STRUCTURAL VALUES OF OLD LUMBER

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STRUCTURAL VALUES OF OLD LUMBER

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Summary

Normal aging effects in old structural lumber include weathering (in exterior exposure), hydrolysis, seasoning, and plastic yield from long-continued load. The most important single deteriorating influence is decay. Others may include high temperature (including fire) and chemical attack.

In appraising the structural value of old lumber, the three principal considerations are species, grade, and condition. Species can usually be identified in the field, but, in some instances, laboratory examination is required. The principal features affecting the strength grade are knots, cross grain, and checks or splits. In the absence of comparable existing standard grades, strength ratios can be used with basic-stress values to give safe working stresses. Condition factors include moisture content, decay, and occasionally other deteriorating influences.

Strength tests have been made on wood from centuries-old Japanese temples, Douglas-fir railway bridge stringers, and floor beams from a 100-year-old church. They show that when decay or other abnormal influence is not present, the wood does not deteriorate in strength or stiffness from age alone for periods of 100 years or more. A considerable loss of shock resistance may occur after several centuries.

Reuse of old lumber often results in a cost saving as well as conservation of the supply of structural wood. The old lumber should be carefully inspected for species, grade, and condition. Examination for decay is always advisable. Salvage of old lumber is not difficult, and with proper precautions, is often advantageous.

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

Introduction

Wood is one of the oldest and most widely used of all structural materials. New and old wood structures are in evidence everywhere. It is thus not surprising that questions frequently arise about strength values in old wood or adequacy of old timber structures. This report summarizes the experience and knowledge at the Forest Products Laboratory that bears on those questions.

Information for this report is drawn from a number of sources. Basic studies of various kinds show directly or indirectly how age and long-time loading affect wood in general. The Laboratory has frequently been called upon to examine and appraise old wood structures and has thereby accumulated a fund of first-hand information and experience. The field observations have been supplemented in some instances by strength tests of old timbers after a long period of service. Observations of reuse of structural lumber have been made. Studies of wood failures in service have sometimes contributed knowledge of strength-affecting factors that operate over long periods of time.

Effects of Age

The effects of age on wood include those that normally occur under proper use and those that are preventable or are associated with improper use.

Weathering

When wood is exposed outdoors, the alternate wetting and drying sets up surface swelling or shrinkage stresses that loosen and eventually separate the surface fibers. Mechanical erosion by rain accelerates the process. Although this weathering is generally very slow, cedar shingles on a barn in southern Wisconsin have weathered in 60 years to about half their original thickness. Weathering affects only the surface, and its progress is readily estimated from visual inspection.

Hydrolysis

Hydrolysis is a chemical change of the celluloses in wood that takes place very slowly at ordinary temperatures and normal moisture content. Its structural effects are a reduction of shock resistance, followed after a long time by reductions of the other strength properties. In the normal life of a wood building, say 100 years, the structural effects of hydrolysis are negligible. Tests indicate that the effects may become significant in periods of 300 to 1,300 years. With above-normal temperature and moisture content, hydrolysis may be more rapid.

Seasoning

Seasoning is not strictly an aging effect, since most of it takes place during the first year or so of the life of a structure. In heavy timbers, however, seasoning continues for a long time. Structural lumber in covered buildings eventually reaches a moisture content in the range of 8 to 12 percent.

The immediate effect of drying is a strengthening and stiffening of the wood substance. In lumber of structural size and character, however, the gain may be largely offset by the development of checks or splits that reduce the resistance to longitudinal shear. As longitudinal shear stresses are set up when a beam or a joist is loaded, the net gain in strength from drying is negligible. Posts or short columns are not stressed in longitudinal shear, splits and checks do not affect their strength, and the gain in strength from drying is thus substantial. Thin structural lumber, such as is used in laminating, can be dried with little or no checking, and its net gain in strength with seasoning is considerable.

Plastic Yield

Wood under load or stress takes on an immediate elastic deformation that is recoverable with the removal of load. With long-continued load the immediate deformation is increased by a plastic yield that is largely nonrecoverable. In studies of plastic yield at the Forest Products Laboratory,[2] it has been found that the yield takes place very slowly and continues for many years. Its total magnitude does not exceed that of the immediate deformation unless serious overstress occurs. Yield of this kind is most commonly seen as the "set" or sag in old beams. Sag of wood trusses in long-time service is only partly caused by plastic yield; it is chiefly the result of inelastic slip at joints or fastenings. Yield takes place more rapidly under variable than under uniform temperature and moisture conditions.

Plastic yield is the normal reaction of wood to stress and does not necessarily indicate deficiency of a structural member. After a few years, its increase normally becomes so slow as to be undetectable by ordinary measurements. Only under conditions of serious overstress does it continue at a constant or an increasing rate.

Although plastic yield under normal working stresses will alter the shape of a wood member, it does not affect its strength or stiffness.

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[2] Wood, L. W. Relation of Strength of Wood to Duration of Load. Forest Products Laboratory Report No. R1916, 1951.

This is shown conclusively by laboratory tests on specimens that have been under continuous load for several years. Old wood beams showing a moderate amount of "set" need not be discarded as having lost their strength.

Decay

Decay is the most important of the preventable influences that affect the value of old structural lumber. It is not in itself an effect of age, since wood can become badly decayed in a year or less. At the same time, decay figures in the majority of appraisals of old wood structures, and the possibility of its presence should always be kept in mind.

The effect of decay on the structural properties of wood is severe, and is the more dangerous because it is hard to estimate from visual inspection. Even the incipient stages, before the wood is noticeably softened, have an effect on strength and a greater effect on shock resistance. For this reason, decay is excluded or is closely limited in the strength grades of new lumber. Old lumber with decay should not be used where strength requirements are high.

Since decay develops only where the moisture content exceeds 20 percent, it is most likely to be found in places like the bases of columns (fig. 1) or in any undrained or unventilated pockets that may remain more or less continuously damp or wet. Incipient stages of decay are marked by discolorations, often of reddish or brownish hues. In more advanced stages, the wood becomes crumbly or pocketed, cross-cracking may occur, or pronounced brown or white spots or zones may appear.

A more detailed discussion and a complete bibliography on decay are found in another Forest Products Laboratory publication.[3]

Other Deterioration

Prolonged exposure to temperatures above 150° F. can damage structural wood. The visible effect is a darkening of the color, in some instances almost to black. Shock resistance is reduced first and most seriously, but other mechanical properties are also affected.

Where there has been fire in a structure, the heat exposure is shorter but more intense. The damaging effect of overheating may extend beyond the material obviously destroyed. Darkened zones adjoining charred areas are almost certainly affected.

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[3] U. S. Forest Products Laboratory. Wood Handbook. U. S. Dept. Agr. Agriculture Handbook No. 72 (In press).

Deterioration from chemical exposures is relatively uncommon, since many chemical solutions do not affect wood. Evidence of this is most likely to be seen in a discoloration of the wood. Some studies of the problem have been made.[4]

Evaluation of Old Lumber

In appraising the structural value of old lumber, the three principal things to consider are species, grade, and condition.

Species

Different species of wood have different strength values. Dense southern yellow pine, for example, may be twice as strong as white pine. If a strength value is to be assigned, the species must be identified. This can often be done from visual examination in the structure, while in other instances it may require a microscopic examination by a trained specialist. Laboratory examination can be made on a specimen as small as a pencil, but the specimen should always contain at least one annual ring.

Grade

Grade also affects the strength. Within a species, a high grade may have twice the strength of a low grade. The most direct way of determining the grade of old lumber is by comparing it to the published descriptions of existing standard grades of the same species. Where the comparable existing grade is a stress grade (one to which a working stress is assigned) the working stress for the existing grade is suitable for the old lumber, except as it may have to be adjusted for condition factors.

In some instances, there is no comparable existing stress grade. When this is true, the principles of stress grading can be used in a more general way to assign a strength ratio to an individual timber or a group of timbers. The strength ratio is a numerical representation of the effect on strength from whatever knots and similar natural characteristics are present. For instance, if a knot in a piece reduces its strength 25 percent below the strength of the clear wood, the strength ratio is 75 percent. Principles of strength grading and determination of strength ratios are fully discussed in the Wood Handbook.[3] The principal features affecting the strength grading of old lumber are knots, cross grain, and checks or splits.

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[4] Baechler, R. H. Wood in Chemical Engineering Construction. Forest Products Research Society Proceedings, 1954.

The effect of a knot upon strength is generally in direct proportion to the portion of the cross section occupied by the knot or to the portion of the width of the surface in which the knot appears. Knots near the bottom edges of beams or joists are about twice as serious as those located elsewhere. Compressive strength is reduced only about half as much as are tensile or bending strength. To illustrate, a 2-inch knot in a 4- by 8-inch timber gives a strength ratio of 50 percent, if located in a narrow face or at the bottom edge of a wide face, and 75 percent if located elsewhere in a wide face. These values apply to the central one-third of the length, where fiber stresses are greatest. Knots near the ends of beams have little effect on the strength.

Knots have no significant effect on bearing strength (compression perpendicular to grain), longitudinal shear, or stiffness. Where there are two or more knots in the same cross section, the effect on strength can usually be estimated from the largest single knot. Two knots of equal size in the same section are generally more damaging than one. Since the principal effects from knots are in the distorted grain around the knot, loose knots or knotholes have about the same effect on strength as intergrown knots of the same size.

Cross grain is of two kinds, spiral or diagonal. Spiral grain is a growth characteristic in which the wood fibers are inclined spirally around the tree instead of straight up and down (fig. 2). It is easily detected by the inclination of season checks with respect to the direction of length of the piece. Diagonal grain results from sawing a crooked tree or sawing not parallel to the bark, and can be detected by the trace of the annual rings on a radial surface. Either spiral or diagonal grain with a slope of 1 in 15 reduces bending or tensile strength by about one-fifth and a slope of 1 in 6 reduces the strength by about one-half. Compressive strength is reduced less.

Splits or deep checks reduce the resistance of beams to longitudinal shear. Only those appearing in the sides of beams need be considered. The reduction of strength is in the same proportion as the depth of the check or split to the thickness of the piece. Where a beam is of such proportions that longitudinal shear stress is low, there is little or no effect. Splits or checks have no effect on the compressive strength of posts or short columns (fig. 3). Shakes, where present, have effects comparable to those from splits or checks.

Where a strength ratio is determined without reference to a specific grade, it can be used with the basic stress to give a suitable working stress. Basic stress is essentially a working stress for clear wood (table 1). If a species of wood has a basic stress in bending of 2,200 pounds per square inch, and a piece or group of pieces in that species has a strength ratio of 50 percent, the safe working stress is 1,100 pounds per square inch.

Condition

It is hard to make more than the most general observations about condition as a factor in appraising old lumber. Broadly, if its condition is good it can be used with the working stress appropriate to new lumber of its species and grade; if its condition is not good, it should not be used for strength purposes at all. There are, however, some factors that may be kept in mind.

Moisture content is usually not an important condition factor. Much old lumber is at a more or less uniformly low moisture content. Further, many structural wood members have about the same strength value whether green or dry. Indirectly, a high moisture content is an unfavorable factor in that it indicates hazards of decay or other deterioration.

Wood with decay should not be used as a primary structural member or where strength requirements are high. At the same time, if only moderate strength is required and if decay is clearly localized, the piece of lumber has some value. A rough approximation is to discount the zone showing decay and to base the load capacity estimate on the remaining unaffected wood.

Deterioration from heat or chemical attack is hard to appraise. Inquiry into the service history of the structure may uncover some helpful information. If there is evidence of any considerable effect from this cause, it will be safer not to use the lumber.

Fastenings

The appraisal of old lumber in a structure may properly include examination of the condition of load-carrying joints or fastenings of the wood members. Bolted or connectored joints should be tight. Nailed joints should be checked for the number and size of nails and their present condition.

Tests of Old Lumber

The Forest Products Laboratory is frequently called upon to make examination or tests of structural lumber after a long period of service. Tests have also been made by other agencies. Some of the more important of these are briefly summarized here.

Tests on a few timbers from temples 3 to 13 centuries old were made at Saikyo University, Kyoto, Japan.[5] Timbers 3 to 5 centuries old showed

[5]Kohara, Jiro. Studies on the Durability of Wood: Mechanical Properties of Old Timbers. The Scientific Reports of the Saikyo University. Agriculture No. 2, 1952, and No. 4, 1953.

reductions in all strength properties, while a timber 13 centuries old indicated increases in all but shock resistance, in comparison to new timbers. The apparent contradiction in these results is probably explainable by the small number of tests and the imperfect matching between old and new timbers. In general, it appears that impact bending strength, a measure of shock resistance, was seriously reduced, but effects on the other properties were small.

Ten 8- by 18-inch Douglas-fir stringers were tested at the Forest Products Laboratory[6] after 23 years of service in a Chicago, Milwaukee, St. Paul and Pacific Railway bridge in South Dakota. Fiber-stress values at maximum load ranged from 2,560 to 7,600 pounds per square inch, being limited in most instances by failures in longitudinal shear. Small clear specimens of wood from the stringers showed fiber-stress values from 8,210 to 12,940 pounds per square inch. The tests indicated no deterioration in quality of the wood substance from age or loading, but showed that resistance to longitudinal shear was decreased by checks and shakes and, in some instances, by the effect of stress concentration around bolt holes. The proportions of the stringers and the method of test loading were such that longitudinal shear stresses were rather high.

Southern pine structural timbers placed in the White House in 1816 were examined in 1949 and 1950.[7] While no strength tests were made, careful visual examination showed no evidence of deterioration. Some of the timbers had been deeply cut in connection with remodeling operations and had therefore become inadequate for the loads currently imposed.

More recently, tests were made on two hand-hewn white pine floor beams removed in connection with the remodeling of St. Raphael's Cathedral, Madison, Wis. (fig. 4). The beams had been in service for 100 years and had survived a severe fire. They were of high grade and were in good condition except for a small area of char from the fire and a small area of surface decay where one beam was in contact with a masonry pier. Moisture content was 11 percent. Fiber-stress values at maximum load on the beams were 6,530 and 5,160 pounds per square inch, the latter being limited by a failure in longitudinal shear along a deep seasoning check. Small clear specimens of wood from the beams showed fiber-stress values of 10,850 and 8,590, compared to a species average for new wood of 8,600 pounds per square inch. Values in the toughness test, a measure of shock resistance, were also slightly higher than the species average for new wood. Other values in compression and shear tests were likewise good. It was notable that, when the beams were cut open, the

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[6]Newlin, J. A., and Heck, G. E. Tests Show Strength of Douglas-Fir Stringers after 23 Years Service. Railway Engineering and Maintenance, 30(8):427-428, Aug. 1934.

[7]Reynolds, W. E. White House Renovation Project Preserves Original Features of Historic Structure. Civil Engineering, 19(11):32-34, Nov. 1949.

wood had the appearance and characteristic odor of fresh white pine. White pine timbers of the same age in trusses supporting the roof of the Cathedral were examined and found to be in good condition and are being continued in service in the remodeled structure.

Reuse of Structural Lumber

Reuse of old lumber assumes increasing importance with todays high prices and the shortages of some grades and sizes in new lumber. The Stanford Research Institute[8] reported that the 1952 reuse of lumber was about 160 million board feet and predicted that the figure will rise to 700 million board feet in 1975.

Reuse of old lumber often results in a cost saving as well as conservation of an important structural material. Old lumber has the advantage that it is usually thoroughly seasoned and can be refabricated with assurance that it will maintain its size and shape. Many old timbers are in large sizes or of high grades that are now scarce and expensive.

The salvage of old lumber is not difficult. Nails can usually be pulled out without serious damage. At Fort Lewis, Wash., it was reported that a dynamite charge inside a barracks building loosened nailed joints more easily and with less damage than the usual wrecking-bar methods. Construction employing bolts or connectors can be disassembled and re-erected with little difficulty. Repairs or reinforcements, when needed, can be made a part of the operation.

In combining new material with old, best results are obtained when both are at about the same moisture content.

Reuse of material that has been damaged by accident or overload may present special problems. Pieces that have been heavily loaded should be carefully examined for incipient failures. A good additional precaution is to reuse beams or girders with the same side up as before, to avoid reversal of stress. Fire-charred timbers may be weakened by the effects of high temperature beyond the area of charring, and generally should not be reused where strength requirements are high. Structural material from storm wreckage should be carefully examined and repaired or replaced as necessary.

Much old lumber has been reused in structures. Figure 6 shows roof trusses and structural columns from an Army ordnance plant in Illinois

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[8] Wood and Wood Products. Vol. 59, No. 10, pp. 20-22, 60. Oct. 1954.

re-erected at the University of Wisconsin. Hangar roof trusses damaged in a windstorm at a Wisconsin airport were re-erected at another airport some 100 miles away. In this instance, broken pieces were repaired or replaced, and the trusses were strengthened by adding ring connectors to bolted joints.

In any instance of structural reuse, the old lumber should be carefully inspected for species, grade, and condition. Examination for decay is always advisable. Requirements of the new use must be considered. With proper precautions, a considerable amount of used material may thus become available.

Table 1 --Basic stresses for clear lumber under long-time service at full design load[1] -- for use in determining working stresses according to grade of lumber and other applicable factors

Species[2]	Extreme fiber in bending or tension parallel to grain	Maximum horizontal shear	Compression perpendicular to grain	Compression parallel to grain L/d = 11 or less	Modulus of elasticity in bending
1	2	3	4	5	6
	P.s.i.	P.s.i.	P.s.i.	P.s.i.	1,000 P.s.i.
SOFTWOODS					
Baldcypress (cypress)	1,900	150	220	1,450	1,200
Cedar					
Alaska-	1,600	130	185	1,050	1,200
Atlantic white- (southern white cedar) and northern white-	1,100	100	130	750	800
Port-Oxford-	1,600	130	185	1,200	1,500
Western redcedar	1,300	120	145	950	1,000
Douglas-fir					
Coast type	2,200	130	235	1,450	1,600
Coast type, close-grained	2,350	130	250	1,550	1,600
Rocky Mountain type	1,600	120	205	1,050	1,200
All types, dense	2,550	130	275	1,700	1,600
Fir					
Balsam	1,300	100	110	950	1,000
California red, grand, noble, and white	1,600	100	220	950	1,100
Hemlock					
Eastern	1,600	100	220	950	1,100
Western (west coast hemlock)	1,900	110	220	1,200	1,400
Larch, western	2,200	130	235	1,450	1,500
Pine					
Eastern white (Northern white), ponderosa, sugar, and western white (Idaho white)	1,300	120	185	1,000	1,000
Jack	1,600	120	160	1,050	1,100
Lodgepole	1,300	90	160	950	1,000
Red (Norway pine)	1,600	120	160	1,050	1,200
Southern yellow	2,200	160	235	1,450	1,600
Dense	2,550	160	275	1,700	1,600

(See footnotes at end of table.)

Table 1.--Basic stresses for clear lumber under long-time service at full design load[1] -- for use in determining working stresses according to grade of lumber and other applicable factors--Continued

Species[2]	Extreme fiber in bending or tension parallel to grain	Maximum horizontal shear	Compression perpendicular to grain	Compression parallel to grain L/d = 11 or less	Modulus of elasticity in bending
1	2	3	4	5	6
	P.s.i.	P.s.i.	P.s.i.	P.s.i.	1,000 P.s.i.
Redwood	1,750	100	185	1,350	1,200
Close-grained	1,900	100	195	1,450	1,200
Spruce					
Engelmann	1,100	100	130	800	800
Red, white, and Sitka	1,600	120	185	1,050	1,200
Tamarack	1,750	140	220	1,350	1,300
HARDWOODS					
Ash					
Black	1,450	130	220	850	1,100
Commercial white	2,050	185	365	1,450	1,500
Aspen, bigtooth and quaking	1,300	100	110	800	800
Beech, American	2,200	185	365	1,600	1,600
Birch, sweet and yellow	2,200	185	365	1,600	1,600
Cottonwood, eastern	1,100	90	110	800	1,000
Elm					
American and slippery (soft elm)	1,600	150	185	1,050	1,200
Rock	2,200	185	365	1,600	1,300
Hickory, true and pecan	2,800	205	440	2,000	1,800
Maple, black and sugar (hard maple)	2,200	185	365	1,600	1,600
Oak, commercial red and white	2,050	185	365	1,350	1,500
Sweetgum (gum, red gum, sap gum)	1,600	150	220	1,050	1,200
Tupelo, black (black gum) and water	1,600	150	220	1,050	1,200
Yellow-poplar (poplar)	1,450	130	160	1,050	1,200

[1]These stresses are based on the strength of green lumber and are applicable, with certain adjustments, to lumber of any degree of seasoning or lumber used under any conditions of duration of load.

[2]Species names from approved check list, U. S. Forest Service. Commercial designations are shown in parentheses.

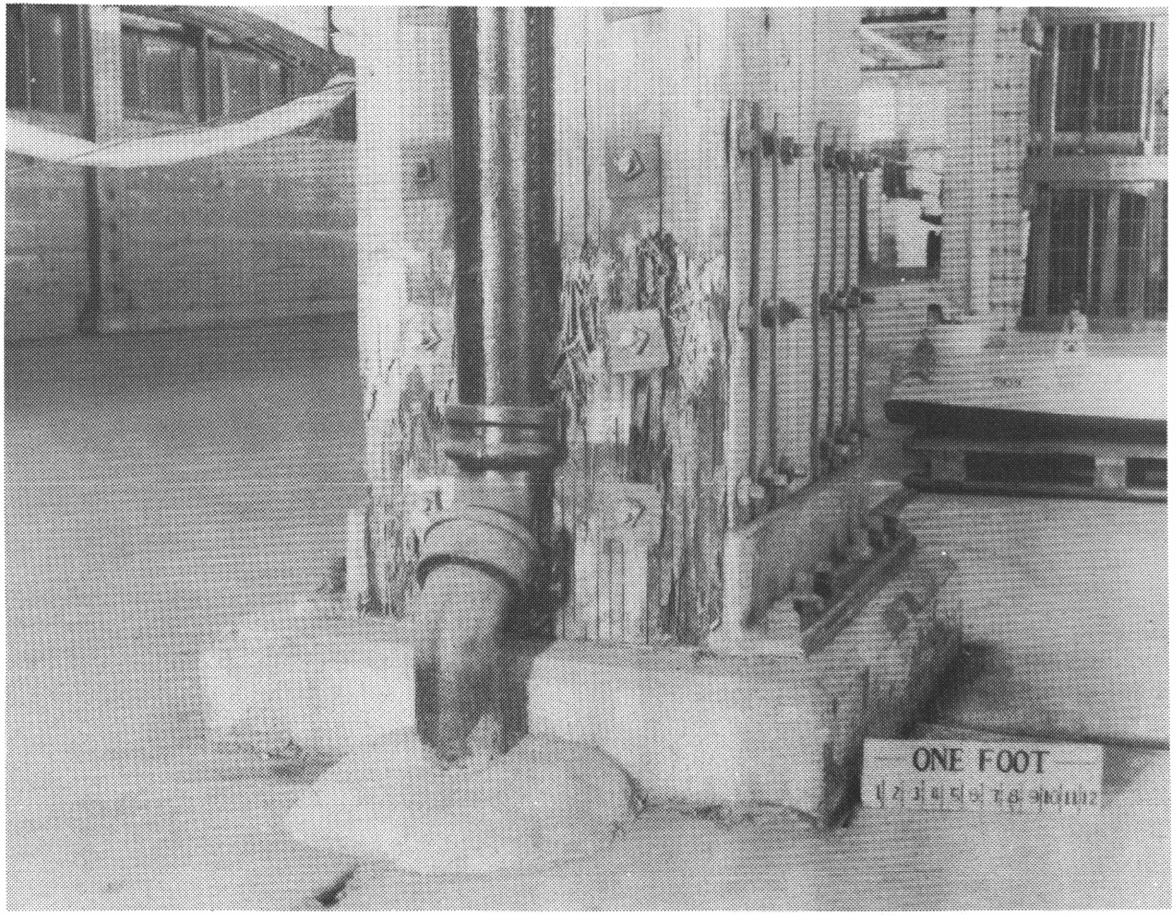

Figure 1.--Damage from decay at the base of a structural wood column. Leakage from a drainpipe kept the wood moist.

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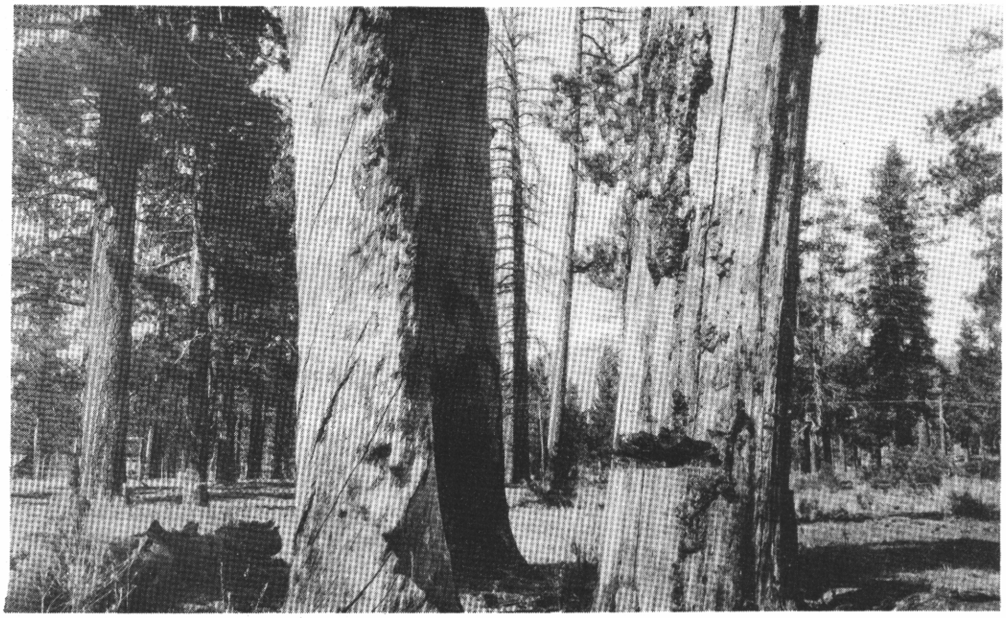

Figure 2.--Spiral-grained and straight-grained trees.

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Figure 3.--Heavy wood girders and short columns with deep seasoning checks. The checks may affect the strength of a girder but not of a short post.

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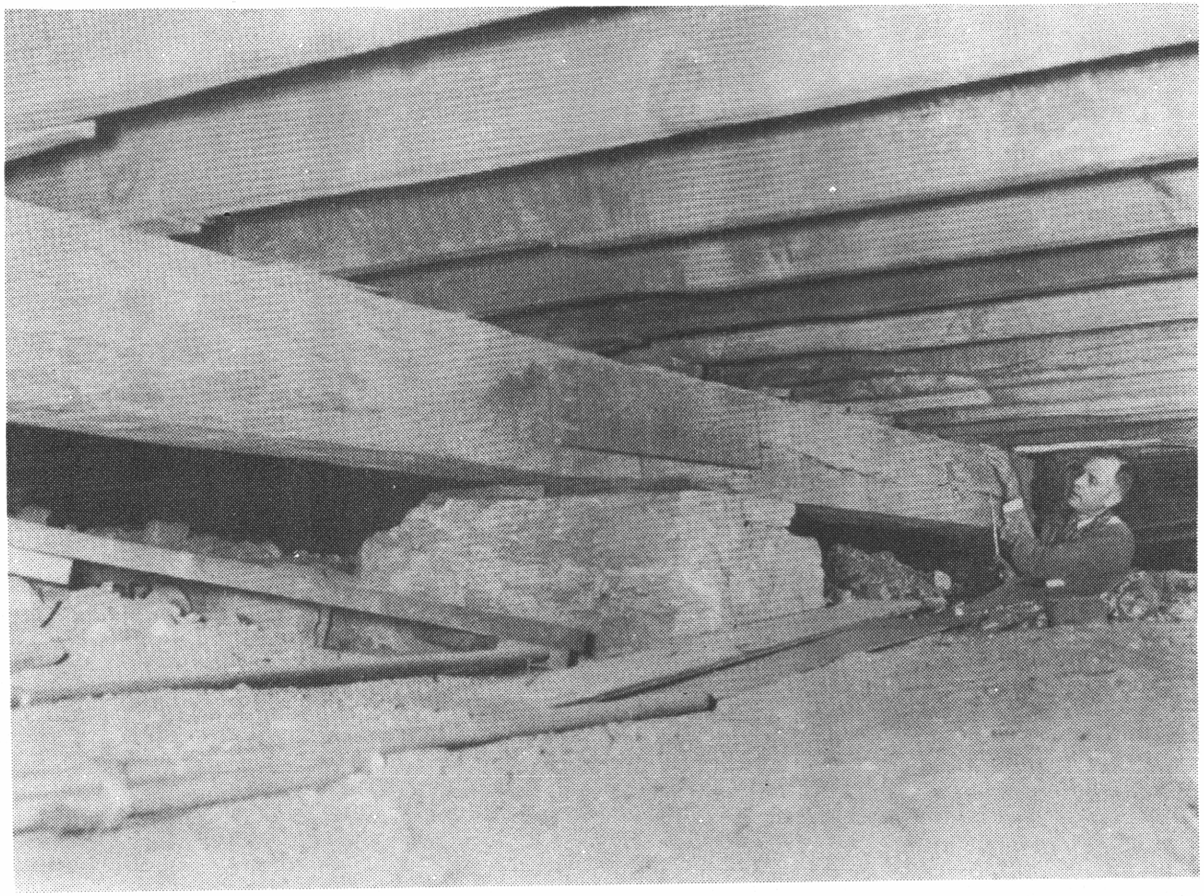

Figure 4.--Hand-hewn white pine beams supporting the floor of St. Raphael's Cathedral, Madison Wis.

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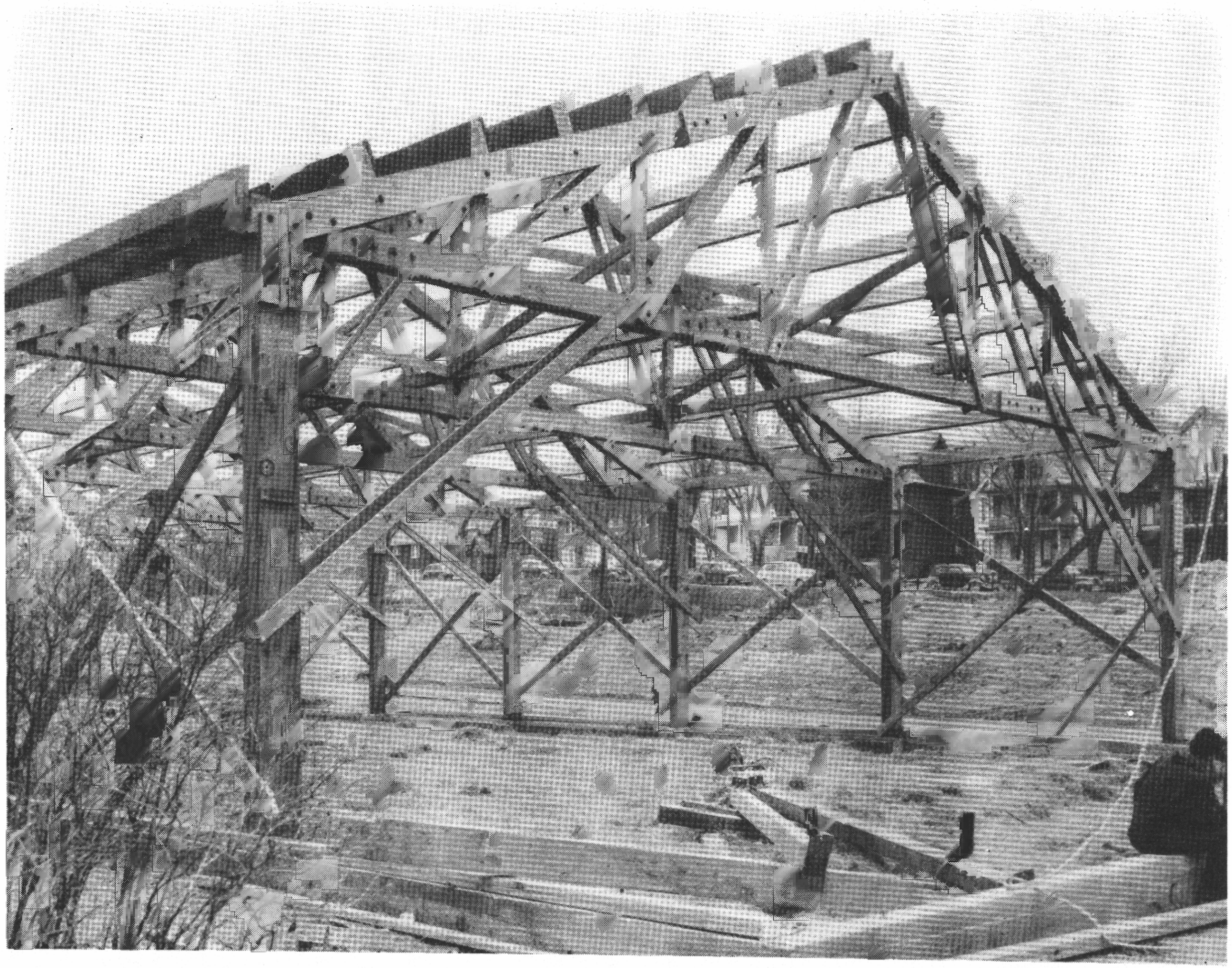

Figure 5.--Wood roof trusses and structural columns from an Army ordnance plant in Illinois re-erected at the University of Wisconsin. Span 50 feet.

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