Demonstration Building Constructed with Round Mortise and Tenon Joints and Salvage Material from Small-Diameter Tree Stems

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Abstract

Rectangular mortise and tenon construction has been widely used in barns and other buildings in this and other countries, and there is a long history of its performance. Round mortise and tenon joints are essentially a modern variation of this construction. They are much easier to manufacture because 1) the tenons can be cut with hole saws; and 2) the mortises can be drilled rather than chiseled. As a result, this method of construction lends itself to mass production techniques. Using this construction, a variety of modular building frames can be constructed “tinker toy” style from a relatively small set of standardized parts. Potentially, this system provides an outlet for small-diameter tree stems that are presently of essentially no economic value, but more importantly, it provides the basis for solving numerous housing and other building shortages in underdeveloped regions at the cottage industry level. To obtain insights into the specific characteristics and peculiarities of round mortise and tenon joint building frame construction, a small building was designed and constructed utilizing this system. A description of the building and the lessons learned from its construction are given in this paper.

According to Wolfe (2000), many forest stands in this country are overstocked with small-diameter trees. This material poses both a health hazard and a fire hazard, and the excess stems should be selectively thinned, but they presently have too little market value to justify their removal. A similar situation exists in many developing countries that have replanted denuded forest areas (Ramirez 1998). Thus, large quantities of potentially useful but largely unused wood materials presently exist and are available for conversion into value-added wood products, but these products must be of sufficient value to justify harvesting costs. As pointed out by Wolfe (2000) and Wolfe and Moseley (2000), structural applications offer a high-potential value-added market for small-diameter stems. From a structural perspective, however, several problems must be solved. In particular, strong yet cost-effective methods must be found to join the members together (Eckelman 1995, Karlson 1967, Rug and Potke 1990).

Studies in related areas (Eckelman et al. 2000) suggest that round mortise and tenon joint construction may provide a partial answer to the problem of the structural joining of small-diameter tree stems economically. Specifically, round mortise and tenon joints are easily constructed and lend themselves to the fabrication of standardized parts that can be incorporated easily into modular constructions. Furthermore, the tenons themselves are efficient load carriers (Eckelman 1970) and are highly resistant to cyclic loading in bending (Haviarova et al. 2001a, 2001b).

It is recognized, however, that the bending strength of round mortise and

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It must also be recognized that for many applications, round timbers would need to be squared before they could be used. Although this can be done with a small portable band mill, a Scrugg saw would be needed for a large-scale operation.

Preservative treatment of the wood would be important in areas subject to termite infestation or where the wood would be used in applications where it is frequently wetted. Ideally, the wood should be treated after tenons and mortises have been cut.

Finally, building construction is a very conservative trade and change is slow because the adoption of new methods represents an investment of both time and capital. New materials and systems, therefore, not only need to meet basic strength and durability requirements, but the systems need to be as simple as possible to reduce the need for specialized labor (Ramirez 1998, Leandro 1996). Acceptance of round mortise and tenon construction on a regional basis requires the standardization of parts and components to ensure that they will fit together when brought to a building site. Widespread use of the system also dictates that simplification and standardization of components must occur without unduly limiting design possibilities or dictating the nature of the building that can be constructed from them (Jensen et al. 1990). Thus, although round mortise and tenon joints can be used in one-of-a-kind unique constructions, there is strong need for the rational development of standardized components that can be used to fabricate a wide variety of frame systems.

Rectangular mortise and tenon construction has been widely used in barns and other buildings in this and other countries, and there is a long history of its performance (Sloane 1967). Round mortise and tenon construction differs essentially only in the geometry of the joint, but information is lacking concerning its use in building frame construction, although the use of dowels as connectors has been investigated (Stern 2001). Information is needed, therefore, concerning the basic characteristics and the idiosyncrasies of round mortise and tenon frame construction. Initially, background information is needed concerning the difficulties encountered in cutting round tenons and mortises of a size suitable for use with small-diameter roundwood, the ease of assembly with round mortise and tenon frame construction, and the integrity of the assembled frame. To obtain insights into whether this construction is practicable, as well as further insights into the specific characteristics and peculiarities of round mortise and tenon joint building frame construction, a small building was designed and constructed utilizing this construction system. A description of the building and the lessons learned from its construction are given in this paper.

**MATERIAL**

All of the material used in construction of the frame was obtained from a study conducted by Serrano (1999) on the effect of longitudinal growth strains on lumber warp in material cut from small-diameter yellow-poplar logs. The larger structural members obtained from this study measured a nominal 3-1/2 inches square. A part of these members had been cut as is from small-diameter yellow-poplar stems and included the core of the tree in the center of the cross section. The remainder of the members were fabricated by Serrano (1999) by sawing squared stems lengthwise into two identical parts and then gluing the outside broad faces back to back, which places the core of the stem on two opposite outside faces of the resulting square timber. Smaller members, measuring 1-1/2 by 3-1/2 inches in cross section, were cut from small-diameter stems without regard to core position; i.e., no attempt was made to position core material in a specific position in the end of the member.

**MACHINING OF MEMBERS**

Tenons for the frame were cut with 2-inch diameter by 12-inch long deep hole saws produced by a commercial supplier. A simple low cost “drill press” was developed to machine the tenons (Fig. 1). In practice, the squared tree stem, or other structural member, was first positioned and secured in place in the machine. The hole saw was then advanced into the end of the member until the desired depth of cut (tenon length) was obtained. The excess material was then removed from around the tenon with a handsaw in order to leave a uniform rectangular shoulder on the member. Diameter of the tenons at the time of machining was a nominal 2 inches.
Mortises were drilled in the members with 2-1/16-inch-diameter Forstner bits. Diameter of the holes measured a nominal 2-1/16 inches.

**Frame design and construction**

Drawings of the frame developed during the study are given in Figures 2 and 3. Overall, the frame measured 6 by 12 feet in cross section by 9 feet tall. These dimensions were chosen in order to allow the use of material that had previously been processed from small-diameter timber.

All of the material was first cut to size. Tenons were then cut on the ends of the members and mortises drilled into the sides of the members as needed.

Construction of the frame itself began with the insertion of the floor joist tenons into the corresponding mortises in the sills. Once this was done, the resulting floor system consisting of floor joists and sills was secured on the foundation. The corner post tenons were then inserted into the corner sill mortises. Since the side sills were constructed of two pieces, wall stud tenons were inserted into the two overlapping sill joints to join these two members together. The floor joist tenons on either side of this joint were then pinned to the sills. The remaining wall studs and doorposts were then added by inserting their tenons into corresponding mortises in the sills.

The tenons of the window headers and sills were then inserted into their corresponding mortises cut in the wall studs. Next, the front and back top plates were slipped in place over the tops of the front corner and door tenons and the back wall corner and stud tenons and seated on the shoulders of the tenons. The tie beam was installed in a similar manner. The side rafter plates were then slipped in place over the ends of the sidewall stud tenons and the corner post tenons (Fig. 4).

The ridge beam support columns, or king posts, were next inserted in place. Then, the rafters were slipped into place over the tops of the wall stud tenons while the rafter tenons simultaneously were slipped into corresponding mortises in the ridge beam. Each rafter was "pinned" to its corresponding wall stud tenon with a 12-penny nail. It should be noted that the outer faces of the ridge beam were cut at an angle so that they were perpendicular to the longitudinal axes of the rafters. The ridge rafter beam along with the side rafter plates were extended beyond the front and back plates in order to support fly rafters needed to provide an overhang for the front and back of the structure (Fig. 5). Finally, the facia headers were added.

After the frame was erected, the walls and roof were sheathed with appropriate standard grades of plywood and the roof was covered with asphalt shingles. Treated facia boards were used to cover the exposed face of the facia headers. Short lengths of facia were also installed in each gable end. Finally, the building
was floored with additional material salvaged from small-diameter yellow-poplar stems.

Construction of the frame is such that the sills are locked together at the corners by the corner post tenons. These joints locate the corners of the structure and provide resistance to lateral loading of the sills. Likewise, the sills are linked together at the mid-length points by the tenons of the wall studs supporting the tie beam. If the sills are not fastened to a secure foundation, the floor joist tenons that frame into the sills on either side of the intermediate sill joint are pinned to the sills in order to provide resistance to lateral loading.

The front and back top plates along with the tie beam provide resistance to lateral forces applied to the walls by the side rafter plates and also locate the position of the tops of the corner posts spatially in a side-to-side direction.

Vertical forces applied to the ridge rafter beam by the rafters are transferred to the front and back top plates and the tie beam by the ridge beam support posts, or, king posts. Hence, the ridge beam roof loads are transferred to the top plates at their center points. For longer spans, intermediate beam and column construction can be used so that these loads would be transmitted to the third or quarter points of the end plates and tie beams as desired. The rafters are notched and mortised so that they slip over the tenons of the wall studs and seat on the top surface of the side rafter plates. The side rafter plates, therefore, carry a large part of the vertical roof load and also provide resistance to the horizontal components of the roof load.

**DISCUSSION**

The frame was first erected within the Wood Research Laboratory, disassembled, transferred to the construction site, and then re-erected. Time to disassemble was about 15 minutes; time to reassemble was about 40 minutes. The consensus of those participating was that structures such as this could be assembled easily and rapidly from a stock of standardized parts, essentially without the use of any tools.

It was found that when parts with matching tenons and mortises were allowed to dry, the mortises often shrank more than the tenons. The closeness of fit between tenons and mortises is quite important since the tighter the joint the stiffer the structure. On the other hand, the tighter the fit, the more difficult the assembly of the frame. Unequal shrinkage could be a serious problem with parts precut from green or partially seasoned wood and stored for significant periods of time before assembly. Ideally, such parts should be cut from seasoned wood.

Experience with the simple horizontal drill press indicates that round tenons can be cut both easily and quickly with the simple equipment developed. In general, the tenons are round and true. Mortises are cut easily with Forstner type bits. Exploratory tests indicate that the same equipment can be used equally
well with 3- and 4-inch-diameter hole saws.

Additional work is underway to develop other designs and constructions. Roof frame designs and roof frame systems are of particular importance. Work is also underway to obtain information concerning the bending strength, lateral shear strength, and pinned strength of round mortise and tenon joints since this information is critical for the rational design of frame systems based on round mortise and tenon joint construction.

Conclusions

Results of this exploratory building project indicate that round mortise and tenon joinery provides a simple straightforward method of constructing building frames. Erection techniques are simple and only basic tools are needed. Furthermore, basically unskilled labor can be used to erect a frame.

The system lends itself to the production of standard parts that can be manufactured locally by cottage level industry or regionally by major producers. Standardized parts can be easily incorporated into modular constructions to serve a wide variety of needs.

On-site frame assembly times are short and assembly can be accomplished with unskilled labor. The system is thus well suited to the rapid solution of widespread building construction needs.

Importantly, the system is well suited for the use of large amounts of small-diameter tree stems for which there is now little use. Furthermore, costly connectors are eliminated because they are integral parts of the members themselves.

In summary, round mortise and tenon construction joinery provides a means of utilizing low-value wood material in the construction of useful building frames. Some of these building frames might be used to satisfy the simple need for backyard storage sheds in developing countries, while others might be used to provide the basic framework for shelter for the less fortunate, for farm buildings, and light industrial buildings.

Literature Cited


