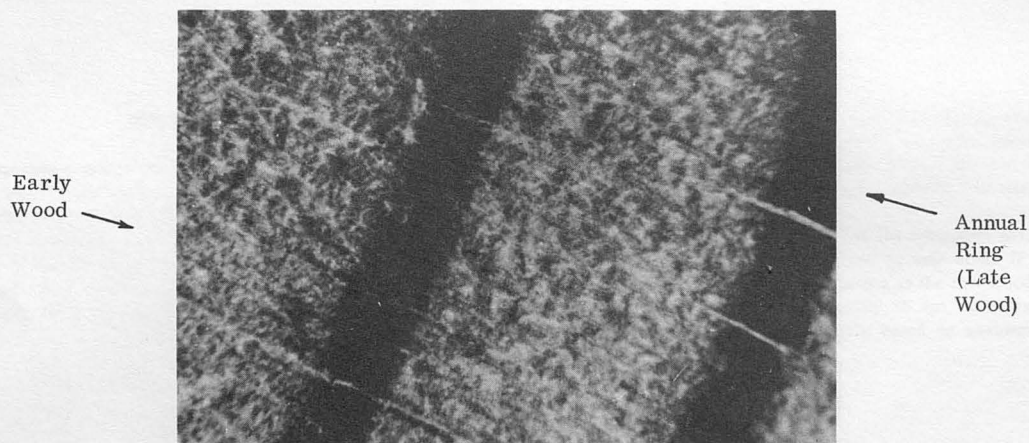


Figure 14. Side View of Bright Wood from Pier No. 2, Magnified 17.5X.

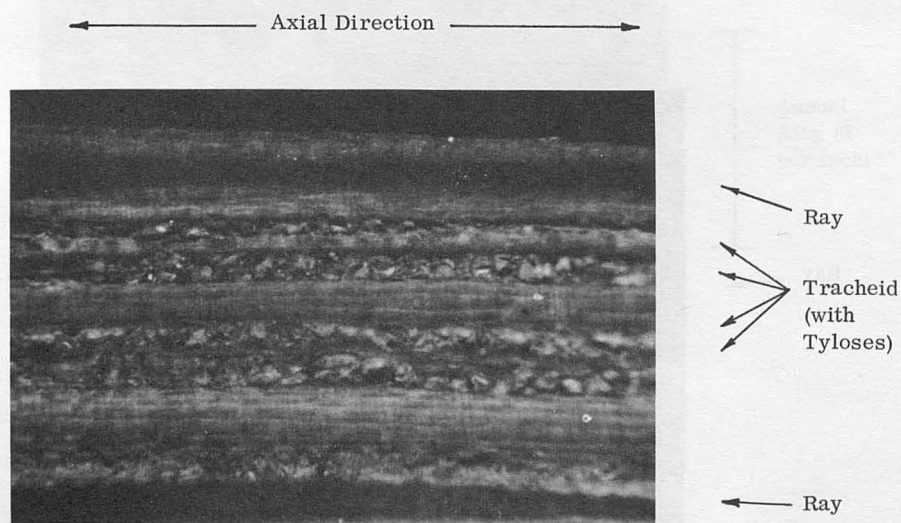


Figure 15. Cross-Sectional View of Pine from Pier No. 2, Magnified 17.5X. In contrast to hardwoods, strength of conifer woods increases as the number of rings per inch increases.

REFERENCES

1. *The River Spans of the Cincinnati and Covington Elevated Railway, Transfer and Bridge Company*, Wm. H. Burr; *Transactions, ASCE*, Vol. XXIII, August 1890.
2. Report of John A. Rockling, Civil Engineer, to the President and Board of Directors of the Covington and Cincinnati Bridge Company; April 1, 1867.
3. *The Superswollen State of Wood*, Harold Tarkow and Wm. C. Feist; *The Journal of the Technical Association of the Pulp and Paper Industry*; Vol. 51, No. 2, February 1968.
4. *Plant Anatomy*, Katherine Esau; John Wiley and Sons, 1965.
5. *Condition of the Pier-Supporting Wood Grillage of the U. S. 25 Highway-Railroad Bridge over the Ohio River between Covington and Cincinnati*, Report to Department of Highways, by Joe W. Clark, Pathologist, Forest Products Laboratory, Forest Service, U. S. Department of Agriculture, at the University of Wisconsin, Madison; May 1970, and supplement, September 19, 1970.
6. *Condition of Pine Piling Submerged 62 years in River Water (14th Street Bridge Over Potomac River, Washington, D. C.)*, Theo. C. Scheffer, C. G. Duncan, and Thos. Wilkinson; *Wood Preserving*, January 1969.
7. *Evaluation of Cored Specimens from Timber Caisson beneath Pier No. 2 of the U. S. 25 Bridge over the Ohio River between Covington and Cincinnati, F 141 (1)*, Research Report 301; Jas. H. Havens and Assaf Rahal; Department of Highways, December 1970.