Grading Structural Timbers, New and Old

THE first-ever Timber Frame Engineering Council timber grading training course, hosted in April by the Heartwood School in Washington, Mass., was a sold-out, three-day event attended by sawyers, timber framers, engineers and architects. The range of professions represented at the course was a good indication of the broad interest in this topic and its importance. The days were divided between classroom and yard, where full-size timbers were available for grading, provided by sawyers Dave Bowman and Jim Rogers as well as engineer Phil Pierce.

Our instructors were Ron Anthony, wood scientist and president of Anthony & Associates, Inc., Fort Collins, Colorado, and Bob Falk, research engineer with the USDA Forest Products Laboratory in Madison, Wisconsin. Our trainers were Matt Pomeroy, director of inspection services for the Northeastern Lumber Manufacturers Association, and Don Pendergast, lead trainer for NeLMA.

Goals of the course A primary goal was to offer training specifically in the grading of structural timbers, but also to go beyond rote memorization and application of rules (not differentiating between new and seasoned lumber, for instance, or not interpreting requirements) to explain the technical basis for the grading rules.

While grading agencies and so-called third-party inspection agencies exist in all parts of the United States and Canada, timber framing materials differ from those of mainstream wood construction. Timbers often have not been graded by an approved lumber grading or inspection agency, as they were obtained from small sawmills that do not regularly employ graders. Some jurisdictions do not require grading of lumber. On occasion structures are fabricated from ungraded, unsawn timbers left in the round (logs) or from squared timbers converted by hewing.

Further, when antique or reclaimed timbers are used in timber-framed structures, they are typically not graded. There is no established, generally recognized approach to stress-grading timbers in situ (in place) in historic structures that are to be restored or repurposed. Yet there may be structural design reasons for wanting to verify the grade of a timber for a given structural application. These industry-wide characteristics justify a need for workers with a good understanding of grading rules and how to apply and interpret them, but who do not need the broader and more exhaustive training required of a certified lumber grader.

Workers for sawmills or timber framing companies can become certified lumber graders after a certain amount of training and payment of a monthly membership fee to a grading agency to cover the costs of monthly inspections and ongoing training, but they are only certified to grade at the specific mill or timber framing company and only for the size of lumber or timber for which they have been trained.

Becoming a certified lumber grader is not practical for those not working for a major lumber producer or for a third-party inspection agency, simply because the administrative rules and training requirements present a barrier to entry. Our timber grading training course was intended to provide education for those working at small mills or shops, or making grading decisions at a variety of sites but only periodically. There have been no established programs to fill this need.

In addition to training in the application of grading rules, a goal of the course was to consider the issues of grading reclaimed and antique timbers put to new uses, as well as timbers in an existing frame being evaluated for its load carrying capacity to accommodate new uses. These issues are relevant to timber framers working with salvaged materials and to architects and engineers conserving and adapting existing structures.

Overview of grading concepts *Wood versus timber.* Those words capture the central challenge of understanding the behavior of structural timbers and establishing safe working stresses for timbers in service. To help us learn what that phrase implies, Ron Anthony took us through the history of the development of established mechanical properties of wood and the development of grading concepts and standards. He showed us how to follow the thread from the American Society of Testing Materials (ASTM) D143 *Test Methods for Small Clear Specimens of Timber* to D2555 *Practice for Establishing Clear Wood Strength Values* to D245 *Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber*, and finally to the allowable stress values we see in the *National Design Specification for Wood Construction*, the *NDS*.

The practice of determining the strength of materials by physical testing goes back at least as far as Galileo and Newton. Naturally the more nearly ideal the material (that is, homogeneous and isotropic), the simpler the determination of the strength of the material. Wood offers considerably less than ideal behavior compared with a material like steel, but the behavior still can be quantified. Traditionally, small clear specimens of wood are tested to establish basic mechanical properties useful to us in design of beams and columns: bending strength (*Modulus of Rupture*, or MOR), tensile strength parallel and perpendicular to the grain, compressive strength parallel and perpendicular to the grain, and stiffness parallel to the grain (*Modulus of Elasticity*, or MOE). But of course full-size timbers of practical dimensions for construction are never made up completely of perfect wood. Trees often grow crooked, with some twist in the grain, and with branches, compression wood and other natural characteristics that result in sawn timbers containing knots, slope of grain, shake and other features that cause their behavior under load to vary from that of the clear wood samples used in laboratory testing.

Even within a given species, there is considerable variability in the results obtained from testing small clear specimens in accordance with ASTM D143. To establish safe upper limits on allowable stresses for a given species, it's important to have an understanding not only of the average strength of clear wood for that species but also of the degree of variability in a given strength property. ASTM D2555 provides us with tabulated values of the important mechanical properties of a whole range of commercial hardwood and softwood species along with the standard deviation from the mean strength value for the various properties. The standard deviation is then used to calculate the difference between the mean value for a given property and the 5 percent exclusion limit (that is, the value below which only 5 percent of the samples tested fell) that needs to be used for derivation of allowable stresses. This is a valuable foundation, but still only part of the story.

A real timber contains various features at different points along its length that cause it to behave differently from a piece of clear, straight-grained wood. In considering how slope of grain, knots, shakes and checks may affect the strength of a timber, it's helpful to think of the timber as a chain under tension: somewhere there's a weak link that will be the first to fail under load. That weak link in timber may be slope of grain that induces tension perpendicular to the grain (which has less than 10 percent of the strength of wood parallel to the grain). It may be caused by knots or groups of knots that reduce the effective section available to resist loads and that may cause some significant localized slope of grain as well. When that weakest link fails, the timber fails no matter how strong the other links may be. ASTM D245 is the document that formalizes the safety factors and strength ratios that account for the various growth "defects," defining for us how visible defects reduce the probable strength of a piece of timber relative to the small clear specimen values.

ASTM D245 also takes the values obtained from the D2555 tables and brings them down to a normal load duration, that is, C_D equal to 1.0. It goes on to provide adjustment factors for duration of load, moisture content, and other end-use variables that allow us to establish design values for an individual timber. D245 does not establish grades, however.

Lumber grades are established by rules-writing committees to market reasonably predictable lumber for structural applications and consistent visual appearance. For structural applications, grading rules provide a way of prebundling ranges of possible grade-limiting characteristics into discrete groups. These groups were originally called S1, S2, S3 and S4, but have been simplified to Select Structural, No. 1, and No. 2. In establishing allowable stresses for structural timber, we work our way down from the average strength values of small clear specimens by applying reductions for various maximum allowable defects within a given grade as well as by applying various safety and adjustment factors.

Grades then are a commerce-driven concept and are partly analogous to grades of steel for structural applications. Once we know the species and grade, we can look up the allowable stresses in the *NDS*. It certainly would be inconvenient and impractical if we all had to evaluate every piece of lumber for a structure and assess all of the strength-reducing characteristics case by case by applying the rules of D245. Ron Anthony, however, emphasized that we *may* do so if we wish. I will return to this practice as we discuss grading of timbers in situ. Ron pointed out that much of the timber harvested today is plantation-grown and is, therefore, of different quality from older material we often encounter as timber framers. Fortunately, we can still use the ASTM standards and small-clear-specimen data to determine structural grade and material properties of both new and old timber.

This approach to developing allowable stresses sounds somewhat indirect and theoretical, and in fact there is another way of determining allowable stresses for real lumber containing defects, that is, an in-grade testing program which relies on full-scale lumber tests to determine material properties. This approach comes from the opposite direction of the previous process by establishing the maximum defects permitted within a grade and then testing a large quantity of full-size specimens within that grade to determine allowable stresses. This process was incorporated into grading rules and the *NDS* in the 1980s to determine allowable stresses for dimension lumber. To date, it has not done so for structural timbers for practical and economic reasons.

Photos Tom Nehil

Don Pendergast, lead trainer for NeLMA, in action. At left, Ron Anthony, wood scientist. Both taught in grading course.

It's helpful to keep in mind that grading rules are commerce driven and address more than just structural requirements. Looking at the rules associated with a given grade of structural lumber (for example, No. 1 Beams and Stringers from the NeLMA grading rules), we see that some limitations relate to structural performance (for example, knots and slope of grain) while others are related more closely to appearance (pitch streaks and pockets, wane) and some relate to potential decay or insect damage (pin holes, stain).

A certified lumber grader working at the mill is in effect a policeman: he doesn't make the rules, he just enforces them. NeLMA as well as other grading organizations and mill graders are required to strictly adhere to the grade rules and are not allowed to deviate from any limitations of the rules unless specific interpretations permit. Graders and inspectors have no way of knowing the end use of a timber and cannot consider all the possible outcomes.

An engineer focusing on structural performance of a timber may find some of the rules superfluous (such as those relating to pitch pockets) and may choose to ignore them when evaluating grade-limiting characteristics for a piece of timber. That of course does not mean that the other characteristics identified and limited by the grading rules are not important to the end user, the building owner, and so they should never be simply ignored for convenience. Matt Pomeroy, NeLMA's director of inspection services, emphasized during the course that NeLMA in no way advocates modifying or ignoring certain grade rules when evaluating timbers. After material is inspected at full length and assigned a grade by an agency or certified mill, it would be the responsibility of the individual as a structural engineer to make any exceptions or determinations for their design, based upon their own knowledge of the grades, the limiting characteristics and the effects on strength.

Taking the above into consideration, grading rules for any particular job may be customized; the rules may be made more stringent or relaxed as ordered by the client. Checks and shakes at the ends of a timber might be prohibited entirely because of their possible effect on joinery, for example, but limitations on wane might be made more generous if acceptable to the client.

Any of us using the *NDS* to obtain allowable stresses for a given species and grade encounters the distinction made in the code between *beams and stringers* and *posts and timbers*. These classes are differentiated by the aspect ratio of timber width and depth. Timbers (of 5 in. minimum width in NeLMA Section 25.0) whose depth is more than 2 in. greater than their width are assumed to be bending members, whereas timbers (5x5 and larger, NeLMA 26.0) whose width is *not* more than 2 in. greater than their depth are assumed to be axially-loaded compression members. The allowable stresses listed are different because the grading rules used are different between beams and stringers and posts and timbers. This is nothing more than a simplifying assumption.

There is nothing inherently different about the wood in a timber just because it was sawed as an 8x8 rather than a 7x10. The living tree functioned both as a post and a cantilevered beam. In timber framing design, we know that beams and joists might be square in cross-section while posts might be markedly rectangular in cross-section. As part of customizing the grading requirements for a particular job, it is possible to request that all grading be performed following the rules for beams and stringers regardless of the aspect ratio.

NDS values for beams and stringers are typically slightly higher than those for posts and timbers and so naturally they are desirable as we start pushing timbers to their limits. Remember though that knots on the wide and narrow faces of beams and stringers are treated differently in their grading rules, and slope of grain is more tightly controlled.

One of the great advantages of grading timber at the timber framing shop is that decisions can be made on the spot as to how to modify a given stick before it is put to use. If the grade-limiting defect is located at the end of a stick, it may be possible to improve the grade dramatically simply by cutting off the offending portion, resulting in a shorter timber of higher grade. The grader working at the sawmill cannot apply such thinking since the end use and final length of the timber cannot be foreseen.

Grading timbers in existing buildings Engineers involved in conservation and adaptive reuse often find themselves needing to judge the load-carrying capacity of timbers in an existing building. There are key differences between grading green timbers coming off the saw and attempting to grade timbers in situ. According to ASTM D245 and all lumber-grading rules-writing agencies, strictly speaking it's not possible to assign a grade to a timber in place since all six surfaces cannot be viewed.

When examining timbers in situ, the investigator assesses visible defects that would exclude the timber from a specific grade. The more of the stick exposed to view, the better the judgment will be. For example, exposed joists and beams in buildings can typically be viewed along their full length on three surfaces, which doesn't leave a lot of room for defects to hide. Timbers in built-up assemblies where only one or two surfaces may be visible, and perhaps only for part of their length (for example laminated truss chords or Town lattice trusses), are more problematic, not only because defects may be difficult to detect but damage also may be hidden. In fact, condition assessment and grading are inseparable activities when examining timbers in place.

A key advantage to grading timbers in place is that it's possible to see exactly how the stick is being used and where the defects are located along the length. Large edge knots in an area of low bending stress may not be cause for concern. The "grader" is able to focus on the defects located in areas of high demand and that might cause failure under load, while at the same time largely ignoring most appearance-related aspects of the grading rules. (Can a pitch pocket really hurt you?)

In doing so, a clear understanding of the reasons behind the grading rules is needed, so that good judgments can be made as to which features need particular attention and which are of lesser concern. In particular, checks and splits, killers in grading green timber at the mill, may be of little consequence in an existing building in service (provided joinery is not adversely affected), since typically these features do not have major effects on performance and are already accounted for in the allowable stresses given in the *NDS*.

Certified graders from NeLMA and some other grading and inspection agencies in North America understand these issues and are willing to work with a framer, architect or engineer on site to assist them in identifying grade-limiting defects in an assembly of timbers in situ. The grader in these situations is not officially grading timbers since that can only be done on timbers with all six faces exposed to view. Their assistance in identifying features that might limit the grade of the timbers, however, will certainly add confidence and credibility to structural decisions.

Grading of reclaimed timbers The discussion of grading timbers in situ sets the stage for thinking about grading of reclaimed timbers salvaged from a structure. One often hears that old wood is much better, much stronger than the wood harvested these days. While the wood contained in certain species of timber harvested from old-growth forests in previous centuries may be better and stronger, timber grade always trumps wood quality, since defects can limit the load-carrying capacity of an otherwise beautiful stick. Mechanical damage (modifications) or damage from use and weathering also can have a major impact on the strength of the timber, no matter how fine the clear, straight-grained portions of the stick may be.

We should differentiate between two different grading practices for reclaimed timbers. Grading timbers sitting at the reseller's yard, with no certainty as to their final use, makes it unavoidable that we follow grading rules as written, treating mortises, notches and peg holes as if they were voids or knots (that is, areas of interrupted grain), and that the stick be graded at its length as found at the yard. Such treatment possibly grades a beautiful piece of timber as No. 2 or worse. On the other hand, if we grade the salvaged timber in a manner similar to that of grading in situ, where the use of a timber in a frame is determined, where we can know the spans and intended loads, where we can cut off defects or position mortises, notches, or deterioration at locations where the consequences are minimal, then we may be able to take advantage of the high quality of the remaining wood in the timber. Mortises and notches in such an application can be treated as mechanical alterations and we can turn to the Timber Frame Engineering Council *TFEC 1 Standard for Design of Timber Frame Structures and Commentary* for guidance how to quantify the effect of these notches on the strength of the timber. After all, we don't change the grade of a new timber when we cut mortises, drill holes or drive screws into it. As Bob Falk of the Forest Products Lab put it, "Why is a nail in a piece of lumber not a problem until we take it out?" Bob is asking in effect whether there is any more damage to the fibers after the nail is pulled than there was before, the answer being "not really." We don't consider a joist reduced in strength after we nail a ceiling to the underside, thereby poking holes in the tension face, or, more to the point, we don't change its grade.

Old-growth spruce timbers that might be rejected under grading rules for new mill-sawn timber. Use of ASTM standards or informed consideration of relevant grading rules might result in acceptance as structural timbers, with notches and mortises considered as they would be in a new timber frame.

Take-home messages While it was good to become more familiar with the grading rules as published by NeLMA, which are for the most part identical to those of all grading agencies in North America, it was also good to learn that there can be quite a bit of flexibility in the application of these rules, particularly when done by individuals with a good understanding of the why behind the rules. Grading rules can be customized for a given project, although defects that have consequences on strength, principally knots and slope of grain, cannot be overruled.

It's possible to hire representatives of NeLMA or other grading agencies and third-party inspection agencies, such as Timber Products Inspection (TPI), to guide you in applying the rules, especially those you consider important for a given project. They may not grade the timbers but will help you identify grade-limiting characteristics as you request and then let you make the call as to suitability for use.

Combining structural engineering with a good understanding of the grading rules and their foundation, that is, ASTM Standards D143, D2555, and D245, can put an engineer or designer in a powerful position to make informed judgments about the capacity of reclaimed or in situ timbers, much better in fact than a certified lumber grader who may have impeccable knowledge of the grading rules and how to apply them to green timber but lacks the training—or freedom—to consider how they affect the performance of timbers in a structure. As we learned from Ron Anthony during the course, this approach to looking at timbers in situ and evaluating reclaimed timbers is sound practice, not a quasi-legal corruption of the grading rules.

Future direction Rules for assigning grades to timbers in situ (really the process of trying to account for the presence of grade-limiting defects), in order to make possible the use of allowable stresses associated with the highest reasonable grades, have not been clearly formalized, to my knowledge. The document prepared by the Association for Preservation Technology and the National Center for Preservation Technology and Training, *A Grading Protocol for Structural Lumber and Timber in Historic Structures*, of which Ron Anthony was a principal author, lays a valuable foundation. Hastily made assumptions as to species of wood and grade, that document observes, can yield overly-conservative estimates that lead to unnecessary expense in strengthening and replacement of adequate members and degradation of the integrity of the original structure. Many of us have seen the wholesale application of steel plates to serviceable timbers in older timber framed buildings, for example. (Of course hasty assumptions can lead to *unconservative* estimates of strength as well.) To keep the document from becoming too complicated for the typical practitioner, however, the APT-NCPTT grading protocol stops short of laying out the more technical aspects of using ASTM Standards D2555 and D245, only presenting the background to the rules, the rules themselves and generally how to use them.

I believe it's important to establish as acceptable practice the application of the procedures of D245 to determine the actual strength reduction resulting from the features in a given stick, especially when it contains fewer and smaller defects than are permitted within a given grade. Equally important is to establish acceptable practices for applying structural analysis to identify stresses resulting from in-service loads and support conditions, and then to examine grade-limiting characteristics of the given timber at the critical regions along its length.

The timber grading training committee of the TFEC intends to offer the grading training course next in the spring of 2015. The course provides such valuable core information about our work and our medium that anyone associated with timber framing, from milling through fabrication and installation, stands to gain valuable insights. —Tom Nehil

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