

TRUSSED ASSEMBLIES FROM SMALL-DIAMETER ROUND TIMBERS

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SUMMARY

This paper discusses issues regarding the use of small-diameter round timber in wood construction. Standards relating to grading and establishing design values are discussed, as well as an overview of past research related to strength properties and connections for round timbers. Trussed assemblies, including plane trusses and space frames, provide the greatest potential for value-added structural applications of small-diameter timbers.

1 INTRODUCTION

An overstock of small diameter timber has created a forest management problem for major lumber producing areas in the United States. Small-diameter timber is defined as trees having diameters at breast height less than 9 inches (229 mm). Competition for essential nutrients results in suppressed tree growth, reduced resistance to disease and an increased susceptibility to catastrophic fire. If a fire starts in one of these areas, the build-up of small trees having a high surface to volume ratio will make the fire burn hotter and longer than would be expected in a mature forest where trees are larger and more widely spaced. These conditions not only threaten a major loss of forest resource, but also present a hazard to people living in heavily forested regions.

The obvious solution to this problem is to cut out the majority of small-diameter and poorly formed or diseased trees. Such a job is prohibitively expensive if the material removed has little or no value. Finding value-added uses that will, pay the cost of the removal is the challenge facing the Forest Service.

No single application will provide a value-added use for all material that needs to be removed. Some applications, such as firewood and pulp chips, barely cover removal costs when there is a local market. If these materials must be shipped over 500 miles costs exceed the value in most cases. Other uses such as poles, posts, piles, pallets, furniture, paneling, millwork, and artwork have much higher value but the markets are easily saturated. Lumber can be produced from these trees, but small size and downfall due to defects and warp increase production costs over that of lumber from larger trees.

Light frame building systems provide the largest market for lumber in the United States. These systems include residential structures as well as light commercial, industrial, and agricultural buildings. These markets have evolved to use standard dimension lumber and panel products. To gain acceptance of small-diameter round timber in these established markets, proposed uses must demonstrate a compatibility with existing structural systems and economic incentive in terms of both material and labor cost.

2 STANDARDS AND SPECIFICATIONS

The greatest challenge to using round timbers in structural applications is developing design standards and material specifications to address the appropriate strength and quality issues. Several associations maintain standards to govern the selection and assignment of design stresses for round timbers. In North America, the most widely referenced round-timber standards are published by the American Society for Testing and Materials (ASTM)[1,2,3,4] and the American National Standards Institute (ANSI)[5,6]. Both ASTM and ANSI publish round timber specifications, giving minimum quality requirements and size classifications for round timber piles [2] and poles [5]. They also publish standards to cover the derivation of design stresses for pole and pile applications. [1,3,4,6]. The American Society of Agricultural Engineers (ASAE) also publishes a standard for round construction poles [7] used in agricultural buildings; design values in this standard are based on ASTM and ANSI standards.

Standards written for the derivation of pole and pile design stresses do not consider pole size to be a variable that affects the maximum bending or axial stress. The ASTM standard [1] bases the derivation of design stress of various species of

round timber on published strength values of small clear specimens. This “clear wood strength” is adjusted for the effect of defects and for the known difference in variability between small clear specimens and full-size round timbers. It is also adjusted for variation in the strength of wood with height in a tree. The ANSI standard provides minimum values for circumference 2m (6 ft) from the butt for various pole classes on the basis of a species-dependent fiber stress value, which is assumed to be independent of pole size. There are sufficient data to verify that the fiber stress values published by ANSI are close to the mean modulus of rupture (MOR), but the derivation of design stress in both the ANSI C2 [6] and ASTM D2899 [1] standards are subject to debate.

A pilot study conducted by Wolfe [8] determined that the mean bending strength, predicted using the ASTM standard, was either within or slightly below the measured 95% confidence interval on the mean bending strength of tested small-diameter poles. The predicted axial compression strength, however, was significantly greater than that measured. This led to the conclusion that the juvenile wood portion of a round timber cross section has a significant effect on the design capacity of a round timber. In bending, the juvenile wood, located close to the center of the cross section, is not stressed as highly as the stronger, mature wood in the outer growth rings, thus having little effect on bending strength of the section. When a concentric axial load is placed on a round-wood section, the stiffer mature wood still carries a greater share of the load. The assumption of uniform stress distribution, however, makes the net section property appear to be below that predicted on the basis of small clear strength tests. Therefore, axial load capacity of these small-diameter timbers should be adjusted for juvenile wood portion

Conventional round wood design standards consider only one stress grade. Both ASTM and ANSI round timber standards assume one stress grade: To meet it, all timbers must meet a set of minimum quality requirements. Unlike lumber, visual characteristics such as knots and spiral grain have little effect on the strength of unprocessed round timber. This phenomenon is most evident in the variability of strength properties. For example, a comparison of bending strengths between Select Structural (SS) Douglas fir (DF) dimension lumber at 12% and 23% moisture content (MC) [9], and small diameter (less than 0.25m.) Douglas fir poles tested at moisture contents exceeding 30% [10] is made in Table 1.

In the dryer condition, the graded lumber had a slightly higher mean strength, but almost three times the coefficient of variation (COV) of round timber selected to meet minimum specifications.

This partially explains the low incentive for incremental stress grades for poles.

Douglas-fir product	Bending strength	
	Mean (MPa)	COV (%)
SS 2x8 lumber @12% MC	58.5	30.1
SS 2x8 lumber @23% MC	40.5	26.4
Round timber >30% MC	54.7	11.3

Table 1 - Round timber compared to lumber strength in bending.

3 GEOMETRIC ADVANTAGES

In addition to exhibiting greater strength and less variability, utilizing the whole log rather than cutting it into prismatic timbers has both structural and economic advantages. In their natural form, small-diameter timbers (SDT) will have a load capacity that exceeds that of the largest prismatic timber that could be sawn from them. This is due in part to the section geometry. Axial capacity is directly related to cross-sectional area, bending strength is a function of section modulus (S) and stiffness is directly related to moment of inertia (MOI). A round section's area, S and MOI will be 1.57, 1.66, and 2.35, times the respective properties of the largest inscribed square.

Log taper gives added advantage to the SDT beam as shown in Figure 1. This figure shows ratios of effective section properties for tapered versus prismatic beams from the same log. These properties were calculated on the basis of bending strength and stiffness for 2.4m-span beams loaded to the same level of stress or deflection. For this

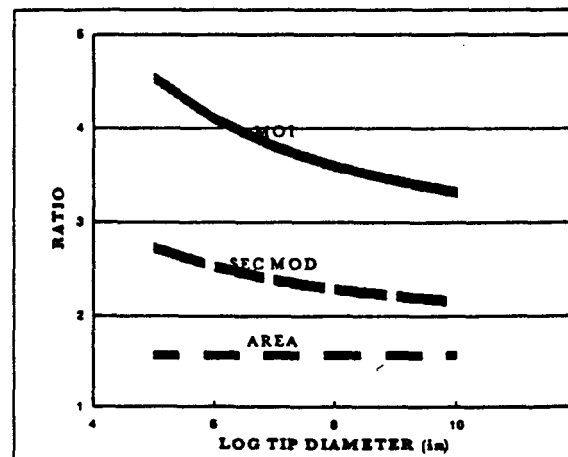


Figure 1 Effective section property ratios for beams of SDT compared with the largest sawn timber section they would yield

comparison, the SDT beams were assumed to have a diameter taper of .01 m/m and tip diameters ranging from 10 to 25 cm. The effective SM is equal to the ratio of loads to give equivalent maximum stress and the MOI is the ratio of loads to give equivalent maximum deflection.

combining strength and section property advantages of the round tapered section results in significant increases in design capacity over that of solid sawn elements. The lower strength COV and comparable mean will give a higher fifth percentile strength to the round timber. Combining the higher design stress and larger section modulus gives a load capacity ratio exceeding 2 when stress controls and 4 when stiffness controls. Taper holds little advantage for axial capacity except when buckling capacity is a consideration.

Finally, maintaining the natural shape minimizes processing waste. The stronger, stiffer wood of the outer shell of the tree is kept rather than cut off as tapered slabs are good only for chips and fuel

4 STRUCTURAL APPLICATIONS

Several conventional structural applications make use of small-diameter round timbers. Their use in building systems is limited, however, by the lack of a more rigorous assignment of allowable stresses, construction problems associated with the round tapered shape, and the lack of efficient connections.

4.1 Pole Buildings

In the United States, round timbers are used primarily for agricultural equipment and storage sheds. There have been a number of publications however that provide design and construction details for pole frame buildings. [11,12,13] The ASAE published construction standards for pole buildings. The round timbers in these structures serve primarily as beam/columns framing members in the walls. Design stresses for these applications were derived on the basis of small clear stresses [1] rather than full size pole tests. Innovative architects have utilized poles for residential structures [12]; however, these must be custom designed as there are no established design guidelines published in the United States for residential pole structures.

4.2 Log Cabins

ASTM standard D3957 [4] provides a very conservative derivation of effective section properties as a means of assigning design stresses for wall logs. This standard was developed following the same general procedures outlined for the derivation of lumber stresses. For most wall

log applications, the design is not governed by stiffness or strength of the log, but by aesthetics or thermal conductivity. Design values normally only control when the logs are used as structural headers over window and door openings.

4.3 Rafters/beams

Design standards used for poles are also applicable for beam and rafter design. ASTM [1] provides design stress derivation for bending based on small clear test values. This application is commonly found in the southwestern US where the round timbers serve as roof beams.

5 TRUSS AND SPACE-FRAME SYSTEMS

There are no established design standards for round timber trusses and space-frames. The primary reason for this is the difficulty of designing and connecting round wood members compared to prismatic standard dimension lumber. Difficulties in dealing with the natural shape have made this an unattractive option. Timber connections have been developed for the more easily handled standard dimensions of flat surfaced timbers. However with a growing demand to make use of small-diameter round timber, it may be time to begin developing details and connections to make their use more attractive.

Truss systems hold strong potential for value-added use of round timbers. It is possible to use round wood with little processing other than peeling and drying. The taper is not a major problem as the perimeter of the truss or space frame can be held to constant dimensions despite the use of tapered chords and webs (Figure 2). For aesthetic applications where the structural system is to be totally exposed, there may be some preference for uniform diameter members. This can be accommodated using peeler cores or a dowel-milling machine.



Figure 2 - Truss constructed using tapered round timbers may be fabricated to maintain uniform outside dimensions.

Space frames (Figure 3) are a relatively new concept [14]. They require a more complex design than plane trusses, but with the development of computer-aided design (CAD) and more user friendly finite element analysis (FEA) packages, the design of space frames is little more difficult than that of a truss assembly.

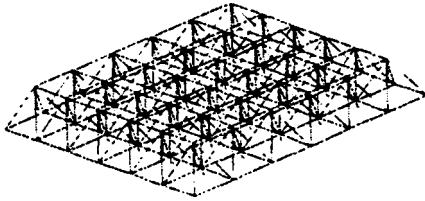


Figure 3 - Space frame assembly made from round timbers having equal length throughout

The major problem in analyzing space frames is accurately modeling the connections and the boundary conditions. If a space frame such as that shown in Figure 3 were designed as a roof with a 8m x 8m plan, having a 1.07m. depth and 1.5 cm diameter round timber members, the maximum stress under a load of 2.4 kPa would be under 689kPa (100 lb/in²) at design and connection forces would be under 13kN (3000 lbf) Such a structure could easily be designed to use the small-diameter timber with design stresses ranging from 6.9 to 14 MPa (1000 to 2000 lb/in²).

The major challenge is getting a compatible connection detail. Requirements for the connection include low cost, ease of installation, and design capacities in the range 1.3 to 45 kN (300 to 10000 lbf). Round timbers are not as likely to bow or warp as is dimension lumber. Round timber may have a tendency to twist about the long axis, depending on the amount of spiral grain-permitted. If twisting is a potential problem, the connection may have to provide a rotational degree of freedom. For most trussed assemblies, the structural elements are assumed to carry only axial loads, but unless the loads are applied only at the nodes or connection points, some bending moments will be imposed if the connection is not a pure pin

Lukindo [15] provides a summary of a number of techniques, which have been proposed and used for connecting round timbers. Some of these make use of a "Flitch-plate" type connection comprising a steel plate placed diametrically through the timber with a dowel connector passing through the wood/metal section to transfer shear loads from the log to the metal plate. Other connections include steel clamps fastened around the perimeter, dowel-nuts such as those commonly used in furniture [16],

and form fit nail plates such as those used in light frame trusses.

There has also been some work done in the area of adhesive connections [17]. There are still several problems with using a combination of steel dowels and hard-setting polymeric adhesives. One problem has to do with compatibility. Wood has a different coefficient of thermal expansion than do steel or plastic, and it also exhibits greater dimensional change under changing moisture conditions. Such incompatibility leads to splitting and eventual weakening if the connectors are not detailed to accommodate these differences. Another problem with adhesives is related to the effects of moisture. When moisture content in the wood exceeds 15%, chemical interaction can cause bubbles to form in the adhesive layer, reducing the effective shear area in the glue line.

Huybers [18,19] has conducted one of the more rigorous studies to develop a connection for small-diameter round timber. He developed a steel-wire laced connection to deal with problems associated with in-place drying of round sections. His connection makes use of a flitch plate held in place by hollow pins to transfer axial and bending loads. To limit effects due to splitting, Huybers and his peers developed a tool for applying a wire lacing which is wrapped around the log and through the hollow pins. This connection detail allows them to use green timbers with limited degradation in joint capacity due to in-place drying.

To facilitate the construction of space frames and trusses, quick-connect-type ball, or hub connections, are commonly used. Ball connectors normally use a threaded fastener to connect the ball to the framing member. A hub-type connection, such as that shown in Figure 4, consists of a slotted cylinder and interlocking plates that slide into the slots. The other end of the plate can be fastened to the end of the timber truss element by means of a flitch plate, a fitted sleeve, or a dowel-type connection

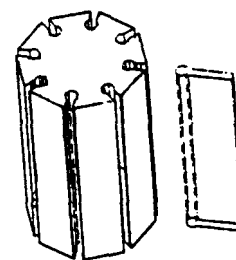


Figure 4. Hub connector fabricated to permit plate connectors to slide in from the top or bottom and to be locked radially.

Figure 5 shows a connector that could be adapted for use with small-diameter timbers. Connection plates, dowels or sleeves could be fastened to the ends of the timber members in a fabrication plant. In the field, these ends would be easily connected to the hub element and the entire assembly would be bolted together. A threaded stud on the top or bottom of this hub can be used to fasten panelized sheathing elements directly to the node, minimizing bending moments on the truss element and using the node point to define the top plane of the assembly rather than the tapered round timber truss element.

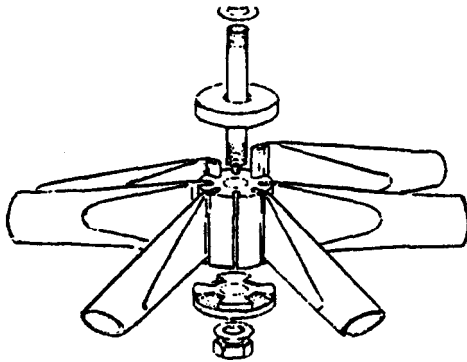


Figure 5 Space-frame node connection will accept up to 8 members and provides a connection point for cladding.

6 CONCLUDING REMARKS

Studies that have been completed, or are currently in progress, provide a basis for developing design standards for the use of small-diameter timbers in structural applications. The application that appears to offer the greatest potential for value-added use of this material is the three-dimensional truss or space-frame structural configuration. For many conventional structures having spans up to 10 m (30 ft), space frames can be designed using round timbers having diameters in the range 100 to 200 mm (4 to 8 in). The most critical 'element to this system is the connection and there are a number of details that have been proposed that could be used to facilitate the design and field construction of these assemblies.

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