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

By

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According to Wolfe (2000), many forest stands in this country are over-stocked with small-diameter trees. This material poses both a health 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; Karlsen 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 tenon joints is limited by the strengths of the tenons themselves—if higher strengths are needed, there is no simple way to reinforce the joints. Thus, building frames must be designed in such a way that internal bending forces are distributed as uniformly as possible to the various members and joints. In addition, a sufficient number of members must be included in the design to ensure that the total internal strength of the construction is
sufficient to carry the loads imposed on the structure. The inherent nature of these designs is such, therefore, that numerous small members should be used to form a construction rather than a few large members.

It must also be recognized that the use of tight fitting joints would make joining of members difficult. In practice, therefore, round mortise and tenon joints cannot be expected to have high tensile strength, and, in general, should not be designed to function as primary tensile load connectors in building frame constructions. In general, therefore, frame designs must be developed that avoid tension loading of tenons. Pilot studies, however, indicate that relatively high levels of withdrawal strength can be obtained with pinned tenon joints – in those cases where tension loading of joints cannot be avoided. In these joints, a cross pin of half the diameter of the round tenon is inserted crossways in a hole drilled through the tenon and the member it joins together. It is anticipated that these joints would provide sufficient strength for secondary joints such as those used to anchor roofs against the uplift forces created by wind loads.

The variability anticipated in the strength and condition of the cores of small stems also dictates that some type of pre-treatment would be needed before tenons could be cut on the ends of some members. The inside/outside cut and glue process of Serrano (1999) in producing nominal 4 x 4s from 2 x 4s cut from small stems (in which the core material is placed on the outside faces of the 4 x 4s) provides one means of obtaining sound cores from small stems. In the case of smaller stems, tenons can be cut that are of about the same diameter as the small end of the member, thus preserving the strength of the material outside of the core area.

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 Scragg 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 was 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 is referenced (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, as outlined above, 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 the paper that follows.

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 x 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, Figure 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, Figure 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, Figure 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 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 re-assemble 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 that are 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 straightforward, 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 construction joinery provides a means of utilizing what is at present a problem wood material in the construction of useful building frames. Some of these building frames might be used to satisfy the simple needs for backyard storage sheds in developed countries while others might be used to provide the basic framework for shelter for the less fortunate, for farm buildings, and light industrial buildings.

References


Figure 1. Horizontal drilling press used to machine tenons.
Figure 2. Diagram showing installation of the tie beam and side rafter plates.
Figure 3. Diagram showing roof frame assembly.
Figure 4. In progress assembly of the frame.
Figure 5. The nearly completed frame.
