A Grading Protocol for Structural Lumber and Timber in Historic Structures | 2009-01

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A Grading Protocol for Structural Lumber and Timber in Historic Structures

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DISCLAIMER

Any design or structural analysis requires that the engineer or architect rely on published data and standards when conducting their analysis. Nonetheless, it is the sole responsibility of the designer (engineer, architect, consultant, or other professional) when making a decision to base their analysis on any calculations or technical data. Paramount to that responsibility is an understanding of the basis of the information or data upon which they rely. This report, database, and program have been produced based on publically available information. Some of that information comes from grading rules promulgated by various trade associations, or grades identified within the National Design Specification for Wood Construction. None of the trade associations that produced the grading data or the American Wood & Paper Association are responsible for the production of the report, database, or program generated under this project. The National Center for Preservation Technology and Training and the Association for Preservation Technology International, while providing either financial or administrative support, are not responsible for the content or use of the information by individuals. Anthony & Associates, Inc., while soliciting review from industry and trade professionals, as well as practitioners familiar with timber design and grades, does not warrant that the data in the program have not, or will not change as changes to the grading rules take place. **As such, it is the responsibility of any user of this database and program to understand the information being provided and accept sole responsibility for its use.**

A Grading Protocol for Structural Lumber and Timber in Historic Structures

EXECUTIVE SUMMARY

For historic buildings and structures, engineers and architects often rely on current standards and design values to determine adequacy of the wood members to remain in service, but current standards are generally based on lower quality material than was used in many historic buildings. Historic structures built before the establishment of building codes or design values for wood products (or structures which lack grade stamps on individual wood members) present a quandary when determining what design values are appropriate. Frequently an assumed species and grade are assigned, only to show that the wood members are structurally deficient, despite the fact that the structure has stood for decades or centuries without failure. The results of assuming a species and/or grade are often an overly conservative estimate of the design values and unnecessary replacement, repair and retrofit decisions along with associated unnecessary project costs and destruction of historic fabric.

This grading protocol is a review of historical wood testing and standards development, wood condition assessment basics, and a query-based wood grading program. The goal of this protocol is to change the typical decision-making process by giving engineers and architects the means to better understand the grading of wood members in relation to building code requirements.

All work on historic structures should comply with the Secretary of the Interior's Standards for the Treatment of Historic Properties and, therefore, be compatible both physically and visually with the structure, as well as documented and identifiable (upon close inspection) for future research and preservation efforts. If repairs are necessary, the existing condition should be evaluated to determine the appropriate level of intervention needed. If there are areas of deterioration severe enough to require repair or limited replacement of a member, the deteriorated material should be replaced with the same species and match the original material in composition, design, color, and texture.

Ultimately, the choice to retain historic fabric and reduce costs for historic preservation projects lies in the hands of the engineer who determines the structural capacity and safety requirements for current or future structure use. The grading protocol is intended to provide engineers with additional tools to make more informed decisions regarding these choices.

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A Grading Protocol for Structural Lumber and Timber in Historic Structures

INTRODUCTION

Every day, structural engineers make decisions about lumber and structural timber (wood members) in historic structures. They do so often without the necessary tools to properly assess the suitability of historic fabric to provide reliable, long-term, safe performance. Due to uncertainties about the allowable design values that can be assigned to the wood members, very conservative decisions to replace or reinforce these members are often made, even though the wood members are "working," i.e. they have and will continue to safely carry the loads imposed upon them. Too many of these decisions result in the replacement of historic fabric that could, in fact, remain in service without compromising structural integrity. This grading protocol is a review of historical wood testing and standards development, wood condition assessment basics, and a query-based wood grading program. The goal of this protocol is to change the typical decision-making process by giving engineers and architects the means to better understand the grading of wood members in relation to building code requirements.

BACKGROUND

Lumber and structural timbers used in new construction are intended to comply with the relevant building code for that jurisdiction. For wood construction, structural engineers rely on design values referenced in the building code to determine an acceptable species, size and grade for a particular load condition. The design values given in the building codes for solid wood products are established by the American Forest & Paper Association and American Wood Council (2005) and published as the *National Design Specification for Wood Construction*. The published design values are based on various test data and procedures published by the American Society for Testing and Materials (ASTM, 2007) that demonstrate the engineering performance of the material.

These design values are given for wood members of a particular wood species, or species group, and structural grades. Milled wood products are graded and stamped in accordance with procedures promulgated by one of several forest products industry associations, such as the Western Wood Products Association (WWPA), the Southern Pine Inspection Bureau (SPIB), the West Coast Lumber Inspection Bureau (WCLIB), or the Northeastern Lumber Manufacturers

Association (NELMA), each of whom define grades for a specific species or a limited group of species.

Assessing Historic Structures

For historic buildings and structures, the engineer often relies on current standards and design values to determine the adequacy of wood members to remain in service, but current standards are generally based on lower-quality material than was typically used in historic buildings. Historic structures built before building codes or design values for wood products were established (or structures which lack grade stamps on individual wood members), present a quandary when determining what design values are appropriate. Frequently an assumed species and grade are assigned, only to show that the wood members are structurally deficient, despite the fact that the structure has stood for decades or centuries without failure. The results of assuming a species and/or grade are often an overly conservative estimate of the design values and unnecessary replacement, repair and retrofit decisions along with associated unnecessary project costs and the loss of historic fabric.

Determining the species and grade, however, are not sufficient for assessing the serviceability of wood elements within a historic structure. **In addition to determining the species and grade of historic timbers, it is essential that the condition of the timber being graded be known.** Deterioration due to decay or insect attack, member failure, mechanical damage or alterations and other conditions can adversely affect the performance of structural timber even though it may appear to meet the requirements for a particular grade. For this, a detailed wood inspection is essential. There are three primary reasons to conduct a wood inspection: (1) concerns about moisture and its effects, (2) the concerns about deterioration (both physical and biological) and (3) a need to know material properties. Of these reasons, determining the grade addresses only the need to know material properties. Wood behavior is highly variable and it is that variability relative to the use of wood in historic structures that it is important to understand. There are numerous references that provide information on the pertinent aspects of a wood condition assessment. The following paragraphs contain a summary explanation of wood condition assessment tools and procedures and are excerpted from an *APT Bulletin* Practice Points article by Anthony (2007).

All wood is subject to a variety of deterioration mechanisms, the most prominent of which is wood-decay fungi, which can ultimately lead to the inability of structural members to perform their function. Large timbers, depending on wood species, frequently will rot on the interior where absorbed moisture is retained, with no externally visible sign of the deterioration. Moisture absorption though end grain, checks or holes provides a highly favorable environment for decay fungi to attack the heartwood at the center of a large timber. The heartwood (the inner growth rings of the tree) typically has more decay resistance than the sapwood (the outer growth rings of the tree). However, even the heartwood of a decay-resistant species, such as chestnut, when exposed to enough moisture, will decay. Deterioration is a particular concern where the wood is in contact with the ground or other materials, such as porous stone, that may provide for moisture absorption into the wood.

There are three "tools" for a basic wood inspection – visual inspection, a probe (such as a blunt awl) and a moisture meter. Nondestructive evaluation equipment is available that can give much more information about wood condition, but use of such tools should be reserved for situations where a basic inspection cannot sufficiently answer the questions about the wood that need to be addressed by the architect, engineer or owner.

A visual inspection is just that – looking for things that do not appear to be right. Visual examination of the wood allows for identifying components that are missing, broken or in an advanced state of deterioration. Missing components are those which have been removed or have fallen away, frequently due to extensive deterioration. If missing components were intended to provide structural support or protection from the elements (e.g. prevent moisture intrusion), their replacement may be essential to prevent long-term damage to the structure. Missing roof shingles or sheathing that cause roof leaks are common examples of a missing elements that are essential to the long-term preservation of a historic structure.

Visual inspection also allows for the detection of past or current moisture problems, as evidenced by moisture stains on the exposed surface of the wood. Further, visual inspection enables detection of external wood decay fungi or insect activity as determined by the presence of decay fruiting bodies, fungal growth, insect bore holes, mud tubes, or wood substance removed by wood-destroying insects. Visual inspection provides a rapid means of identifying areas that may need further investigation.

Probing the wood with a blunt awl enables rapid detection of voids in the wood that may not be visible on the surface. Internal decay is often masked by the lack of evidence on the exposed surface of the wood. For advanced decay, where large internal voids are present near the surface, probing allows for detection of potentially serious deterioration. Even for the early stage of decay, termed incipient decay, probing is beneficial. Probing can often reveal areas of incipient decay in timber, which has experienced sufficient deterioration due to decay fungi to allow for easy entry of a probe although no void is yet present. Wood without incipient decay tends to offer more resistance to probing due to the higher density and more intact internal wood structure. For internal voids in large timbers, more advanced inspection methods are generally required to detect the void.

The true moisture content of wood can be determined only by oven drying a sample removed from a structure. Fortunately, portable moisture meters are available that allow us to take a reading of the approximate moisture content of wood without removing a sample from the structure. There are two primary types of portable moisture meters. A capacitance-type meter measures the electrical field within a small area of wood and does not require penetration of probes into the wood. It will generally provide the average moisture content throughout a certain depth, typically less than an inch. A conductance-type meter is based on the principal of electric current being conducted through wood between two probes, which come in different lengths, and can be inserted into the wood to various depths. This allows for determining the moisture content at a specific depth. This is particularly useful to determine whether wood is drying or taking up moisture.

Knowing where to inspect and what tools to use depends on the goal of the inspection. The condition of wood components is the most common reason for conducting an inspection. That being the case, it makes sense to look for problems where they are most likely to occur in a structure. A visual inspection will often locate areas that warrant further investigation. Missing or failed components, moisture stains, the presence of fungal fruiting bodies, decayed wood, insect bore holes, mud tubes or frass are indicators of areas that need closer investigation. An inspection should focus on areas where problems are known to be common, such as:

- Wood in ground contact
- Wood that exhibits moisture stains
- Wood with visible decay
- Material interfaces (e.g. wood and masonry), such as beam pockets
- Floor joists and girders
- Roof framing
- Sill beams and plates, particularly when in contact with masonry
- Top plates
- Structural lumber or timbers near openings (doors and windows)
- Porches
- Crawl spaces and basements
- Areas of the structure that have been modified
- Exterior wood work, including cladding, shingles and soffits

HISTORY OF WOOD INVESTIGATION AND THE DEVELOPMENT OF STANDARDS

Early Investigations of Wood Properties

Human beings have been building with timber for millennia. Evidence of timber construction has been found in many of the earliest human societies. It is this history and familiarity with timber that allowed for the building of some of the world's most magnificent structures, including the roof trusses of Palazzo Vecchio in Florence, Italy; Westminster Abbey in London; the stave church at Borgund, Norway; and the Horyuji Temple in Ikaruga, Nara Prefecture, Japan. All of these structures were built well before the strength properties of wood were well understood and documented. Yet, they still stand today. For the most part, tradition and experience governed construction with timber until the late 19^{th} and early 20^{th} centuries.

One of the earliest individuals to investigate the properties of wood was Theophrastus (372-287 B.C.E.) in ancient Greece. He is best known as the successor of Aristotle, but he spent much of his time in botanical investigations. His nine volumes on *Enquiry into Plants* and six on *Causes of Plants* were the primary resources on botany well into the Middle Ages. In volume five of *Enquiry into Plants*, called *Of The Timber Of Various Trees And Its Uses*, Theophrastus outlines his investigations on the properties of wood (knots, texture, ease of use, hardness and heaviness), its relative strength (which woods can best support weight), and best uses (for ships, houses, and types of carpentry).

More specific investigations in to the properties of building materials did not occur until the 17^{th} and 18^{th} centuries. Galileo took time from his study of the heavens in the 1630s to investigate the strength of building materials, including wood. His description of a tension test was the first known attempt at measuring that particular property (Booth, 1964). Knowledge of other types of failure was advanced in the late 17^{th} century when Mariotte, Hooke and Parent looked at the failure of cantilevered and fixed beams (Booth, 1964).

Musschenbroek, however, in the mid-18^{th} century was responsible for the greatest early advances in testing wood. He developed a machine to test tensile strength, used it on various species and cuts of wood, examined the buckling of columns and failure of confined timbers, and studied the effects of moisture content on wood density and strength. During this time, Buffon was also studying the failure of large wood beams (up to 30 feet long), and examining the effect of load duration. The findings of his experiments on both small clear specimens and large beams were reproduced in tabular form. He ultimately concluded that it wasn't possible to predict properties of large wood members from the test of small specimens without defects (Booth, 1964; Sganzin, 1828).

Early Work in the United States on Wood Properties

Prior to the early part of the 20th century, no design values were published, nor did building codes govern construction. Yet many buildings were built that still stand today. Although tests to determine mechanical properties of timber were conducted as far back as the 1700s, as discussed above, it was not until the late 19th century that research scientists conducted tests specifically designed to provide more reliable data on properties of wood for use in buildings. Generally unknown today, the research of Roth and Fernow (1895), Hatt (1904, 1905), Talbot (1909), Cline and Heim (1912) and others provided the means of designing with timber based on an understanding of material performance.

In 1895, Filibert Roth and B.E. Fernow published Forest Service Bulletin No. 10, which reported on the influence of weight and moisture content on the strength of clear wood specimens and summarized much of the available knowledge on wood behavior to that point. That same year, the committee of the American International Association of Railway Superintendents of Bridges and Buildings presented a report (finally published as Berg et. al., 1907) which also included a summary of available data on wood properties and behavior. These data pointed to 15 recommendations made by the railway committee, some of which foreshadowed modern design and grading rules.

Beginning in the late 1800s and continuing into the early 1900s, a concerted effort was made by U.S. Division of Forestry (under B.E. Fernow) and several universities (including Washington University, Yale, Purdue, and the University of California at Berkeley) to systematically extend this knowledge through well-designed testing programs. However, there was some disagreement about whether the best approach was to test small, clear specimens or larger wood members. Proponents of the first approach thought it important to identify clearly how wood behavior differs among various species, while proponents of the latter approach thought that the behavior of large members with defects such as knots, wane, and slope of grain, would not be adequately predicted from the characteristics of small clear specimens. An excellent summary of this historic controversy is provided by Green and Evans (2001).

In the early 1900s, W. K. Hatt (in charge of the timber testing program at Purdue University), who considered both approaches valid and significant, designed a testing program to address both methods. Forest Service Circular 38 (Hatt, 1905) was an attempt to summarize existing data and standardize programs among the various testing laboratories. At the University of Illinois Engineering Experiment

Station, Arthur Talbot was also working on testing of timber beams. Talbot conducted horizontal shear tests on large timbers and small samples cut from the larger timbers to determine correlative values (Talbot, 1909). Talbot also examined the strength-limiting properties of knots, shake, and cross-grain, as well as moisture content, seasoning, and the strength difference between creosote treated and untreated timbers.

After data on both small clear specimens and large timber beams began to accumulate, other investigators looked at more subtle properties of wood. For instance, McGarvey Cline and Harry Tiemann conducted research on the effect of load rates on the strength and stiffness of wood (ASTM Proceeding 1908; Green and Evans, 2001), while Rolf Thelen investigated the testing of green and partially seasoned timbers (ASTM Proceedings 1908). While much testing had been conducted prior to 1910, little had been done to consolidate the findings into any sort of grading criteria based on the research results.

In 1912, Cline and Heim produced Forest Service Bulletin 108, which was a complete summary of the full-sized testing program, and provided an important reference for subsequent grading rules because it identified the strength of beams tested in bending and compression, both parallel and perpendicular to grain, as a function of their characteristics (moisture content, splits, knots, etc.).

There were two distinct mindsets developing in conjunction with these early investigations into the properties of wood. Many researchers felt that timber testing programs and any subsequent grading standards should develop data necessary for engineers and architects to reduce both the waste involved in overbuilt structures and to ensure minimum standards for structural integrity and safety. Timber tests, the proponents of this perspective argued, should therefore be conducted on full size members available to consumers (Green and Evans, 2001).

Many foresters and others, however, felt that timber tests should focus on the qualities of trees rather than the potential design uses for lumber. Timber tests, according to their perspective, should serve to provide data on the average strength properties of different species and demonstrate how growth conditions and other factors can affect the averages. Proponents of this perspective believed that multiple small sample tests should be conducted to provide strength averages without incurring the expense and waste that a full size test program would generate (Green and Evans, 2001).

These two perspectives led to considerable conflict as organizations began to develop grading standards for the lumber industry. Additionally, the discrepancy between test results for small clear samples and full size members was problematic. In order to correlate the data from both types of tests, researchers began to focus on so-called "defects" such as knots, splits, checks, wane, shake, and cross grain that seemed to limit the stress properties of full size members. This focus, along with the development of strength ratios based on results of both tests, provided the historical data that led to modern grading standards based on visual characteristics and mechanical tests.

Early Development of Standards and Building Codes in the United States

While formal standards for grading can be found as early as 1754 in Europe (Shelley, 1992), published standards and grading rules in the United States were not produced until the early 20th century after timber test results began to be published. The American Society for Testing and Materials (ASTM) was formed in 1898 (Green and Evans, 2001) and marks the beginning of formal standards for testing that would ultimately lead to the standards we have today. In 1905, Committee Q (the Committee on Standard Specifications for the Grading of Structural Timber) was formed. This committee identification changed to its current form, Committee D7, in 1910.

While Committee D7 was organizing and working on the development of grading rules, the U.S. Forest Service (USFS) was also investigating how these rules might work in practice. In 1915, at the 18th Annual Meeting of ASTM, H.S. Betts discussed a potential set of grading rules developed by the USFS, based in part on the work of Cline and Heim (1912) and others mentioned above. Finally, in 1922, ASTM tentatively approved *ASTM D143, Standard Methods of Testing Small Clear Specimens of Timber*, which was formally established as a standard in 1927 (ASTM D143-27). A similar standard for testing full-sized timbers, *ASTM D198-27* was also established in that year (Green and Evans, 2001).

In 1922, while ASTM was drafting the standards for testing, the Central Committee on Lumbers Standards, in the Department of Commerce (now the American Lumber Standards Committee, ALSC), was formed due to discussions between a committee formed by the National Lumber Manufacturer's Association and Secretary of Commerce Herbert Hoover (Shelley, 1992). The ALSC produced "Simplified Practice Recommendation No. 16" as the first national standard for lumber sizes and grades in 1924. This standard focused on nomenclature, the visual properties of wood members, and standardization of sizes. It did not include any information on allowable design values (Shelley, 1992).

Information on allowable design values was first published as USDA Forest Products Laboratory Circular 295, "Basic Grading Rules and Working Stresses for Structural Timbers" (Newlin and Johnson, 1923). This circular outlined a system of grading similar to our current one, with four grades of lumber (S1 to S4) which were limited to 88, 75, 62 and 50 percent of the strength ratios of clear wood, respectively (Green and Evans, 2001). This system for grading and allowable design values contained values for approximately 40 different species. However, values were shown without regards for width or thickness of members, and there were no special rules for lumber four inches or less in thickness. A companion paper, USDA FPL Circular 296, "Standard Grading Specifications for Yard Lumber," contained recommendations on sizes and moisture content adjustments (Ivory, et al., 1923).

With this promising start, ASTM went on to promulgate and improve upon numerous standards that today are the basis for grading and assigning allowable stresses to lumber and timber. The most important of these for grading of structural lumber and timbers in historic structures are:

- *ASTM D 2555, Standard Methods for Establishing Clear Wood Strength Values.* This standard was first issued as a tentative standard in 1966, then a full standard in 1969. It was developed to provide an "authoritative compilation of clear wood strength values for commercially important species" and marked the first use of the 5th percentile for deriving allowable wood properties.

- *ASTM D245, Standard Methods for Establishing Structural Grades for Visually Graded Lumber*. The original version, written as a tentative standard in 1926 and a full standard in 1927, was based on the work of Newlin and Johnson (1923) and focused on a means of selecting material for strength values.

Once test data were available and testing standards and procedures for grading lumber and timbers with defects were developed and established, the means to use the information for designing wood structures needed to be codified. Individual jurisdictions typically wrote their own building codes – New York City and Chicago are just two examples – however these codes listed basic design stresses for wood but often no criteria for defects that might be present in the lumber or timber.

Beginning in 1915, code-writing organizations were formed to address the need for building standards that safeguarded public health and safety. With the advent of the early building codes, Woolson, et al. (1926) made recommendations on working stresses (a form of design value) to the U.S. Department of Commerce. Betts and Helphenstine (1920, 1933) discussed lumber-grading procedures and T.R.C. Wilson (1934) produced a guide for the grading of structural timbers, USDA Miscellaneous Publication No. 185. A detailed summary of wood properties followed in 1935 by Markwardt and Wilson. These publications discuss early grading procedures and material properties, much of which may still be relevant and applicable to historic structures.

During the 1940s, as the country recovered from the depression and prepared for war, there was an interest in expanding design values to “yard” or dimension lumber (since previous research was focused on larger structural timbers). A supplement to USDA Miscellaneous Publication No. 185 was published, standards for stress grading of lumber were loosened, and grades were developed for lumber with less than a 50 percent strength ratio to that of clear wood (Shelley, 1992). This work culminated in recommendations by the National Lumber Manufacturers Association in 1944 known as the *National Design Specification for Stress-Grade Lumber and Its Fastenings* (1944). This document has evolved into the *National Design Specification for Wood Construction* (American Forest & Paper Association and American Wood Council, 2005).

During the 1950s and 1960, the most important debate in lumber standards was about the simplification and unification of size standards, a problem which had been ongoing since the inception of grading rules in the early 19th century. This problem was eventually resolved in the 1970s, when the American Lumber Standard (ALS) was revised as *Voluntary Product Standard PS20-70 American Softwood Lumber Standard* (Shelley, 1992). PS20-70 made substantive changes in lumber grading and marketing and established an independent Board of Review to enforce grading and grade marking portions of the standard. The Board of Review has authority to certify grading agencies and approve lumber design values promulgated by regional agencies in accordance with ASTM standards (Shelley, 1992). The ALSC is active today in establishing procedures for grading dimension lumber.

In a manner similar to the development of grading and lumber design values, building codes evolved from multiple sources. Eventually, there were three primary organizations that had responsibility for code writing. Each of these three organizations developed their own building code, which is used in specific zones of the U.S., generally covering geographic regions of the U.S. as stated below.

- **Building Officials and Code Administrators International, Inc. (BOCA).** This group was created in 1915, and administers the *Standard National Code* that was used in the eastern and Midwest portions of the U.S.

- **International Conference of Building Officials (ICBO).** Formed in 1922, this group’s code (the *Uniform Building Code*) was used in the western U.S.

- **The Standard Building Code Congress International (SBCCI).** This group was formed in 1941, and its code (the *Standard Building Code*) was developed for the southern states.

Recently, these code-writing organizations were consolidated into the International Code Council, Inc., which produces the *International Building Code*.

A BRIEF SUMMARY OF GRADING OF NEW LUMBER AND TIMBERS

Over time, grading rules were modified as more technical data became available on material properties, and the effects of knots, slope of grain, and sawing defects on material properties. Lumber trade associations modified their own grading rules, based on the American Lumber Standards Committee framework.

In the 1970s an in-grade testing program was initiated for dimension lumber. Prior to the in-grade testing program, lumber was assigned design values based on tests of small clear specimens to determine clear wood strength. The clear wood strength values were reduced by a number of factors, such as the size and location of knots and slope of grain as specified in ASTM standards. The ASTM standards and procedures are still in effect today, with numerous revisions over the years. However, tests on full-size lumber, coupled with concerns over changing forest resources, made it apparent that the small clear specimen approach did not accurately reflect the strength of full-size lumber.

The in-grade testing program conducted by the U.S. and Canadian forest products industry led to modifications in the design values assigned to a particular lumber species, or species group, based on the dimensions and defects present. The design values were coordinated through the industry trade associations. For western timber species, the Western Wood Products Association (WWPA) and West Coast Lumber Inspection Bureau (WCLIB) were instrumental in the work on softwood lumber. The Southern Pine Inspection Bureau (SPIB) was involved with the testing and analysis of southern yellow pine data.

These design values are used by architects and engineers to determine the appropriate size of lumber to resist loads on and within a structure. The loads are due to wind, snow, people and furnishings, and the weight of the structure. The design value is known to the architect or engineer by the grade assigned to and stamped on the lumber.

The grade stamp on a piece of lumber is the means by which the end user knows how the piece can be used. It specifies wood species and grade overseen by the industry trade associations in accordance with the American Lumber Standards Committee rules. The grade stamp does not guarantee that a piece of lumber has a particular strength, only that the piece of lumber met the requirements to be assigned a particular design value. The requirements are determined by the grading rules and include species, dimensions, knot size and location, slope of grain and manufacturing defects (such as skip and wane).

The grade stamp is recognized by architects, engineers, builders and building officials as a measure of the quality of a piece of lumber. A typical grade stamp is shown in Figure 1. The grade stamp generally has the following characteristics:

- Certification mark - indicates the supervising grading agency
- Species – identifies the wood species or species combination
- Mill identification – the number or brand of the firm that produced the board
- Grade name – indicates the grade for which the piece meets the requirements
- Moisture content – indicates the target moisture content to which the wood was dried or the moisture content at which it was surfaced (planed).

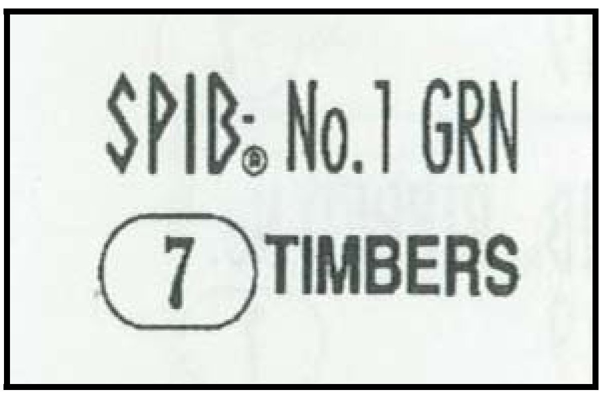


Figure 1. Grade stamp from SPIB for No. 1 Timbers for southern yellow pine. Moisture content is in the green (unseasoned) condition, over 19 percent (SPIB, 2002).

Appearance grades are used in structures to satisfy architectural requirements (e.g. free of knots) or for secondary industries, such as furniture manufacturers. Grades for hardwood lumber are established by separate industry trade associations, such as the National Hardwood Lumber Association. Most hardwood species of lumber and timber are typically not used in structural applications today. The difference between structural and non-structural grades is that structural grades are referenced in model building codes and, as such, carry a legal burden of safety. The failure to either be properly specified or to meet the grade requirements may also compromise safety. If a building collapses, the grade of the lumber may be called into question. In contrast, failure to meet an appearance grade is a matter of aesthetics, not safety.

The modern architect or engineer, when first exposed to the interlocking complexity of standards, rules, building codes, governing organizations and trade groups may well feel overwhelmed. The process through which standards are developed and implemented through the various organizing bodies is certainly convoluted. The materials to which the grading rules are applied include round timbers and solid-sawn structural lumber. There are three size classifications for wood products that are commonly found in historic structures:

- Boards – less than 2 inches in nominal thickness (before the board is planed to provide a smooth surface). **Boards are non-structural and are not included in this grading protocol**.

- Dimension lumber – 2 to 4 inches in nominal thickness and 2 or more inches wide. **Dimension lumber up to 4 inches in width is considered light framing or structural light framing and is not included in the grading protocol.** Dimension lumber greater than 4 inches in width is considered Structural Joists and Planks.

- Timbers – 5 or more inches in nominal least dimension.

The classifications of structural lumber are, generally, graded using visual criteria, which is the sorting of lumber into specific categories based on characteristics such as knots, slope of grain, wane, and other characteristics. The characteristics most important to historic structures are defined and discussed in more detail in the section entitled "Field Data Required for Use of the Grading Protocol".

For new lumber and timbers, a trained lumber grader examines a piece and quickly assesses its characteristics, either during or after production. The characteristics examined include:

- Checks
- Grain
- Knots
- Manufacture
- Pitch and pitch streaks
- Bark
- Shakes
- Skips

- Slope of grain
- Splits
- Stains
- Unsound wood
- Wane
- Warp

Definitions of these characteristics are provided in the glossary at the end of this report. Measuring these characteristics, the grader examines a piece and determines the appropriate grade for the piece based on limitations specified for a particular grade and application. As an example, the limitations for these characteristics for No. 1 Timbers (SPIB, 2002) are given in Table 1.

Grading of Lumber and Timbers in Historic Structures

Some of the issues associated with assigning structural values to old lumber were first published by Wood (1954). Rather than simply address design stresses, he focused on what many of us do today – he commented on the significance of wood deterioration, moisture and connections. He also addressed re-use of lumber from demolished buildings, a topic that is currently being researched by the U.S. Forest Products Laboratory (Lantz and Falk, 1996; Falk, personal communication). Understanding how recycled lumber behaves is important but that does not address how wood members can be graded in an existing building where the elements have come to behave as a system.

The question of how to properly assign design values to older wood members that did not have a grade stamp (and, therefore, were not within the traditional guidelines of the building codes) became more prominent as historic structures were lost due to poor decisions. Condition assessments of existing buildings, and the decisions that resulted from the assessments, became major factors in preservation and adaptive re-use projects.

The means to grade wood members is well defined but somewhat obscure. In addition to the information given above, several summary reports exist to help the engineer or architect. Shelley (1992) provided some background on the evolution of standards development in the U.S. that focused on how grading standards changed from the early 20th century to the late 20th century. Following procedures spelled out by ASTM, Loferski et al. (1996) described how the mechanical properties of wood members in existing structures could be determined. Similarly, Keenan and Quaile (1982) described how to estimate the load-carrying capacity of structural wood members within extant structures.

Table 1. Characteristics and limitations for lumber meeting the requirements for No. 1 Timbers (SPIB, 2002).

No. 1
[No. 1 Timbers]
Compression wood – prohibited if in readily identifiable and damaging form.
Decay – in knots only
Firm red heart – not limited
Slope of grain – 1 in 11
Holes – medium if well scattered
Knots – sound, firm, encased, and pith knots are permitted in sizes not to exceed the following or equivalent displacement:

Nominal Width of Face	Narrow Face and At Edge of Wide Face[(2)]	Centerline Wide Face	Unsound Knots[(1)]
5″	1-3/4″		1-3/8″
6″	2-1/8″	2-18″	1-5/8″
8″	2-1/2″	2-3/4″	2″
10″	2-3/4″	3-1/2″	2-1/2″
12″	3-1/8″	4-1/4″	2-7/8″
14″	3-3/8″	4-3/4″	3-1/8″
16″	3-1/2″	5″	3-3/8″
18″	3-1/2″	5-1/4″	3-1/2″
20″	3-1/2″	5-1/2″	3-1/2″

(1) In unsound knots as allowed, the decay must be confined to the knot itself and not be in surrounding wood and not penetrate deeper than 1-1/2″.
(2) In timbers of equal faces, knots are permitted throughout as specified for narrow faces regardless of location.

Manufacture – standard E
Pitch, pitch pockets, and pitch streaks – not limited
Pith – not limited
Shakes, checks, and splits – splits not longer than the thickness of the piece; shakes and surface checks not deeper than 1/3 thickness if not dry and 3/8 thickness if dry
Skips – hit or miss dressing
Stain – medium if dry; not limited if ordered green
Wane – to occupy not more than 1/6 width of face and 1/3 length
Warp – very light

Despite these efforts, however, the methodology for determining grades of timbers in historic structures has remained obscure. This problem of assigning grade values to timbers in historic structures so that they comply with existing building code requirements is not unique to the U.S. and can be viewed as an international preservation issue; for example, Yeomans (1999) stated the difficulties of addressing the same problem in the U.K.

FIELD DATA REQUIRED FOR USE OF THE GRADING PROTOCOL

Unfortunately, the wealth of information described above often eludes the practitioner who must make a decision about the structural integrity of a building. It is the goal of this project to provide the means for an engineer to use the current grading rules to make an informed decision about allowable design values for wood members in historic buildings. A simple query-based wood grading database, referred to as the wood grading program, was developed in order to provide engineers with the tools necessary to conduct a basic wood grading assessment for timbers within historic structures. To simplify the field data required as input for the program, only the wood species, member thickness, and width of the structural elements in question need to be determined.

Knots and slope of grain are the most common and most limiting of lumber defects (Cramer et al., 1996). Therefore, the grading program uses just these two factors to determine appropriate grade designation for one of five wood species. Prior to utilization of the wood grading program, therefore, a complete wood condition assessment should be conducted to determine the presence and/or significance of any other grade-limiting defects.

Wood Species

To determine the appropriate species, a sample of each type of structural member under consideration for the grading protocol must be removed and sent for analysis. Generally, the same wood species is used for identical framing members such as joists or rafters, however, species may vary between framing member groups (e.g. the rafters may be southern yellow pine, but the joists may be eastern white pine). Samples can be sent to a number of private consultants for a fee or to a public or government institution such as the U.S. Forest Products Laboratory Center for Wood Anatomy Research that can provide species analysis free of charge.

Samples should be taken from sound wood and should measure a minimum of ¼-inch wide x ¼-inch deep x ½-inch long. The soundness of the wood sample can be determined by rolling it between the fingers; if the wood breaks apart, it should not be submitted and a new sample will need to be taken. To extract a sample, use a sharp knife, craft saw blade, and/or a chisel to make two cuts across the grain of the element. These two cuts should be a minimum of $^{3}/_{16}$-inch deep and ½-inch apart. A specimen can be split out by prying up at one of the incised points with a knife, or if a chisel is used, the edge of the chisel can be placed in one of the cuts and then angled down the grain towards the other cut. A sharp tap with a small hammer should provide enough force to remove a good specimen from the wood member. All samples should be taken from an inconspicuous spot on each wood member, and placed within a labeled bag for accuracy. It should be noted that a variety of species can be used within a single building, so at least one sample should be taken for every structural member type (rafters, joists, columns, etc.) under consideration for application of the wood grading protocol.

Knots and Their Measurement

Knots are generally considered the most significant of the numerous strength-limiting defects occurring in lumber. Three major strength-reducing effects arise from the presence of a knot: part of the board cross-section is reduced as harder, denser, but structurally weaker knotwood takes the place of the regular wood fibers; a stress concentration and subsequent reduction in capacity is induced by the material inhomogeneity of the knot surrounded by the rest of the board, and lastly, the growth pattern of the trunk is disrupted by the branch causing the knot, which results in considerable distortion of the grain angle around the knot (Cramer et al., 1996). This grain angle distortion can allow for the development of tensile stresses perpendicular to the grain and the formation of checks and microfractures as the wood dries (Cramer et al., 1996).

The location of the knot has an impact on member strength. Therefore, within the grading program are three knot size limitations for knots based on the location of the knot. Centerline knots on the wide face of an element have the least impact on grade and therefore have the largest allowable knot size. Edge knots on the wide face generally increase localized tensile stresses, and therefore have smaller knot size limitations. The same holds true for knots on the narrow face of an element. For some smaller elements (2 to 4 inches in thickness), knots on the narrow face are considered to be identical to edge knots on the wide face. While the location of a knot along the length of a bending member (within the middle third of the length or in the outer two-thirds) also affects the performance of a beam, this was not taken into account to provide a level of simplicity to the field measurements. This results in a conservative limitation on knot size for the outer third of beams.

The measurement of knots varies depending upon the species, size and function of the element containing the knot. For example, knot measurement on columns under axial loads is different than knot measurement on beams and joists in bending. The following excerpts and figures provide a guideline for the different methods of knot measurement.

From Western Lumber Grading Rules 05 (Western Woods Product Association, 2005, used courtesy of Western Wood Products Assn.):

> ***210.00 KNOTS***
> *In all Framing lumber 4″ and less in thickness, the size of a knot on a wide face is determined by its average dimension as in a line across the width of the piece. The size of knots on wide faces maybe increased proportionately from the size permitted at the edge to the size permitted at the centerline. Knots appearing on narrow faces are limited to the same displacement as knots specified at edges of wide faces. Knots in Beans and Stringers and Post and Timbers are measured differently than knots in 4″ and thinner material. Examples of these measurement methods are shown in Sections 212.00 and 213.00*

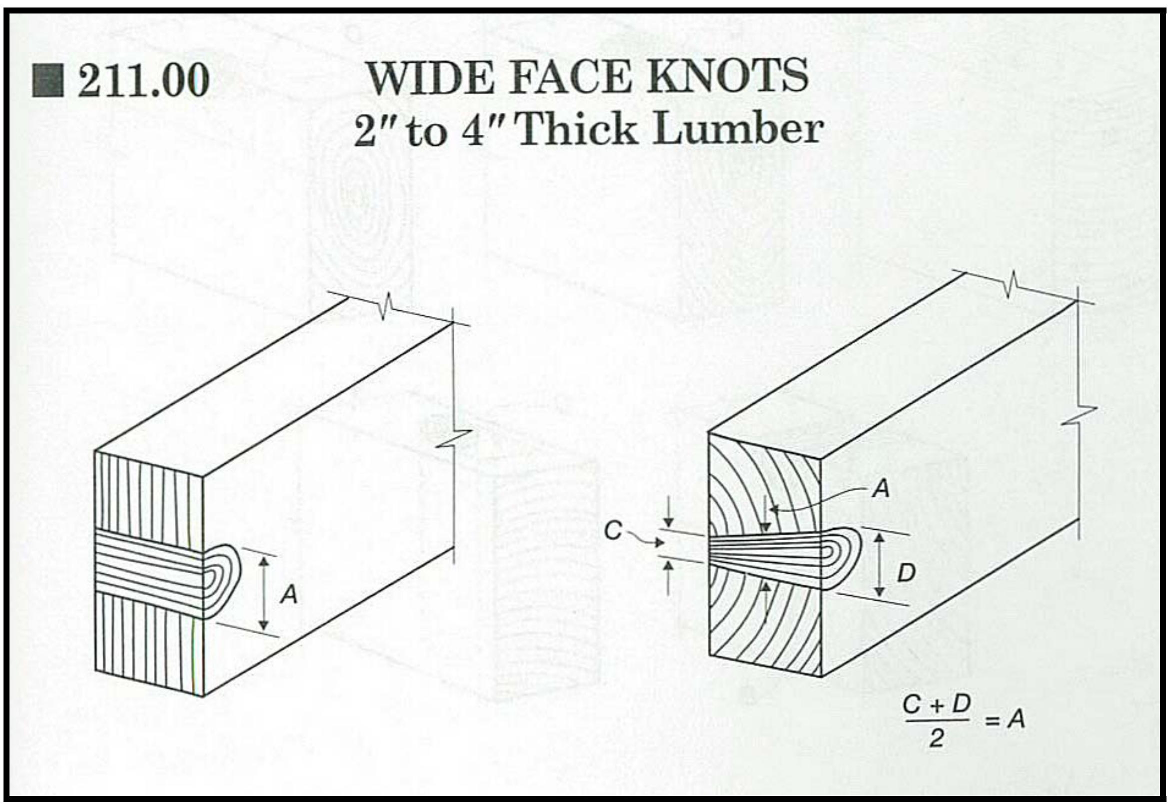


Figure 2. Diagram showing measurement of knots on 2-inch to 4-inch lumber, which includes structural joists and planks (Western Lumber Grading Rules, 2005, used courtesy of Western Wood Products Assn.).

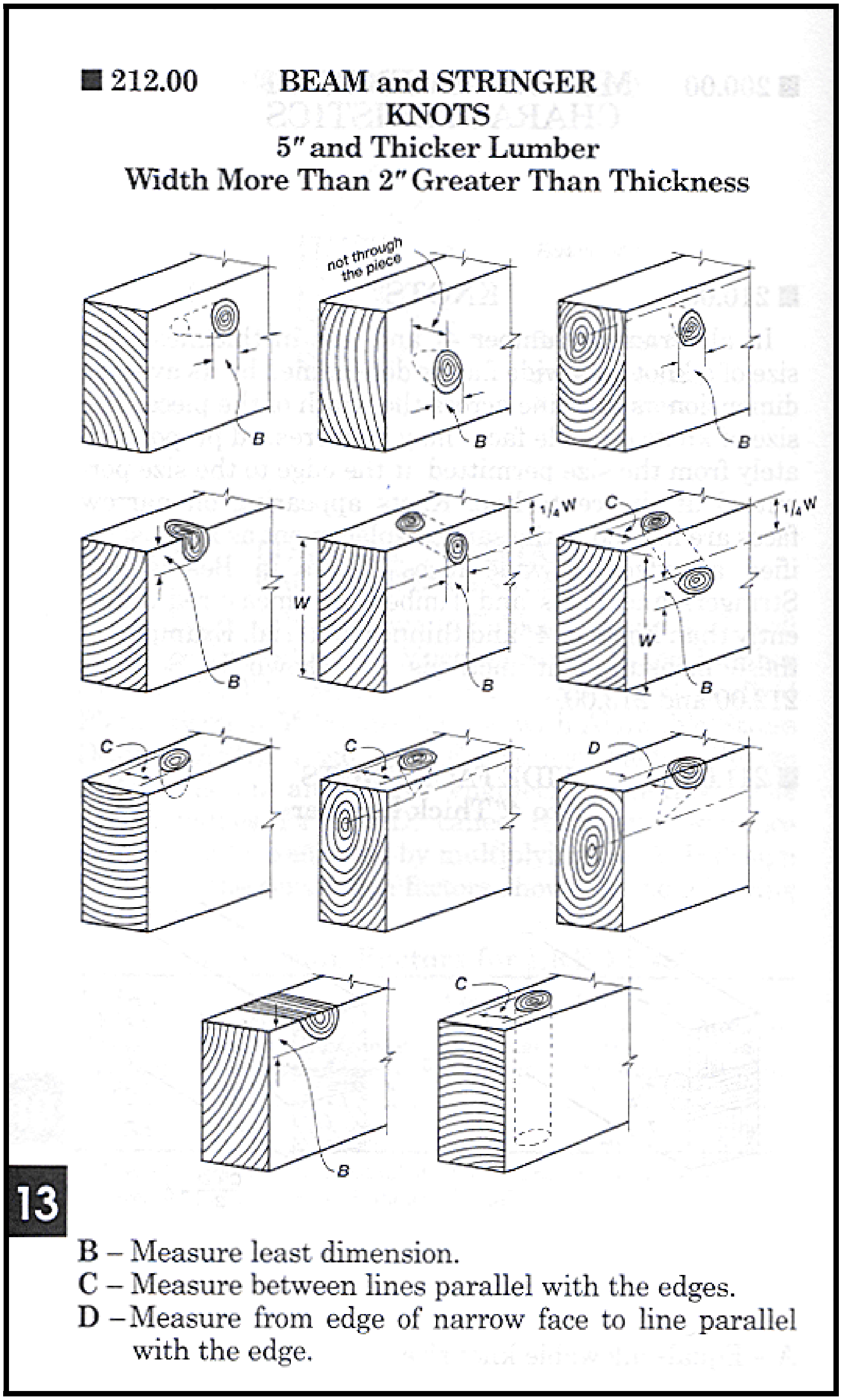
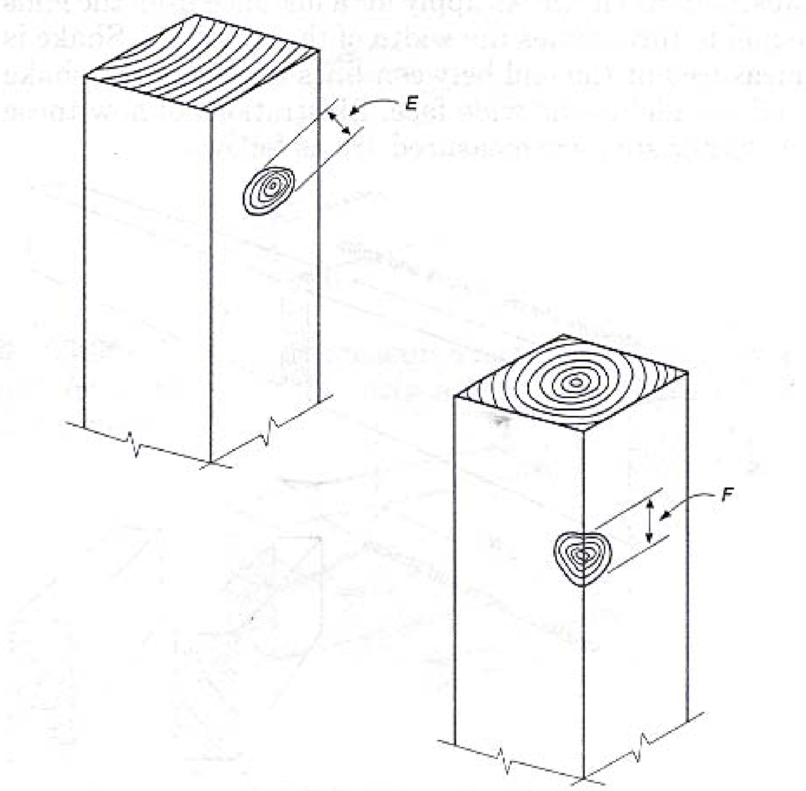


Figure 3. Diagram showing measurement of knots on beams and stringers (Western Lumber Grading Rules, 2005, used courtesy of Western Wood Products Assn.).

■ 213.00 POST and TIMBER KNOTS
5″ x 5″ and Larger Lumber
Width Not More Than 2″ Greater Than Thickness



13

E – Measure least dimension.
F – Measure along corner or measure size most nearly representing diameter of branch causing the knot.

Figure 4. Diagram showing measurement of knots on posts and timbers (Western Lumber Grading Rules, 2005, used courtesy of Western Wood Products Assn.).

Visible knots on lumber or timbers can be measured using an acetate sheet with a ½-inch grid to facilitate measurement (Figure 5). As shown in Figure 2, for structural joists and planks, the size of a knot on the wide face is determined by measuring the knot size on both wide faces and calculating the average knot size through the piece. Knots on the narrow face are assessed in a similar fashion as edge knots on the wide face and are measured with the acetate grid parallel to the long axis of the piece. Knots on larger members are measured differently, as shown in Figures 3 and 4.

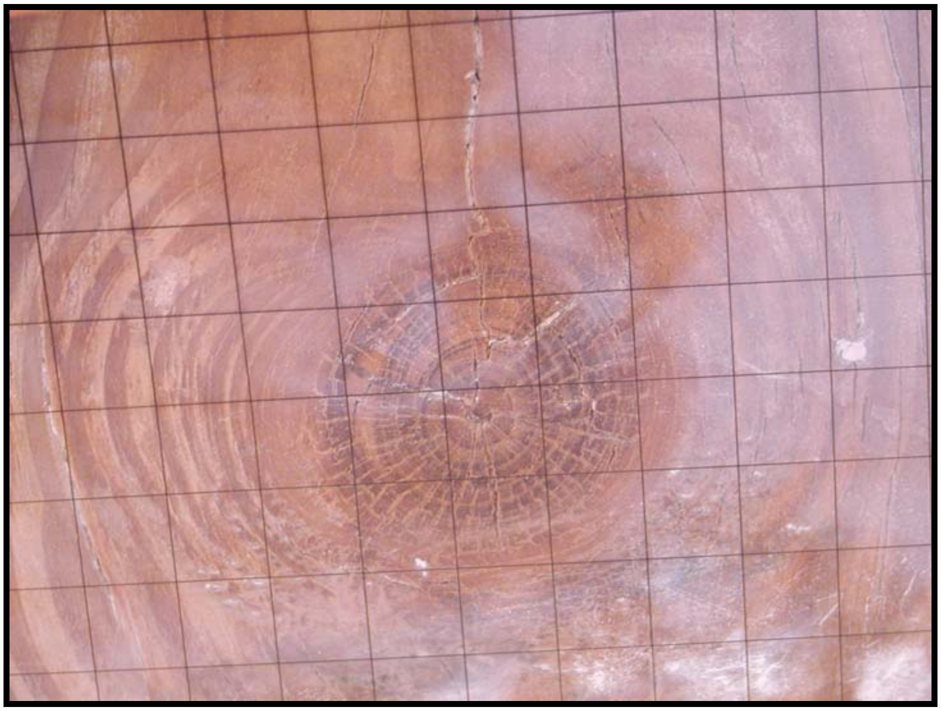


Figure 5. The use of a ½-inch grid on acetate for measuring a knot on a post and timber. This knot is 1-¾ inches in diameter.

For structural joists and planks, and beams and stringers, the grid should be placed parallel to the edge of the timber and the knot dimension measured parallel to the long axis of the timber. For posts and timbers, the grid should be aligned across the narrowest face of the knot and should be measured between parallel lines edge to edge, from the most distinct point of grain deviation. In other words, the acetate grid may not be parallel to the edge of posts and timbers as it is for beams and stringers.

Occasionally, the knot, which is the remnant of a tree branch, has a very distinct boundary, but this is typically not the case, and the measurement is subjective. Because of the firmness of knots (due to denser wood than that surrounding the knot), differential drying of dense knotwood often causes knots to become raised from the normal surface of a timber; hence, knots on painted timbers often “telegraph” through the painted surfaces and are visible for measurement. Also, radial checks may be useful in defining the knot boundary as they will not extend into the surrounding wood.

Slope of Grain and Its Measurement

One reason knots have such impact on the strength capacity of a timber is because of the distorted grain angle that occurs as the tree grows around the branch. When logs are milled into lumber, the areas of distorted grain can be cut so that segments of grain “run out” at one or several locations along a board’s length rather than extend parallel along the entire length of the board. The same effect can occur if the board is milled at an angle that is not parallel to the grain, or if the entire log is twisted due to spiral growth patterns in the tree. Areas of cross grain, or where the grain runs out, create deviations in the way stresses are transmitted throughout the piece and concentrate stresses where the wood fibers have been discontinued and significantly weaken the element.

Slope of grain is generally measured as a ratio of rise to run, that is, the number of inches the grain slopes upward or downward within a given distance (generally 8, 10, 12, or 15 inches) that is parallel to the long axis of the member (See Figure 6). As with knots, while the location of slope of grain along the length of a bending member (within the middle third of the length or in the outer two-thirds) also affects the performance of a beam, this was not taken into account to provide a level of simplicity to the field measurements. This again results in a conservative limitation on knot size for the outer third of beams.

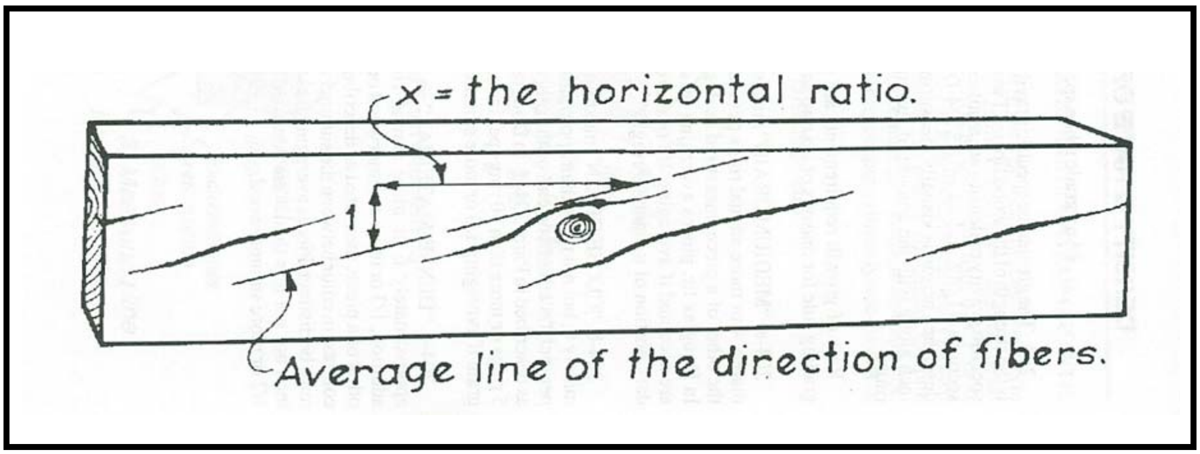


Figure 6. Diagram showing measurement of slope of grain (Western Lumber Grading Rules, 2005, used courtesy of Western Wood Products Assn.).

Typically, slope of grain must extend for 10 inches or more to be considered a grade-limiting defect. Only the most severe slope of grain needs to be checked; however, localized grain deviation around a knot should not be measured to determine slope of grain. To measure slope of grain, a tape measure (Figure 6) or an acetate sheet with a printed ½-inch grid is needed (Figure 7). The length of the area that appears to have significant slope of grain should be measured first from an axis parallel to the long axis of the member. If the length of the slope-of-grain area exceeds 10 inches, then the acetate grid or tape measure can be used to establish the rise over run ratio. To do so, one edge of the acetate grid or the end of the tape must be aligned parallel to the long axis of the member. The total number of inches for the rise can be determined along the vertical axis by counting from the lowest point of the rise to the highest point of the rise (or wherever the grain crosses the edge of the acetate sheet or triangulated from the tape as seen in Figure 6). The total number of inches in the run can be determined along the horizontal axis by measuring with the tape or by counting across from the lowest point of the rise to the highest point of the rise (or wherever the grain crosses the edge of the acetate sheet). This ratio can then be reduced to represent the actual slope of grain over a given length (generally 8, 10, or 12 inches) to determine the appropriate grade.

Figure 7. The use of a ½-inch grid on acetate for measuring slope of grain on a post and timber. This slope of grain is 0.8:10, or approximately 1:12.

Since seasoning (drying) checks in timber generally follow the slope of grain, determining the slope of grain on painted timbers can be achieved relatively easily simply by examining drying checks. All visible faces of the timber should be examined for slope of grain, as not all faces will exhibit the same extent of the slope of grain. While not always conclusive, this approach closely correlates with results achieved using laboratory methods for measuring slope of grain that are not practical for field use.

Seasoning checks, which are separations between wood fibers that do not fully penetrate the width or thickness of a member, are common in structural timbers and rarely affect the performance of a wood member. Splits are separations of wood fibers that extend completely through the width or thickness of a wood member. Short splits typically do not affect the performance of a wood member but long splits should be evaluated by the engineer if there are concerns about shear strength in beams or buckling in columns.

THE WOOD DATABASE GRADING QUERY VERSION 1.0

The grading program is intended for use by engineers or architects when assessing structural adequacy of wood members in historic buildings for their intended or anticipated use. **The wood grading program is just one part of a structural assessment, however. The grading program user must conduct a condition assessment of the wood members as part of the process to determine the presence and significance of other potential grade limiting defects.**

The wood grading program is called the Wood Database Grading Query Version 1.0, but is referred to as the "grading program" in this document. It was developed using Microsoft Access 2003. The directions found below allow you to open the database and query the program for the wood members you wish to investigate. Computers with Microsoft 2003 or later can access the program, although display and security settings may be slightly altered. **The information you will need before you use the program includes the species of the wood members and their dimensions.** Entering this information into the grading program will generate a table that you can use to assign a grade to the wood members. Remember that boards and structural light framing are not included in this program.

Because Microsoft Access 2007 has a number of security requirements that differ from Access 2003, certain steps need to be taken to ensure that the query will function properly. Computers running Microsoft Office 2003 or 2007 will be able to run the program; Computers with Microsoft Office 2000 or any other earlier version of Microsoft will not be able to access this program.

For Microsoft Access 2007 users, the following steps need to be completed prior to opening the database in order for the query to run properly:

1. Open **Microsoft Access**.

2. Click the **Microsoft Office Button** (upper left), and then click **Access Options**.

3. Click the **Trust Center**, and then click **Trust Center Settings**.

4. Click **Macro Settings**.

5. Click **enable all macros (not recommended; potentially dangerous code can run)**, and then click **OK**.

6. Close all windows and close out of Microsoft Access, and then click to open the Wood Grading Database Query.

As long as the database being opened is from a trusted source, enabling all macros will not harm your computer. However, you may want to re-establish the original security settings following utilization of the wood grading program if Microsoft Access is a commonly used program on your computer, as the security settings apply to all databases opened in Access.

As an alternative, you can select "disable all macros with notification". This setting will protect your computer from potentially dangerous code in other Microsoft Access files but will require you to enable the content of the wood grading database every time you run the program (this is accomplished through a security warning options banner that appears on the Terms of Use and Disclaimer screen; see Figure 8).

For Microsoft Access 2003 users, click **OK** for any security warnings and allow/enable all content, and the database query should run properly.
You must enter a password in order to access the program. The password is case-sensitive and is "Guest123". Once the password has been entered, a Terms of Use and Disclaimer Screen will appear.

The program then presents a welcome screen that provides some contact information and additional use information for the wood grading database and accompanying report. By clicking on the "Run Query" button, the user can begin the program.

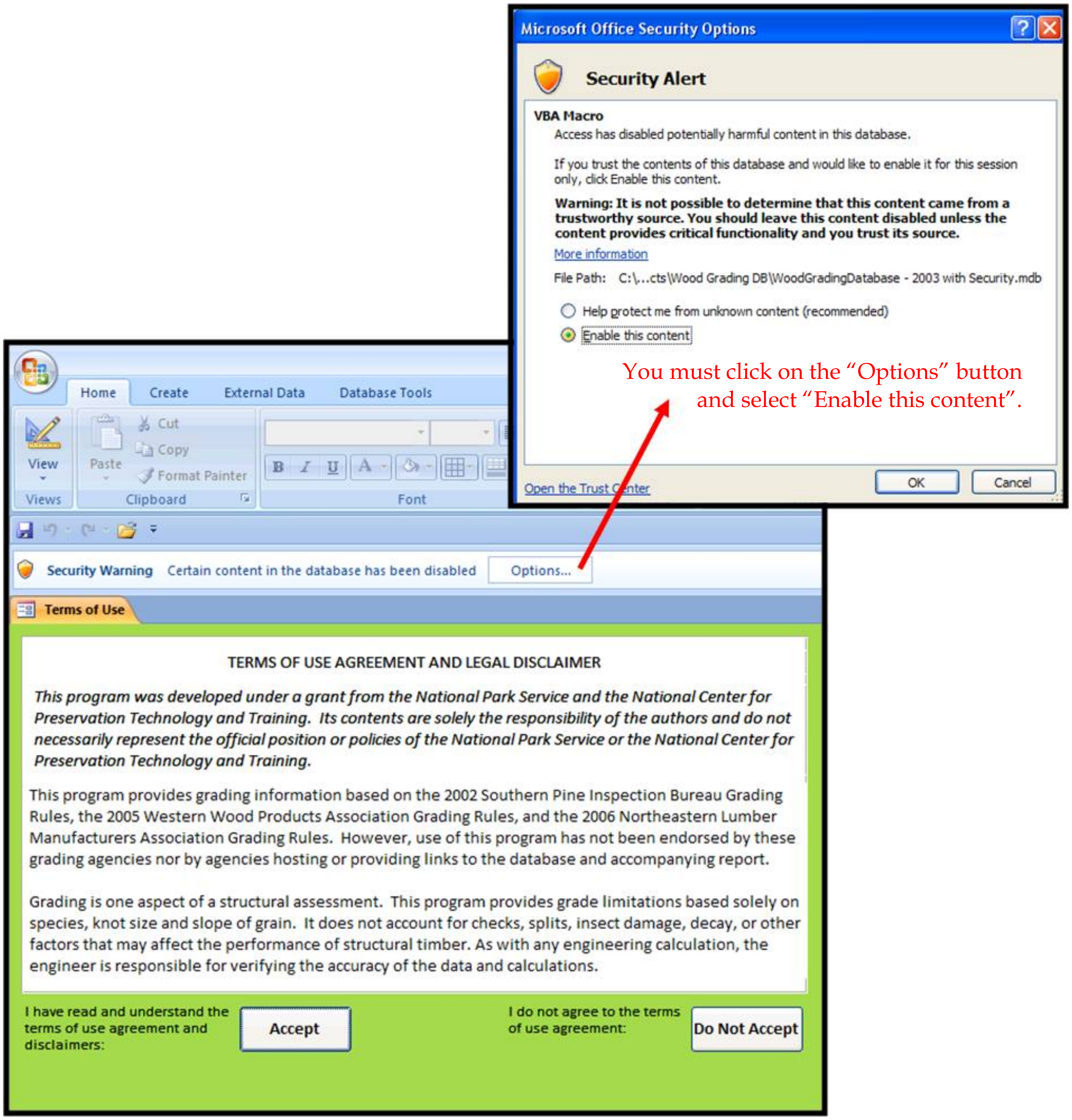


Figure 8. Terms of Use Screen displaying the security warning banner and options screen that will appear if you do not choose to enable all macros.

User Input to the Grading Program

The program first presents a simple, form-type screen to the user (Figure 9). The first program screen has three input boxes that request the user to select a wood species and enter dimensions for the thickness and the width. The dimensions should be actual (not nominal) dimensions and should be rounded to the nearest

0.125-inch. The dimensions must be entered as decimals, and can not include any additional symbols or letters.

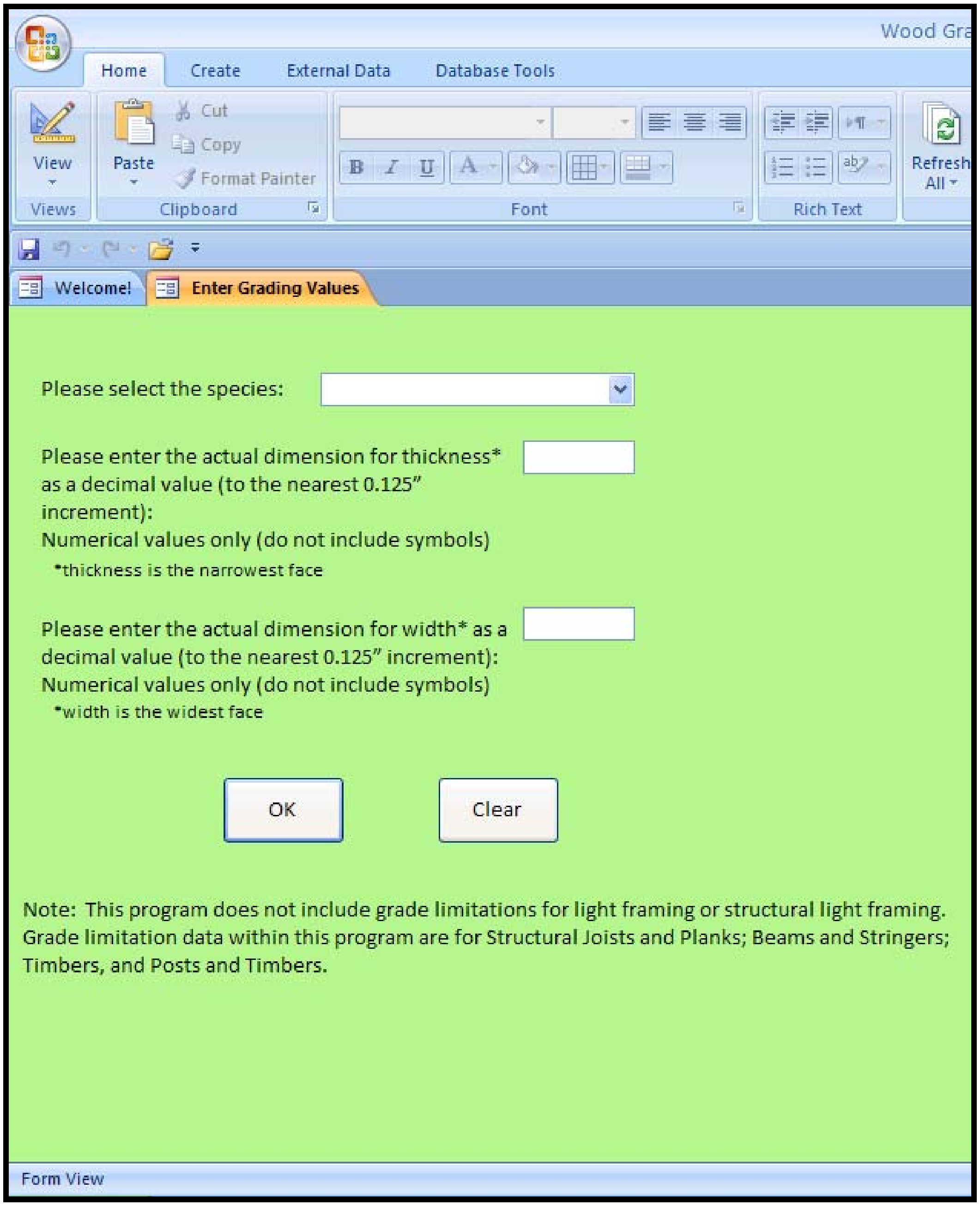


Figure 9. Enter Grading Values Screen.

Once dimensions and species have been entered, a results screen appears (Figure 10) and presents (in table format), four lines of data that include the species group name, the three or four possible grades, the classification type, and the allowable knot sizes and slope of grain for each grade.

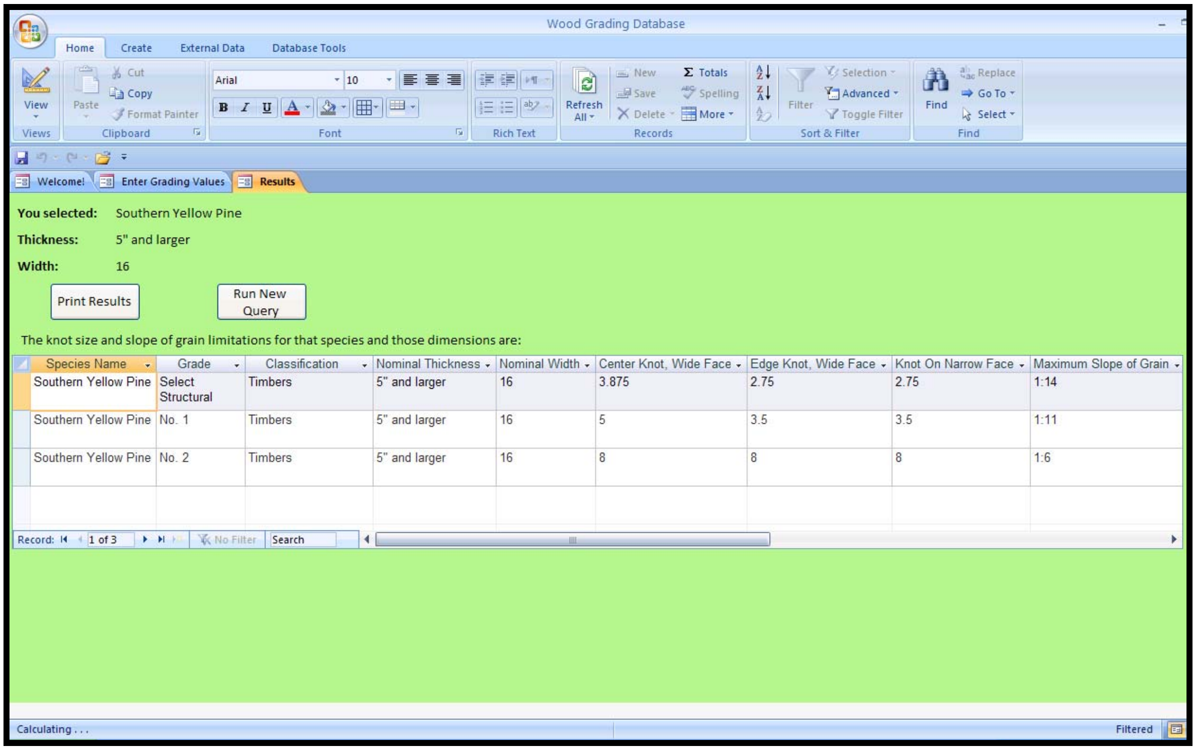


Figure 10. The Results Screen with Data for a southern yellow pine, 8-inch by 15.75-inch Timber.

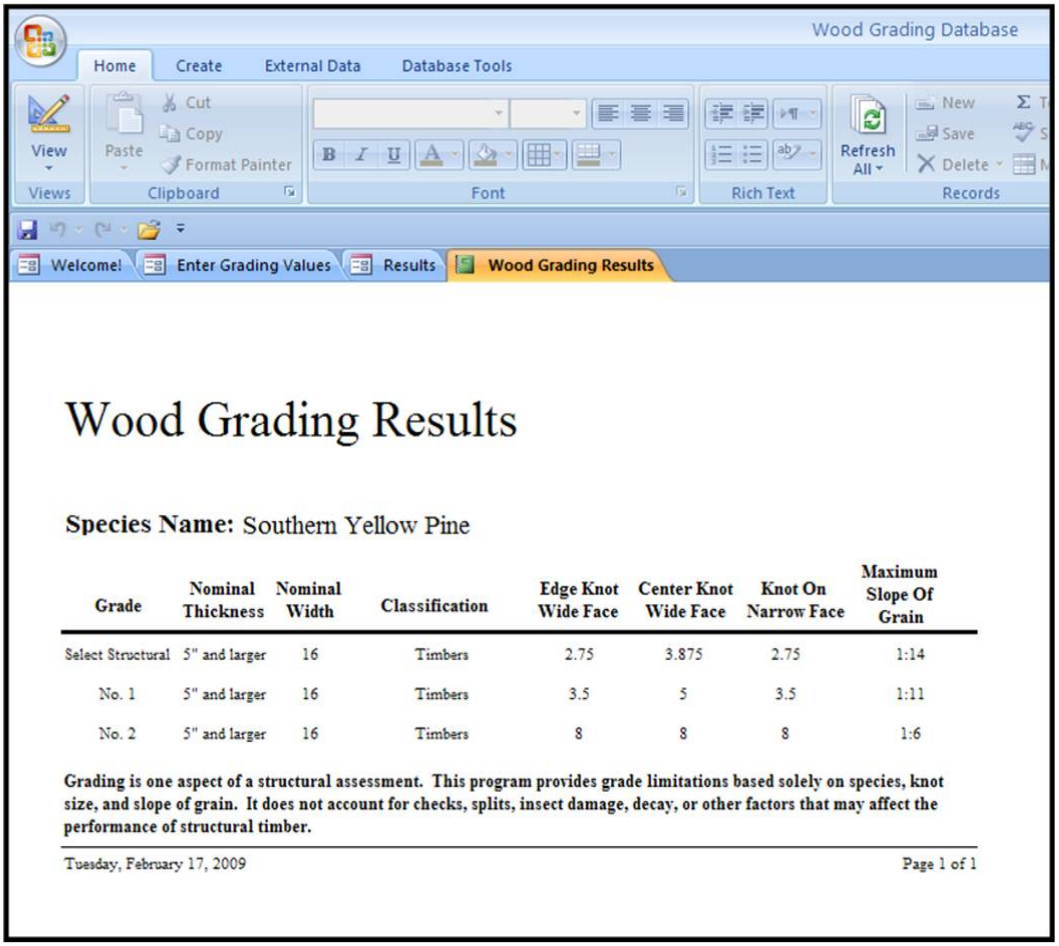
Grading Program Output

By clicking on the "Print Results" button, a single-page report is generated that can be printed for reference or field use (Figure 11).

The grading program functions by determining the appropriate grading limitations based on a set of provided parameters. The dimensions and species are provided by the user, but there are a number of other parameters that are included within the programming. Those parameters, listed below, include:

- Wood species
- Grade
- Nominal Thickness
- Nominal Width
- Classification
- Edge Knots on the Wide Face
- Center Knots on the Wide Face
- Narrow Face Knots
- Maximum Slope of Grain

In order to more fully explain how the grading program functions and the purpose or meaning of some of the results, each of these items are discussed in the following section.



Wood Grading Results

Species Name: Southern Yellow Pine

Grade	Nominal Thickness	Nominal Width	Classification	Edge Knot Wide Face	Center Knot Wide Face	Knot On Narrow Face	Maximum Slope Of Grain
Select Structural	5" and larger	16	Timbers	2.75	3.875	2.75	1:14
No. 1	5" and larger	16	Timbers	3.5	5	3.5	1:11
No. 2	5" and larger	16	Timbers	8	8	8	1:6

Grading is one aspect of a structural assessment. This program provides grade limitations based solely on species, knot size, and slope of grain. It does not account for checks, splits, insect damage, decay, or other factors that may affect the performance of structural timber.

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Figure 11. The Results Report.

Wood Species

The wood species available within the database are:

- Southern Yellow Pine
- Douglas-fir
- Northern Red Oak
- White Oak
- Eastern White Pine

Although there are five species groups, the majority of the included species (Douglas-fir, northern red oak, white oak, and eastern white pine) have identical grading standards and type categories. Southern yellow pine has similar (but not always identical) grading standards but differs in classification. Thus, output data differ slightly depending upon the selected species. These differences can be significant for the resulting grade and allowable design values, however, so the correct species must be established from samples prior to use of the grading program.

Grade

The grade of a piece of wood is determined by a number of factors, most significantly by the knot size and slope of grain. In addition to wood species, these two factors are the only ones included in the grading program. **It cannot be overemphasized that other grade-limiting defects such as splits, checks, damage from insects, and deterioration due to moisture intrusion and/or wood decay fungi can affect the grade of a member. If other grade-limiting defects are present, or are found during the wood condition assessment, this grading program may not provide appropriate results and should not be used for making final decisions about the structural adequacy of wood members**.

In general, wood is considered to have the highest grade (Select Structural) if it is free of knots (or has very small knots) and there is very little slope to the grain (e.g. the grain runs parallel, or nearly so, to the length of the piece). A wood member's grade will be lower with increases in the knot size or slope of grain. There are four grades included within this database. They are:

- Select Structural
- No. 1
- No. 2
- No. 3

It is important to note that the only classification type within this database that uses No.3 grade lumber is Structural Joists and Planks.

Grading Program Output - Thickness

When wood elements are measured in the field, there can sometimes be confusion as to which dimension is the width, and which the thickness. For the grading program, these dimensions are as shown in Figure 12 below.

Thickness is defined here as the narrowest face. The entered dimension for thickness should be an **actual** thickness, while the thickness dimensions in the wood grading program are **nominal** dimensions, meaning that the program rounds up (or down) to place an actual thickness into the appropriate nominal thickness category. Nominal dimensions are not measured (actual) dimensions, but rather are based on the dimensions of the lumber before it has been dried and/or planed or sanded. For example, a 2-inch by 4-inch board does not actually measure 2 inches in thickness and 4 inches in width; it is approximately 1.5 inches by 3.5 inches because the board has been dried and planed since it was first cut, thus reducing its dimensions. The nominal width is 4 inches; the actual width is 3.5 inches. Since dimensions entered into the grading program are **actual** dimensions rather than nominal dimensions, the program makes adjustments to place the entered actual thickness and width into the appropriate nominal size category that corresponds to the National Design Specification for Wood Construction. In order to simplify field measurements and data entry, the actual width should be entered as a decimal in 0.125 inch increments.

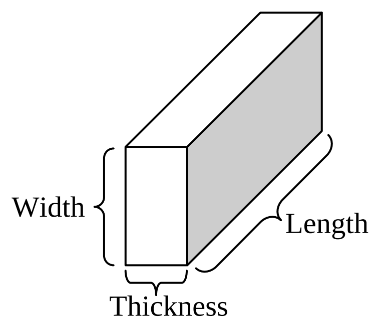

Figure 12. Determining Width and Thickness.

The thickness column within the grading program contains a range of numbers dependent on the type of structural member (classification). **Structural Joists and Planks**, for example, can be anywhere from 2 inches to 4 inches in thickness, and 5 inches or greater in width. Once again, these are nominal dimensions, meaning that the actual size limits for thickness of Structural Joists and Planks are from 1.5 inches to 4.499 inches (the use of decimals is required for the wood grading program). The range of possible nominal size categories for thickness is included in Table 3.

Grading Program Output - Width

As with thickness, the width column within the database contains whole numbers that represent size categories based on **nominal** dimensions. Depending on the member classification, the nominal width may be as high as 24 inches but the minimum nominal width for all classification types can be no less than 5 inches (an actual width of 4.5 inches). See Table 2 for some examples (this is not a complete list of all possible nominal width dimensions within the program).

Table 2. Examples of Nominal Size Categories and Actual Sizes.

Nominal Width Category	Actual Dimensions Included within Nominal Width Category
5″	4.5″ to 5.499″*
6″	5.5″ to 7.499″
8″	7.5″ to 9.499″
10″	9.5″ to 11.499″
12″	11.5″ to 13.499″
14″	13.5″ to 15.499″

*Although given as a decimal to indicate the range of actual dimensions within a nominal width category, what is entered into the database should be in 0.125-inch increments.

Grading Program Output - Classification (Member Type)

There are four structural member types, or classifications, included in the database wood grading program. The nominal dimensions of each classification are given in Table 3. The classifications are:

- Structural Joists and Planks
- Timbers
- Posts and Timbers
- Beams and Stringers

Table 3. Nominal Size Categories by Classification (Member Type).

Classification (Type of Member)	Nominal Thickness Category	Actual Dimensions within Nominal Thickness Category
Structural Joists and Planks	2″ to 4″	1.5″ to 4 .499″
Timbers	5″ and Larger	4.5″ and Larger
Posts and Timbers	5″ and Larger	4.5″ and Larger
Beams and Stringers	5″ and Larger	4.5″ and Larger

Each classification is based on two factors: wood species group and the relationship of width to thickness. Table 4 outlines the relationships in greater detail.

Table 4. Determination of Classification.

Classification	Species Included	Width to Thickness Relationship
Structural Joists and Planks	ALL	None. However, thickness must be between 2″ and 4″
Timbers	Southern Yellow Pine	None. However, width and thickness must be 5″ or greater
Posts and Timbers	Douglas-fir, Northern Red Oak, White Oak, Eastern White Pine	Width can be no more than 2″ greater than thickness
Beams and Stringers	Douglas-fir, Northern Red Oak, White Oak, Eastern White Pine	Width must be more than 2″ greater than thickness

Based on the species and the width to thickness relationship, therefore, the database places the entered (actual dimensions) into the appropriate classification to coincide with the classifications given in the National Design Specification for Wood Construction. For example, if southern yellow pine is selected for the species, regardless of the width to thickness relationship, the database cannot return information on Posts and Timbers, or Beams and Stringers, since the only southern yellow pine classification within the grading program is Timbers. If Douglas-fir is selected as the species and 10.25 inches is entered for the width and 6.5 inches for the thickness, the database automatically places the actual width (10.25″) into the 10–inch nominal size category and the actual thickness (6.5″) into the 5 inches and larger nominal thickness category; however, it also assesses the width to thickness relationship. In this case, the width is more than 2 inches greater than the thickness, and so the database provides information on 10-inch wide Douglas-fir Beams and Stringers.

Grading Program Output - Edge Knot, Wide Face; Center Knot, Wide Face; and Narrow Face Knot Columns

The knot size limitations provided in the Grading Program are the **maximum** allowable knot sizes for each grade. If the measured knots on an element are smaller than the listed knot size, that piece can be assigned the higher grade, provided knot size is the sole grade-limiting defect.

The three columns with knot size information set parameters that determine the grade of the member. Allowable knot size increases as the grade decreases. Each classification has different limits for knot size and may list different knot types (i.e. Edge Knot on the Wide Face, Centerline Knot on the Wide Face, or Narrow Face Knot). For example, there are no data in the Narrow Face Knot column for Structural Joists and Planks because it is assumed that any knots on the narrow face will be treated as edge knots on the wide face. This is due to the limited nominal dimensions (2 inches to 4 inches) for the thickness of elements considered to be Structural Joists and Planks.

Grading Program Output - Maximum Slope of Grain

The slope of grain is a ratio, expressed in inches, of the rise of the grain in comparison to the run. It is expressed in this database as "1:8," for example, or "1:15," which conforms to the style of expression utilized by grading rules and the National Design Specification for Wood Construction (2005). So long as the measured slope of grain of a member is not more than the limit for a given grade, the member can be assigned that grade, provided slope of grain is the sole grade-limiting defect.

SUMMARY

Grading should not be a mystery. Nor should every architect or engineer be expected to be fluent in all of the characteristics of lumber grading in order to make an informed decision. The purpose of this wood grading protocol is not to make every architect or engineer a certified lumber grader but rather to give them a simple tool with sufficient supporting documentation to know whether wood members in a historic building may be sufficient or are structurally deficient.

The need for a simple protocol cannot be overstated. It is likely that nearly all engineers involved in assessment of and modifications to existing structures have encountered a situation similar to the two following examples: A late 19th century cotton mill in South Carolina in the process of being rehabilitated had long-span timber beams. Based on a grade assumption of No. 2 southern pine timbers and existing loads, the beams were found to be in need of reinforcement. Simple visual grading of the beams in place found them to be free of knots and other grade-limiting defects. By today's standards, these beams could be classified as Select Structural, but in fact, they were better than Select Structural because of the lack of defects (since Select Structural allows for knots of a certain size). Using Select Structural design values instead of No. 2 resulted in a 76 percent increase in allowable bending stress, which was sufficient to carry the loads without any retrofit. The cost savings was approximately $1,000,000 to the project.

Similarly, a five-story industrial building in Colorado was found to have a few failed joists. The assumed grade and species dictated that the joists did not have sufficient capacity to carry residential loads, even though the building had served as a warehouse for nearly a century. Grading in place showed that approximately six percent of the joists had large knots or other defects that resulted in grade assignment of No. 3 Douglas-fir to the joists. However, replacement of the few joists with significant knots, splits or slope of grain with higher grade material allowed for use of Select Structural as the grade because the remaining material was primarily defect free. Grading the joists and doing selective replacement saved approximately $900,000 in project costs.

Ultimately, the choice to retain historic fabric and reduce costs for historic preservation projects lies in the hands of the engineer who determines the structural capacity and safety requirements for current or future structure use. The grading protocol is intended to provide architects and engineers with additional tools to make more informed decisions regarding these choices.

BIBLIOGRAPHY AND ADDITIONAL REFERENCES

American Forest & Paper Association and American Wood Council, 2005. *National Design Specification for Wood Construction*, Washington D.C.

American Society for Testing and Materials, Proceedings of Annual Meetings, 1908. 10th Annual Meeting, June 23-27, Atlantic City N.J., ASTM, West Conshohocken, PA.

American Society for Testing and Materials, 2007. *Annual Book of Standards*, Vol. 04.10, D189, Stand Test Methods of Static Tests of Lumber in Structural Sizes; D1990, Standard Practice for Establishing Allowable Properties for Visually-Graded Dimension Lumber from In-Grade Tests of Full-Size Specimens; D4761, Standard Test Methods for Mechanical Properties and Wood-Base Structural Materials; D245, Standard Practice for Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber; D143, Standard Methods of Testing Small Clear Specimens of Timber; D2555, Standard Test Methods for Establishing Clear Wood Strength Values; D2915, Standard Practice for Evaluating Allowable Properties for Grades of Structural Lumber. ASTM, West Conshohocken, PA.

Anthony, R. W., 2004. "Condition Assessment of Timber Using Resistance Drilling and Digital Radioscopy." *APT Bulletin, V*ol. 35, No. 4.

Anthony, R. W., 2007. "Basics of Wood Inspection." *APT Bulletin, V*ol. 37, No. 2-3.

Bert, W.G., J. H. Cumming, J. Foreman and H.L. Fry, 1907. "Strength of Bridge and Trestle Timbers." Proceedings of the Annual Convention of the American International Association of Railway Superintendents of Bridges and Buildings, October 16, 1895, New Orleans, LA, p. 14-63.

Betts, H. S., 1915. "Discussion of the Proposed Forest Service Rules for Grading the Strength of Southern Pine Structural Timbers." 18th Annual Meeting of the American Society for Testing and Material Proceedings, Vol. 15, Pt. 1.

Betts, H. S. and R. K. Helphenstine, Jr., 1920, revised 1933. "How Lumber is Graded." U. S. Department of Agriculture Circular No. 64, 48 p.

Booth, L.G., 1964. "The Strength Testing of Timber during the 17th and 18th Centuries." *Journal of the Institute of Wood Science*. Vol. 3, No. 13.

Cline, McGarvey and A. L. Heim, 1912. "Tests of Structural Timbers." U. S. Department of Agriculture, Forest Service Bulletin No. 108, Forest Products Laboratory Series, 123 p.

Cramer, S., Y. Shi, and K. McDonald, 1996. "Fracture Modeling of Lumber Containing Multiple Knots." Gopu, Vijaya K.A., ed. *Proceedings of the International Wood Engineering Conference 1996,* October 28-31; New Orleans, LA. Baton Rouge, LA: Louisiana State University: Vol. 4: 288-294. Electronic document, http://www.fpl.fs.fed.us/documnts/pdf1996/crame96b.pdf, accessed July 10, 2008.

Green, D. W. and R. Hernandez, 1998. "Standards for Structural Wood Products and Their Use in the United States." *Journal of Contemporary Wood Engineering*, Vol. 9, No.3.

Green, D. W. and J. W. Evans, 2001. *Evolution of Standardized Procedures for Adjusting Lumber Properties for Change in Moisture Content*. U. S. Department of Agriculture, Forest Products Laboratory General Technical Report FPL-GTR-127. Electronic document, http://www.fpl.fs.fed.us/documnts/fplgtr/fplgtr127.pdf, accessed July 9, 2008.

Hatt, W. K., 1904. "Progress Report on the Strength of Structural Timber." U. S. Department of Agriculture, Bureau of Forestry Circular No. 32, 28 p.

Hatt, W. K., 1905. "Instructions to Engineers of Timber Tests." U. S. Department of Agriculture, Bureau of Forestry Circular No. 38.

Ivory, E. P., D. G. White and A. T. Upson, 1923. "Standard Specifications for Yard Lumber." Circular 296, U. S. Department of Agriculture Forest Service, Forest Products Lab, Madison, WI.

Keenan, F. J. and A. T. Quaile, 1982. "Chapter 4 Evaluation." In *Evaluation, Maintenance and Upgrading of Wood Structures, A Guide and Commentary*, Alan Freas, Chairman, American Society of Civil Engineers, New York, p. 159-193.

Lantz, S. F. and R. H. Falk, 1996. "Feasibility of Recycling Timber from Military Industrial Buildings." In *The Use of Recycled Wood and Paper in Building Applications,* Proceedings No. 7286 of the Forest Products Society in Cooperation with the National Association of Home Builders Research Center, the American Forest & Paper Association, The Center for Resourceful Building Technology, and Environmental Building New, Madison, WI, September 1996, p. 41-48.

Loferski, J. R., J. D. Dolan and E. Lang, 1996. "Determining Mechanical Properties by Nondestructive Evaluation and Testing Methods in Wood Buildings." In *Standards for Preservation and Rehabilitation,* Stephen J. Kelley, Editor, ASTM, West Conshohocken, p. 175-185.

Markwardt, L. J. and T. R. C. Wilson, 1935. "Strength and Related Properties of Wood Grown in the United States." U. S. Department of Agriculture, Technical Bulletin No. 479, 108 p.

National Institute of Standards and Technology, 1970. *Voluntary Product Standard PS20-70 American Softwood Lumber Standard.* U.S. Department of Commerce, Gaithersburg, MD.

National Lumber Manufacturers Association, 1944. *National Design Specification for Stress-Grade Lumber and Its Fastenings*. AIA File No. 19-B-1, Washington D.C., 64 p.

Newlin, J.A. and R.P.S. Johnson, 1923. "Basic Grading Rules and Working Stresses for Structural Timbers." Circular 295, U. S. Department of Agriculture Forest Service, Forest Products Lab, Madison, WI.

Northeastern Lumber Manufacturers Association, 1998. *Standard Grading Rules.* Cumberland Center, ME.

Roth, F. and B. E. Fernow, 1895. "Timber: An Elementary Discussion of the Characteristics and Properties of Wood." U. S. Department of Agriculture, Division of Forestry, Bulletin No. 10, 88 p.

Sganzin, M. I., 1828. *An Elementary Course of Civil Engineering* (Translated from the French), 2nd edition, Hillard, Gray, Little, and Wilkins, Boston, MA.

Shelley, B. E., 1992. "Evolutionary Standards Development." In *Wood Products for Engineered Structures: Issues Affecting Growth and Acceptance of Engineered Wood Products*, Proceedings No. 47329 of the Forest Products Society, November 11-13, 1992, p. 87-92.

Southern Pine Inspection Bureau, 2002. *Standard Grading Rules for Southern Pine Lumber*, Pensacola, FL.

Smulski, S. (Ed.), 1997, *Engineered Wood Products: A Guide for Specifiers, Designers, and Users*. PFS Research Foundation, Madison, WI.

Talbot, Arthur N., 1909. "Tests of Timber Beams." University of Illinois Engineering Experiment Station, Bulletin No. 41, Urbana, IL, 80 p. Electronic document, https://www.ideals.uiuc.edu/bitstream/2142/4144/3/engineeringexperv00000i00041.pdf, accessed July 1, 2008.

Wilson, T. R. C., 1934. "Guide to the Grading of Structural Timbers and the Determination of Working Stresses." U. S. Department of Agriculture, Miscellaneous Publication No. 185, 27 p.

Western Wood Products Association, 2005. *Western Lumber Grading Rules*, Portland, OR.

Wood, L. W., 1954. "Structural Values in Old Lumber." In *Southern Lumberman*, December 15, 1954.

Woolson, I H., E. H. Brown, W. K. Hatt, A. Kahn, R.P. Miller, J. A. Newlin, and J. R. Worcester, 1926. "Recommended Building Code Requirements for Working Stresses in Building Materials." U.S. Department of Commerce, Bureau of Standards, Elimination of Waste Series, 53 p.

Yeomans, D. T., 1999. "The Problems of Assessing Historic Timber Strength Using Modern Design Codes." In *The Use and Need for Preservation Standards in Architectural Conservation,* Lauren B. Sickels-Taves, Editor, ASTM, West Conshohocken, PA, p. 119-127.

GLOSSARY[1]

Checks – A separation of the wood normally occurring across or through the rings of annual growth and usually as a result of seasoning.

Grain – The fibers in wood and their direction, size, arrangement, appearance or quality.

Knots – A portion of a branch or limb that has become incorporated in a piece of lumber. In lumber, knots are classified as to form, size, quality and occurrence.

Pitch – An accumulation of resinous material.

Pitch streaks – A well-defined accumulation of pitch in the wood cells in a streak.

Shake – A lengthwise separation of the wood which occurs between or through the rings of annual growth.

Skips - Areas on a piece that failed to surface clean.

Slope of grain - The deviation of the line of fibers from a straight line parallel to the sides of the piece.

Split – A separation of the wood through the piece to the opposite surface or to an adjoining surface due to the tearing apart of the wood cells.

Stain - A marked variation from the natural color.

Unsound wood (decay) - A disintegration of the wood substance due to action of wood-destroying fungi, also known as dote or rot.

Wane – Bark or lack of wood from any cause, except eased edges, on the edge or corner of a piece of lumber.

Warp – Any deviation from a true or plane surface, including bow, crook, cup, and twist or any combination thereof.

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[1] All definitions taken from *Western Lumber Grading Rules 98*