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WOOD FOR USE IN BULK STORAGE STRUCTURES

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Summary

Efficient use of wood in storage buildings requires specialized knowledge of its directional strength properties, its response to long-time loading, its dimensional stability, insulating value, and resistance to fire and decay. Structural elements of wood or wood-base materials include sawn and round timbers, sheet materials, and a great variety of built-up or adhesive-bonded components. The high pressures on walls of storage structures and the moisture problems associated with the drying of stored materials require careful consideration in design.

Introduction

Storage structures for grain or other agricultural produce have been built of wood for many years. Wood is economical and easy to work, and it has a long and extensive service record. Today wood in many forms can be used for storage structures. Lumber, wood poles, plywood and other wood-base materials, and a variety of built-up structural elements such as sandwich-type panels and plywood-stiffened girts all show good structural properties and performance when their use is combined with good design and adequate maintenance. When a wood storage structure is well designed and well maintained, there is little chance that

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

problems will arise. Knowledge of wood's own specific storage environments and its properties can thus help the designer of farm or other storage buildings to prepare a structurally adequate design with a maximum of efficiency and economy.

Storage Environments

Storage environments apply to structures made of any material, but certain features of the environment have special significance to wood or wood-base materials. Three important elements in the environment of wood in structures are loading, moisture, and temperature. Decay and fire also may affect the use of wood in bulk storage structures. Agricultural engineers are fully aware of the importance of environmental studies, and the Farm Structures Division of ASAE has a Special Committee on Technical Data (1)[3] that deals with this problem.

The loading environment is critical in storage buildings of wood, as of other materials. Gravity loadings may be high, and most bulk materials exert lateral as well as vertical pressures. Frictional effects cause downward forces on the side walls as well as on the floors. Dried grain that has absorbed moisture will swell and exert a lateral pressure on the wall of the building. But the ability of wood to yield considerably without breaking is an advantage when it is used in walls of such storage structures that are subjected to the tremendous pressures of contents, such as in a grain bin.

Wood, unlike some other materials, is 5 to 10 times stronger when it is stressed with the grain than across the grain, with intermediate values of strength at angles to the grain (13). In specific strength and stiffness (strength or stiffness divided by specific gravity), the properties of wood in the direction of grain compare favorably with those of steel or concrete. Working stresses recommended by the lumber industry are for "normal loading," which presume a continuous or cumulative duration of design load for 10 years during the life of a permanent structure (110 percent level in fig. 1). The lumber industry recommends that stresses be reduced by 10 percent to the level for permanent or long-time load (fig. 1) if storage periods are expected to exceed this normal amount of loading. In this way, the wood will not be overstressed in the structure.

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[3] Underlined numbers in parentheses refer to Literature Cited at the end of this report.

Drying agricultural produce in storage structures releases large quantities of water vapor. Wood and wood-base materials are hygroscopic and will absorb this moisture if it is not removed by ventilation. Often air circulation from dryers present in the storage structure can help considerably to reduce this moisture. Vapor barriers can also be applied to prevent water vapor from entering and condensing in the colder zones of structural elements, or suitable insulation can be installed to raise interior surface temperatures above the dewpoint.

Slight changes in the moisture content of wood can also be retarded by protective coatings, such as varnish, lacquer, or paint. The practical object of all correct seasoning, handling, and storing of wood for structures is to minimize moisture content variations in service by fabricating or installing the wood at a moisture content corresponding to the average moisture conditions to which it will be exposed (13). Without these precautions, the greatest dimensional change possible may be 5, change probable is about 3 percent across the grain and about one-quarter of 1 percent with the grain.

An advantage of wood that affects its moisture content is wood's relatively low thermal conductivity, which helps to keep inside surface temperatures of wood walls above the dewpoint where condensation of moisture may occur in cold weather. This insulating property is also important in preventing freezing of perishables such as potatoes that are stored throughout the winter.

Decay poses few problems in a properly constructed wood storage structure. However, faulty design, poor construction, or lack of reasonable care in the handling of the wood can all favor decay development. Construction principles that assure long service and avoid decay hazards in buildings include: (1) Build with dry lumber; (2) use designs that keep the wood dry and accelerate rain run-off; and (3) for parts exposed to decay hazards, use preservative-treated wood or heartwood of a decay-resistant species. Wood that is untreated should not be in direct contact with soil or piles of wood debris. The prevention of decay in walls and roofs rests largely in designs that prevent the entrance and retention of rainwater or the accumulation of condensed moisture from the inside. (13).

None of the common surface finishes protect against decay. Both nonpressure and pressure preservative treatments are covered by standards of the American Wood-Preservers' Association. Pressure treatments give greater penetration and retention, and therefore longer life than nonpressure treatments.

The fire behavior of wood in storage structures is not critical because the major fire hazard is in the contents, or with equipment used for drying stored materials. However, dust from drying grains may be a fire or explosion hazard. Suggestions are available for fire prevention in wood construction, protection of heating elements that may be used for the drying of stored materials, and fire–retardant treatments for wood (13). The fire-resistant properties of heavy timbers are now widely recognized by building officials and fire insurance underwriters.

Lumber Structural Elements

Lumber in storage structures may be in the form of boards, light framing, or timbers. It is graded by regional associations of the lumber industry, who publish grading rule books with detailed descriptions of the various grades. They also operate grading services that issue certificates of inspection or grademark each piece if desired. Design stress values recommended by the lumber industry for the stress–rated grades are published in the grading rule books or in the National Design Specification (10) and are widely referenced in building codes. The subject of design stresses for farm buildings was discussed in a recent paper (16) and is under study by the ASAE Farm Building Construction Standards Committee. There is widespread feeling that on–the–farm storage structures may not require as much factor of safety as do structures under the major building codes; this feeling does not extend to the large commercial storage buildings for farm products. Since the higher grades of lumber are in shorter supply and more costly than the lower grades, the designer should use and specify the lowest grade that will do the job satisfactorily.

Boards are traditionally of 1–inch nominal thickness, or about 3/4–inch thick when dressed; there is now much interest in the lumber industry, however, in thicknesses of 11/16 or 5/8 inch dressed. Boards are generally not stress rated, since they are used mostly with conventional spacings of framing members, such as 12, 16, or 24 inches. High pressures in bulk storage, however, require consideration of the strength and stiffness of boards. If stress–rated boards are unavailable, design stresses for 2–inch dimension lumber of the same grade name may be used without serious error, since the failure of an occasional board generally results in only minor property damage. The design engineer should clearly understand and specify the dressed thickness of boards required for his design.

Proposed new size standards for 2–inch (nominal) dimension lumber provide for 1–1/2 inches minimum dressed thickness at 19 percent maximum moisture content. This contrasts with the older specified thickness of 1-5/8 inches without

reference to moisture content. Widths remain unchanged, being generally 1/2 inch under the nominal widths. If lumber is dressed green under the new standards, it is to be oversize by enough so that it will reach the standard size at the standard moisture content. Marketing of lumber under the new size standards has already begun on a limited scale. The designer should clearly understand and specify the dressed sizes of dimension lumber on which his design is based. Stress-rated dimension lumber is now readily available in all of the major construction species of wood.

Solid sawn timbers are always available on order, though retail yards generally stock only a few. Sizes of 12 by 12 inches or larger and lengths of 20 feet or longer are uncommon and may be hard to obtain. Stress-rated timbers and design stresses for them are available. Timbers are often used without seasoning or dressing, and design stresses for wet or green conditions may then be used with the full nominal size. Lower grades of timbers may include pieces that will warp or twist badly in drying, even though they have adequate strength for the working stresses assigned to them.

Wood-Base Materials

Sheet materials like plywood and hardboard differ from solid wood in that their structural properties in both directions are more nearly equal than those of solid wood. This affects not only strength and stiffness but also dimensional change. The problem of splitting is. largely avoided. Because of the two-way properties and the load distribution resulting from the width of the sheets, these materials are commonly used in less thickness than lumber.

Box beams, which consist of one or more vertical plywood webs laminated to flanges that are separated by stiffeners, utilize to the fullest the structural soundness and properties of plywood. These beams are lightweight, easy to build, and can be designed to curve, arch, or taper. Framing and covering members can be nailed directly to the beams (4).

Stressed-skin or sandwich-type panels (15) can be designed for excellent properties of strength and rigidity, though their costs have thus far precluded their extensive use in storage buildings. Girts stiffened with plywood webs, which are suitable against the high wall pressures on bulk storage buildings, have shown good structural properties (7) (fig. 2). A number of investigators have also worked on demountable wall panels.

Many details of structural applications for plywood have been worked out by the Douglas Fir Plywood Association (5). Technical information on fiberboards and particle boards has been published by the Food and Agriculture Organization of the United Nations (9). Commercial standards for plywood are now widely recognized, and commercial standards for fiberboard or particle board are being developed.

Wood Poles

Treated wood poles for structural frames have the advantages of low cost, high strength, and durability.

Poles are often furnished under the specifications of the American Standards Association (2). Building poles are usually specified by top diameter. Preservative treatment is by the standard methods of the American Wood-Preservers' Association. The ASA specifications give fiber stresses for the various species that correspond approximately to the expected breaking strength of a treated pole in service as a simple cantilever. There is some difference of opinion on a suitable design value for poles in building construction. The Uniform Building Code of the International Conference of Building Officials provides about 2,000 pounds per square inch bending stress for southern pine poles under wind loading, while the American Wood Preservers Institute (11) recommends 3,000 pounds per square inch. The strength of poles depends in part on the distribution of loads and stresses, since poles have generally lower unit strength at the tip than at the butt. Many building designs are such that the maximum stress occurs near the ground line of the pole.

Much information on the strength of poles, and factors affecting their strength, was obtained recently in the American Society for Testing and Materials Wood Pole Research Program conducted at the U.S. Forest Products Laboratory (17). The work included a comparison of two test methods (fig. 3), relation of pole strength to the strength of clear wood, effect of natural characteristics on the strength, and strength values of untreated and of treated poles in five species.

Details of design of pole-type buildings have been developed by a number of engineers. The work of the American Wood Preservers Institute has been mentioned (11). Plans have been developed also by the lumber industry, farm management services, and farm building plan services. A rigid frame comprising wall poles and a roof truss was developed and evaluated at the U.S. Forest Products Laboratory, and was able to sustain test loads greater than the computed design load (6) (fig. 4).

Joining Wood Members

Most mechanical fastenings for wood are of such nature that an appreciable amount of slip must take place before the fastening can pick up its load. At a given load, the amount of slip is generally less with nails or toothed connectors driven into the wood than with bolts or ring connectors that go into prebored holes or grooves. Recommended working loads for nailed joints are derived from test loads that cause a slip of 0.015 inch. Because of this joint slip, it is generally assumed that little or no bending moment can be transmitted through most mechanically fastened joints. However, increasing attention is being given to the possibility that a nailed or toothed connector may develop a degree of partial rigidity that can be recognized in structural design.

Most glued joints have a strength and rigidity as great as that of the wood. Gluing is thus structurally effective. Where lumber members have been glued nonparallel, they may undergo differential dimensional changes from variations of moisture content, so this type of gluing should be avoided when possible. Stresses set up by differential swelling or shrinking may seriously reduce the strength of rigidly glued joints with nonparallel members or heavy members. Because of this, research is now being focused on adhesives of more limited rigidity for structural use. Stress resulting from moisture changes is relatively small in parallel-glued members like laminated beams.

Durability is an essential property of glued structural joints; some adhesives will last as long as the wood in exterior exposure. Durability depends also on proper techniques of gluing. Recommended practices and manufacturers' instructions must be followed faithfully if a lasting joint is to be made. Most storage structures with adhesive-bonded joints will require a fully waterproof exterior-type adhesive.

Since glued assemblies are likely to be produced in a factory, a quality-control system like that of the American Institute of Timber Construction or the Plywood Fabricator Service helps to insure that specifications are met and good gluing practices are followed. Field gluing of structural joints is possible, but the proper control of items like glue spread and curing temperatures and pressures is difficult under field conditions. An excellent summary of the application of adhesives to farm buildings was presented by Brouse (3) at a recent American Society of Agricultural Engineers meeting.

Nail-gluing is a common practice, with the nails driven to apply pressure to the glue joint. This results in a strong glued joint because the nails help clamp the glued members together.

Glued-laminated structural members are now available in almost any size and design but generally only to order. Strength factors and design principles are well recognized. The laminating industry has standards for fabrication and design, and a quality-control plan to insure that gluing is properly done (14). Care must be taken in specifying glued members that the type of adhesive is adequate for the service conditions; this is especially important in bulk storage structures that serve as drying units.

Structural Problems in Storage Buildings

Many of the problems in wood storage structures can be traced to inadequate design. Storage loads and pressures are generally predictable, but a designer may fail to realize their magnitude. In a recent instance, a poorly designed pole-type structure in Illinois, storing corn to a depth of nearly 20 feet, with resulting lateral pressures estimated up to 300 pounds per square foot, developed serious bulging and some pole failure. One wall is reported to have broken completely, spilling 30,000 bushels of corn on the ground. This could have been prevented if the designer had realized and planned for the pressures exerted by the grain.

Design for storage pressures requires special consideration at various points. Duration of load must be fully recognized. Designers of storage structures should take into account the fact that continuing load causes the long-time deformation of wood to increase by 1/4 to 1/2 of the initial deformation. Fastenings must follow recognized design methods; the National Design Specification (10) is a guide to this. Slip of loaded joints or long-time set of wood may permit bulging that causes trouble with doors, even though complete failure does not occur. Pressures in storage buildings near main-line railroads may be increased by grain settlement because of ground vibrations. Timber engineering experience and judgment are necessary to deal successfully with storage pressures.

Storage structures have large exposed surfaces, and when empty are especially vulnerable to wind damage. Theakston and Walpole (12) have emphasized the importance of fastenings and anchorage, and they give a number of suggestions for minimizing wind damage. Esmay and Giese (8) have also dealt with the problem.

Chemical changes during drying of some stored commodities sometimes cause temperatures to rise. The barn set on fire by too-green hay is a familiar story. Adequate ventilation and placing material at the proper moisture content in storage can help to prevent this problem. On the other hand, heating appliances

used for the drying of stored commodities need protection, and storage building fires sometimes occur from this cause. Small barns for the flue-curing of tobacco are numerous in some sections of the South, and no one knows how many of these have been destroyed by fire.

Decay and insect damage can cause structural problems, but these can result from design errors such as a flat roof that permits ponding of water or wall details that permit entrance of rainwater. Untreated wood in contact with the ground is a far too common error, and can result in structural failures from decay or termite damage.

Although problems can arise with wood as with any other structural material, most of them illustrate either poor design, carelessness, or inadequate maintenance. Wood has taken its place as a structural material; its engineering properties are now well known, as well as its traditional workability and economy. In storage buildings as well as in other structures, wood will give satisfaction when used correctly.

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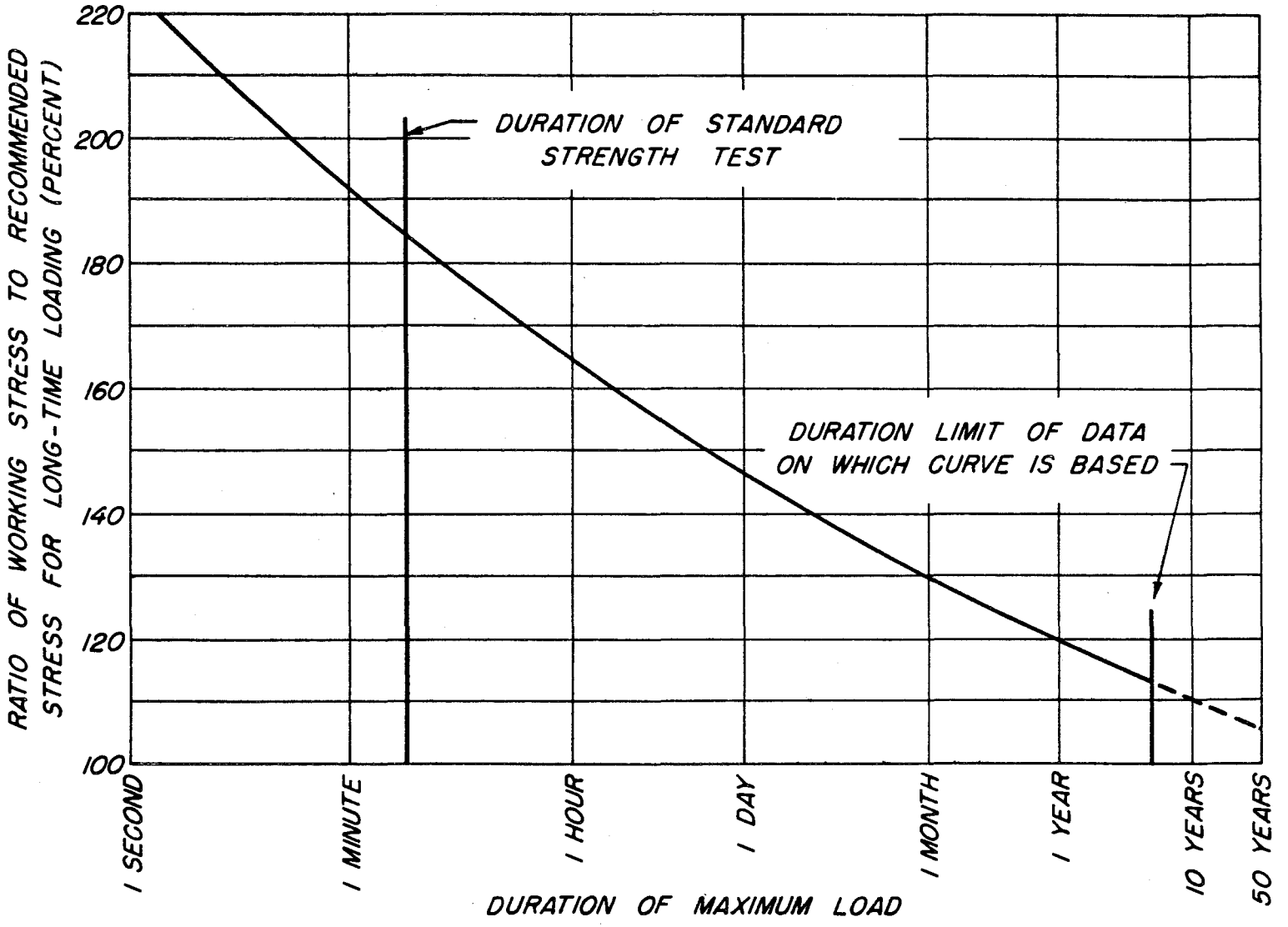

Figure 1. --Relation of working stress to duration of load.

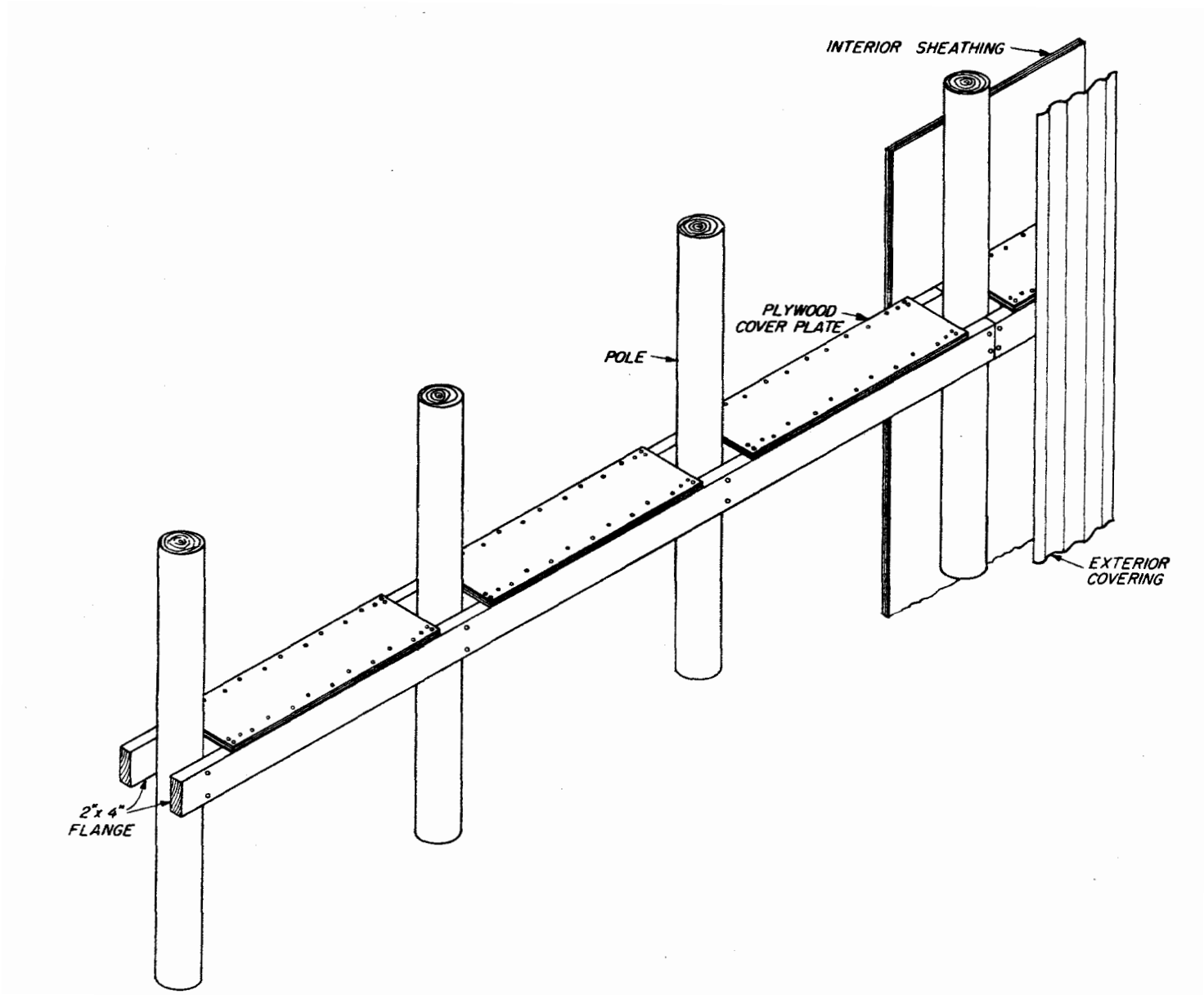

Figure 2. --Plywood cover plates attached to the top edges of the horizontal nailing members or girts in conventional post or pole frame construction increase their strength and stiffness.

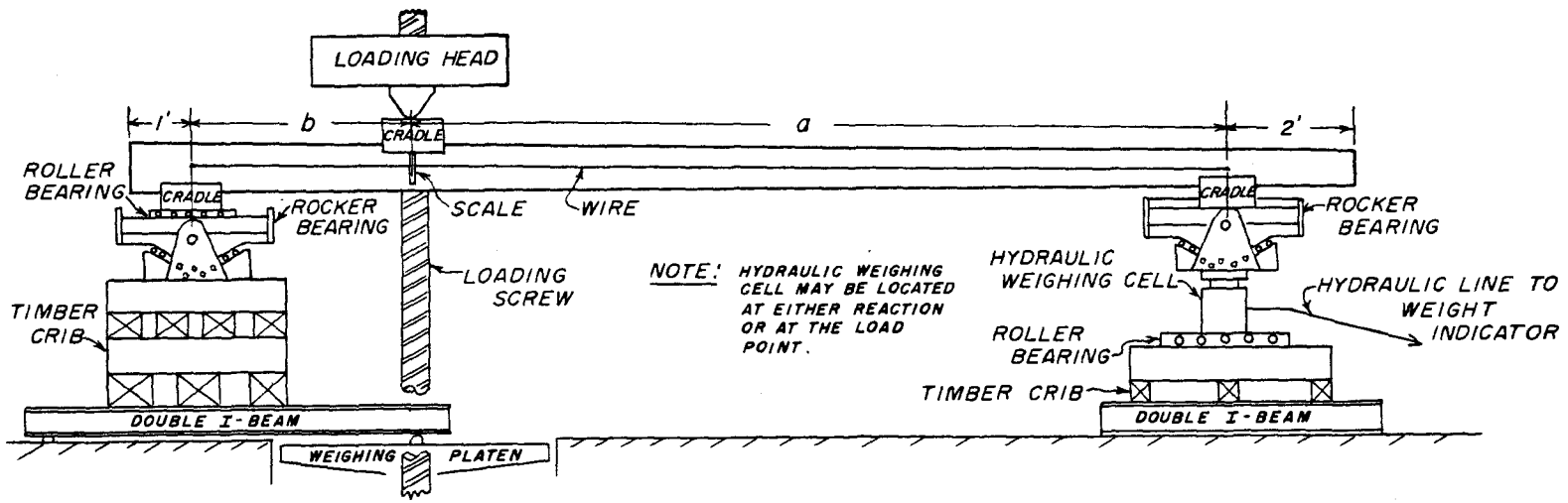

Figure 4. --Diagram of machine test setup used in the majority of American Society for Testing and Materials strength tests of wood poles.

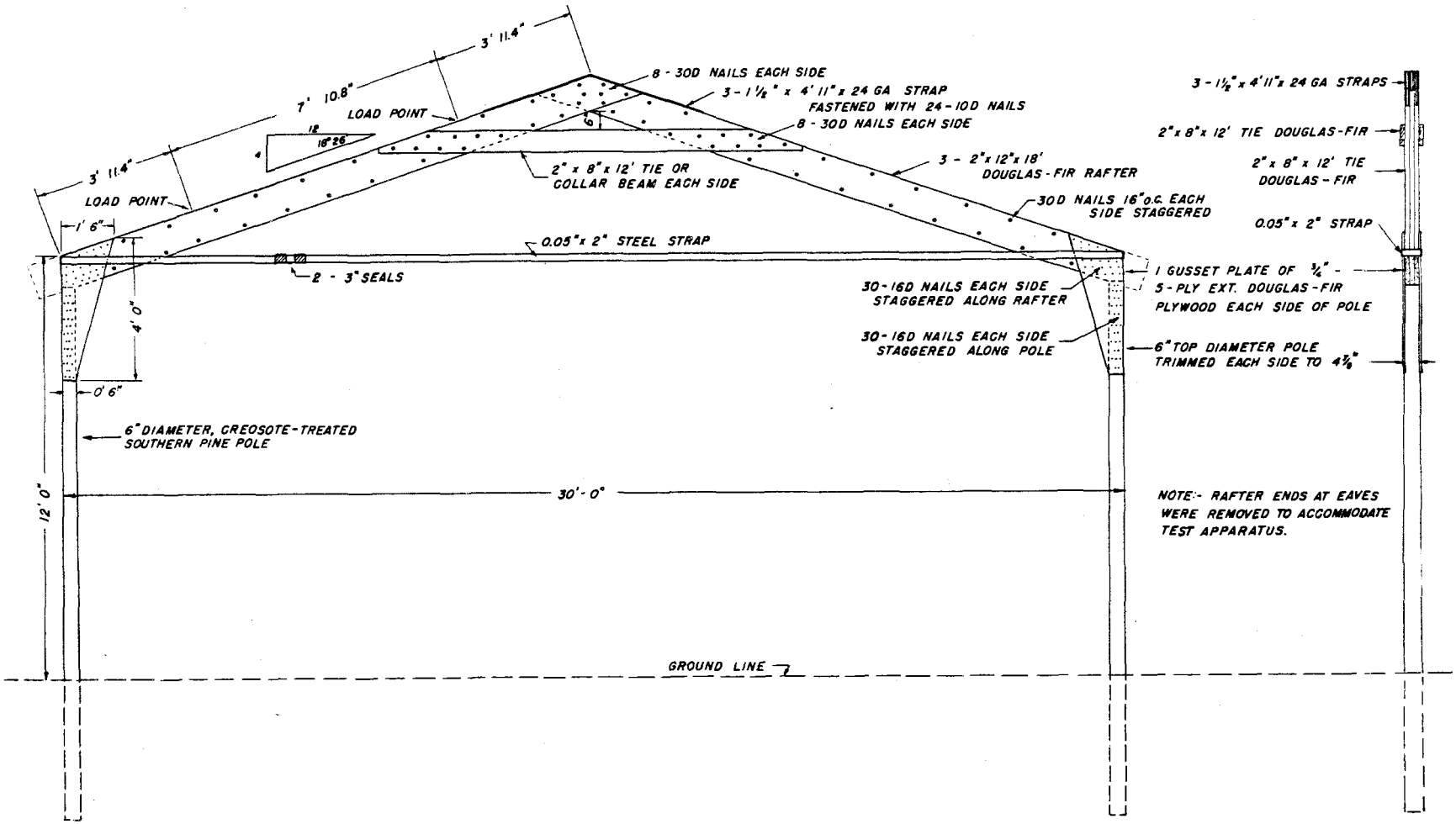

Figure 4. --Construction details of experimental pole-frame assemblies.

SUBJECT LISTS OF PUBLICATIONS ISSUED BY THE FOREST PRODUCTS LABORATORY

The following are obtainable free upon request from the Director, Forest Products Laboratory, Madison, Wisconsin 53705.

List of publications on Box and Crate Construction and Packaging Data

List of publications on Chemistry of Wood and Derived Products

List of publications on Drying of Lumber

List of publications on Fire Performance

List of publications on Fungus Defects in Forest Products and Decay in Trees

List of publications on Glue, Glued Products, and Veneer

List of publications on Growth, Structure, and Identification of Wood

List of publications on Logging, Milling, and Utilization of Timber Products

List of publications on Mechanical Properties and Structural Uses of Wood and Wood Products

List of publications on Pulp and Paper

List of publications on Structural Sandwich; Plastic Laminates, and Wood-Base Aircraft Components

List of publications on Thermal Properties of Wood

List of publications on Wood Finishing

List of publications on Wood Preservation

Partial list of publications for Architect s, Builders, Engineers and Retail Lumbermen

Partial list of publications for Furniture Manufacturers, Woodworkers, and Teachers of Woodshop Practice

Note: Since Forest Products Laboratory publications are so varied in subject no single list is issued. Instead a list is made for each Laboratory division. Twice a year, December 31 and June 30, a list is made showing new reports for the previous 6 months. This is the only item sent regularly to the Laboratory's mailing list. Anyone who has asked for and received the proper subject lists and who has had his name placed on the mailing list can keep up to date on Forest Products Laboratory publications. Each subject list carries a listing of all other subject lists.