CHAPTER 1

TIMBER CONSTRUCTION

1.1 INTRODUCTION

The American Institute of Timber Construction (AITC) has developed this *Timber Construction Manual* to provide up-to-date technical information and recommendations on engineered timber construction. Topics of the first chapter include materials, structural systems, economy, permanence, seasoning, handling, storage, and erection. With an understanding of these topics, the designer can more effectively utilize the advantages of wood construction. Specific design information and recommendations are covered in subsequent chapters, with accompanying design examples. Supplementary information is provided in appendices.

1.2 MATERIALS

This manual applies primarily to two types of wood materials—sawn lumber and structural glued laminated timber (glulam). Sawn lumber is the product of lumber mills and is produced from many species. Glued laminated timbers are produced in laminating plants by adhesively bonding dry lumber, normally of 2-in. or 1-in. nominal thickness, under controlled conditions of temperature and pressure. Members with a wide variety of sizes, shapes, and lengths can be produced having superior strength, stiffness, and appearance. In addition, heavy timber decking, structural panels, and round timbers are also discussed.

1.2.1 Lumber

In its natural state, wood has limited structural usefulness, so it must be converted to a structural form that is compatible with construction needs. The most common structural wood material is sawn lumber. Sawn lumber is also the primary component of structural glued laminated timber. This section will discuss common growth characteristics of wood and their effects on the properties of structural lumber. It will also discuss common grading systems for lumber.

1.2.1.1 Lumber Grading As it is sawn from a log, lumber is quite variable in its mechanical properties. Individual pieces may differ in strength by as much as several hundred percent. For simplicity and economy in use, pieces of lumber of similar quality are classified into various structural grades. The structural properties of a particular grade depend on the sorting criteria used, species or species group, and other factors.

Rules for determining lumber grades are written by rules writing agencies authorized by the American Lumber Standards Committee (ALSC) [1]. Four such agencies are the Southern Pine Inspection Bureau (SPIB) [2], the West Coast Lumber Inspection Bureau (WCLIB) [3], the Western Wood Products Association (WWPA) [4], and the National Lumber Grades Authority (NLGA) [5]. Lumber grading is also certified by agencies authorized by the American Lumber Standards Committee. Generally, the designer of timber structures is not charged with grading but instead with selecting commercially available grades that meet necessary structural requirements.

Lumber rules writing agencies also establish design values and adjustment factors for each grade. Design values provided by the agencies are published in the *National Design Specification*® (*NDS*®) [6]. These values and factors are generally accepted by model and/or local building codes but are occasionally adopted with amendments particular to the jurisdiction.

Grading is accomplished by sorting pieces according to visually observable characteristics (visual grading) or according to measurable mechanical properties and visual characteristics (mechanical grading). Both grading methods relate key lumber characteristics to expected strength.

1.2.1.2 Characteristics Affecting Structural Lumber Quality Within any given species of wood, several natural growth characteristics observed in structural lumber are important for the determination of quality of the material and the assignment of design values. The main characteristics of concern include: specific gravity, knots, slope of grain, and modulus of elasticity. Other important characteristics include reaction wood, juvenile (pith-associated) wood, and compression breaks. Lumber grading rules regulate these characteristics based on the effect they have on the strength of a piece.

1.2.1.2.1 Specific Gravity Specific gravity is a good index for strength and stiffness of clear wood (free of knots and other strength-reducing characteristics). As the specific gravity of wood increases, so do its mechanical properties (strength and stiffness). The specific gravity of certain species of lumber can be estimated by the amount of latewood in the piece. Because latewood is typically more dense than earlywood, higher proportions of latewood equate to higher specific gravities. This relationship is commonly used in grade rules for structural lumber. Visual grading rules classify lumber according to growth ring measurements as having dense, medium, or coarse grain based on the width of the rings and on the proportion of latewood present. Mechanical grading systems may use weight or calibrated x-ray machines to determine specific gravity.

1.2.1.2.2 Knots A knot is formed by sawing through a portion of the tree trunk that formed around a branch. Knots are considered as defects in structural lumber. The presence of a knot disrupts the longitudinal orientation of the wood fibers as they deviate around the knot. A knot may be intergrown with the surrounding wood or encased by the surrounding wood without intergrown fibers. The latter type of knot is called a *loose knot* and often falls out, leaving a knothole. Both types of knots reduce the capacity and stiffness of a structural member, particularly in tension. Grade rules typically restrict the size, location, and frequency of knots, knot clusters, and knot holes allowed by each grade.

1.2.1.2.3 Slope of Grain It is generally desirable to have the longitudinal axis of the wood cells line up with the longitudinal axis of the structural member. However, irregularities in growth and various methods of sawing employed in the manufacture of structural lumber invariably result in a grain at some angle to the longitudinal axis of the member. Because wood is orthotropic, wood is not as strong to resist loads at angles to the grain as for loads parallel to the grain. Consequently, lumber grading rules typically restrict the general slope of grain allowed in any particular grade. Additionally, high-grade tension laminations used in structural glued laminated timber restrict the amount of localized grain deviations, such as those caused by a knot.

1.2.1.2.4 Modulus of Elasticity In structural lumber, a correlation has been observed between stiffness and other properties. Increases in modulus of elasticity are correlated with increases in specific gravity and strength and with decreases in slope of grain. The correlation between stiffness and strength forms the basis for most common mechanical grading systems, which sort pieces by stiffness.

1.2.1.2.5 Other Characteristics Reaction wood, timber breaks, juvenile wood, and decay each negatively affect the mechanical and physical properties of structural lumber. They are, therefore, limited or excluded by lumber grade rules.

1.2.1.3 Grading Systems Visual grading systems employ trained inspectors to look at each side of a piece of lumber and assign an appropriate grade based on the observed characteristics in the piece. Mechanical grading systems use some sort of device to measure properties not apparently visible, such as density or modulus of elasticity (in addition to visual inspection), to assign grades. Mechanical grading systems may also require random testing of pieces to ensure that the assigned strength and stiffness values are met and maintained over time.

Three main lumber products are produced from mechanical grading systems in the United States: machine stress rated (MSR) lumber, mechanically evaluated lumber (MEL), and E-rated lumber. Pieces graded under the MSR and MEL systems are generally used as individual pieces and are consequently assigned design values. E-rating is used primarily for laminating lumber, and design values for individual pieces are not available. Although mechanical grading is increasing in popularity, visual grading remains the most common grading method employed for structural lumber.

1.2.2 Structural Glued Laminated Timber

The term *structural glued laminated timber* refers to an engineered, stress-rated product of a timber laminating plant comprising assemblies of suitably selected and prepared wood laminations bonded together with adhesives. The grain of all laminations is approximately parallel longitudinally. Individual laminations generally do not exceed 2 in. net thickness. Individual lumber pieces may be joined end-to-end to produce laminated timbers much longer than the laminating stock itself. Pieces may also be placed or glued edge to edge to make timbers wider than the input lumber. As such, glued laminated timbers (glulam) may be made to almost any size; however, shipping considerations generally limit the size of glulam normally produced. Glued laminated timbers may also be manufactured into curved shapes, adding to their appeal for use as architectural elements.

Glulam can be custom manufactured for special applications requiring highly specific members with features such as large sizes, taper, curvature, or special fabrication. The versatility of these custom glulam products allows the designer to maximize creativity. Manufacturers specializing in custom glulam often provide engineering for these applications.

Other manufacturers specialize in producing high volumes of straight (or mildly cambered) glulam stock members in commonly used layups and sizes. Long-length stock members are typically sent to distribution yards, where they are held in inventory and cut to length as needed for immediate availability to builders for use as beams and columns. Manufacturers of these “stock” products generally do not offer engineering services.

The AITC quality mark on a structural glued laminated timber member ensures that the member was manufactured in a facility with strict quality control measures in place. AITC-certified laminators meet the highest quality standards of the industry. AITC-certified glulam is available and accepted throughout the United States. Consequently, engineers and architects may readily specify AITC-certified stock or custom members with high assurance of structural quality and reasonable availability and affordability.

1.2.2.1 Benefits of Glulam Structural glued laminated timber marries the traditional warmth and beauty of wood with modern engineering to create a beautiful material with outstanding structural properties. Some of the benefits of structural glued laminated timber are listed as follows:

- *Environmentally friendly*. Wood is a naturally renewable resource. The wood products industry is committed to sustainable forestry practices. Processing logs to make lumber and glulam uses very little energy, reducing the use of fossil fuels and pollution of our atmosphere. Glulam technology also uses small dimension lumber to make large structural timbers, utilizing logs from second- and third-growth forests and timber plantations. Glulam's efficient use of the highest-quality lumber only where stresses are critical further reduces demand on precious lumber resources.
- *Beautiful*. The natural beauty of wood is unsurpassed. Exposed glulam timbers provide structures with a warmth and beauty unrivaled by other building materials.
- *Strong and stiff.* Glulam's superior strength and stiffness permit larger rooms with fewer columns. Pound for pound, glulam beams are stronger than steel.
- *Dimensionally stable*. Glulam is manufactured from small dimension lumber that is dried prior to laminating. This translates to less checking, warp, and twist than traditional sawn timbers.
- *Durable*. When properly designed to keep the wood dry, glued laminated timbers will last indefinitely. In situations where it is not possible to keep the wood dry, pressure preservative-treated wood or heartwood of a naturally durable species can be used to maximize the service life of the structure. The adhesives used in glulam are waterproof to ensure long life. Wood is also very resistant to most chemicals.
- *Fire resistant*. Structural glued laminated timber has excellent fire performance. Building codes recognize fire ratings of up to one or two hours for properly designed, exposed glulam members. Glued laminated timbers can also be used to meet the Heavy Timber Construction requirements in the building codes.
- *Versatile*. Structural glued laminated timber can be manufactured in a variety of shapes, from straight beams to graceful, curved arches. Sizes of individual members are limited only by shipping capabilities. Components for large assemblies can be fabricated in a plant, transported long distances, and reassembled at the job site.
- *Simple*. Design steps are similar to those for solid sawn lumber and timbers. The structural glued laminated timber industry has adopted a stress classification system to simplify the specification of glued laminated timbers.
- *Cost-effective*. The beauty of glulam framing systems allows structures to be designed and built without costly false ceilings to cover structural components. Installation is fast and easy, reducing costs at the job site. High strength and stiffness permit the use of smaller members for additional cost savings.

- *Dependable*. Glued laminated timbers have been used successfully in the United States for more than 75 years. In Europe, glulam has been used successfully for more than 100 years. AITC's quality program ensures consistent, reliable product performance by inspecting all stages of production for conformance with recognized industry standards.

1.2.2.2 Layup Principles Lumber quality varies significantly within any particular lumber resource. High-quality lumber is more scarce and costly than low-quality lumber. The laminating process offers the manufacturer the unique benefit of placing the best lumber only where stresses are critical and using lower grades of lumber elsewhere. For glulam beams, the highest grades of lumber are typically placed near the top and bottom of the member. This placement makes optimum use of the high strength and stiffness material to resist bending and deflection. Laminated timbers intended primarily to resist uniform axial loads or bending loads about the weak axis are manufactured using the same grade of lumber throughout the cross section. The former type of layup is referred to as an *optimized layup*, while the latter is simply called a *uniform-grade layup*.

Optimized layups are further divided into two categories: *balanced* and *unbalanced* (Figure 1.2.2.2-1). Balanced layups have the same grades of lumber in the top half of the beam as in the bottom half. The two halves are mirror images of each other. Unbalanced beams use higher grades in the bottom half than in the top half. Balanced beams are typically used for continuous-span and cantilevered applications. Unbalanced beams are more efficient for simple spans. Unbalanced beams can also accommodate short cantilevers (up to about 20% of the main span) efficiently.

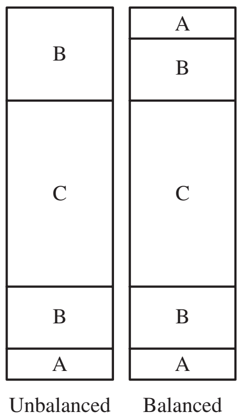

Figure 1.2.2.2-1 Unbalanced layups vs. balanced layups: A, B, and C represent lumber grades, with A representing the highest grade in the lay-up.

1.2.2.3 Combination Symbols Structural glued laminated timber layups are assigned a combination symbol for the purposes of design and specification. The layup requirements for common glulam combinations are provided in AITC 117 [7], Tables B1 and B2. Design values for these combinations are provided in Tables A1-Expanded and A2 of AITC 117 [7] and in Tables 5A-Expanded and 5B of the NDS® Supplement [6].

1.2.2.4 Stress Classes To facilitate selection and specification, similar optimized beam combinations are grouped into stress classes. Designing and specifying with the stress class system simplifies the process for the designer and allows the manufacturer to produce the most efficient combination for his resource that meets the stress class requirements. Design values for the stress classes are shown in Table 5A of AITC 117 [7] and Table 5A of the NDS® Supplement [6]. It is important to note that each layup combination corresponds either to a balanced or unbalanced layup whereas the stress classes do not. Therefore, it is necessary when specifying glulam by stress class to clearly indicate where balanced layups are required.

1.2.2.5 Manufacturing Process Although laminating is a simple concept, the production of modern structural glued laminated timber according to required standards is a complex process. Lumber grades and moisture content are strictly controlled and adhesives must meet rigorous performance requirements. Laminations are machined within precise tolerances and kept clean for bonding. Bonded end joints and face joints are tested daily to ensure that strength and durability requirements are maintained. Code-compliant laminators are required to implement a continuous quality control system with periodic auditing by an accredited inspection agency, such as AITC. The requirements for glulam manufacturing are detailed in ANSI/AITC A190.1 [8] and AITC 200 [9].

1.2.2.5.1 Face Bonds Laminations are stacked and bonded face-to-face to make deep timbers. Adhesive bonds are subject to initial qualification and subsequent daily tests for both durability and strength. Adhesive joints are required to be essentially as strong as the wood they bond. Because of the bond quality and strength, the designer does not need to account for the presence of bond lines during the design process. Consequently, bolts and other fasteners can be placed indiscriminately with regard to bond lines.

1.2.2.5.2 End Joints End joints are used to make individual laminations of essentially unlimited length and to create whole timbers in lengths far exceeding those possible from sawn timbers. The end joint is the most highly engineered and monitored part of the manufacturing process. A manufacturer's end joint strength is established by an initial qualification process, verified through daily quality control tests, and maintained using statistical process control techniques.

These rigorous quality control measures ensure that the strength of the end joint is sufficient to justify the design strength of the glulam beam in which it will be used. Consequently, the designer does not have to account for the presence of end joints when designing structural glued laminated timber members.

1.2.2.6 Appearance Grades Structural glued laminated timber is manufactured to meet any of four standard appearance grades as well as custom appearance options offered by individual laminators. The standard appearance grades are: framing, industrial, architectural, and premium. Framing grade members are surfaced hit-and-miss only to match standard framing lumber dimensions (i.e., 3.5 inches and 5.5 inches wide). This results in a generally poor appearance that is suitable only for concealed applications. Industrial, architectural, and premium grades require more surfacing and are appropriate for applications where the timbers will be exposed to view. The specific requirements for each grade are listed in AITC 110 *Standard Appearance Grades for Structural Glued Laminated Timber* [10].

1.2.2.7 Quality Assurance The International Building Code [11] requires glulam to be manufactured according to ANSI/AITC A190.1 [8], including periodic auditing by an *accredited inspection agency*. The American Institute of Timber Construction (AITC) is accredited to provide inspection and auditing services for structural glued laminated timber and other engineered wood products. The AITC Inspection Bureau visits AITC-certified producers periodically to verify that each plant is meeting the requirements of ANSI/AITC A190.1 and other relevant AITC standards as well as their own internal quality control and procedures manuals. Plants meeting the rigorous requirements of the standard are licensed to use the AITC quality mark on their production (Figure 1.2.2.7-1), signifying compliance with the standard. Building officials recognize the AITC quality mark as evidence that a laminated timber meets the requirements of the code-recognized manufacturing standard. The AITC quality program is summarized in AITC Technical Note 10 [12].

Figure 1.2.2.7-1 AITC Symbol of Quality®

1.2.2.8 Custom Glulam Products In general, the manufacturing process of structural glued laminated timber allows for the efficient use of wood resources, as well as being able to incorporate custom features such as taper, camber, curvature, special appearance, and so on. Such members are well-suited to custom and specialty applications, such as exposed timber trusses, glulam arches, curved beams, and large members. Long lengths, large dimensions, and high design values make glulam desirable for use in situations requiring long spans and/or supporting heavy loads. These applications generally involve engineering calculations provided by licensed professionals, and are typically specific to the individual structures or projects. Indeed, building codes generally require the load-carrying systems of structures to be engineered.

With custom glulam products, the designer has maximum design flexibility. Members can be produced in a wide range of shapes and sizes to fit the particular application. The choice of glulam combinations is practically unlimited. Many custom laminators also provide engineering services, so they can help throughout the design process.

Even though custom glulam products allow for maximum design flexibility, standard sizes should be used where possible. Standard widths for custom southern pine members are 3 in., 5 in., $6\frac{3}{4}$ in., $8\frac{1}{2}$ in., $10\frac{1}{2}$ in., 12 in., and 14 in. Standard widths for custom Alaska cedar and Douglas fir members are $3\frac{1}{8}$ in., $5\frac{1}{8}$ in., $6\frac{3}{4}$ in., $8\frac{3}{4}$ in., $10\frac{3}{4}$ in., $12\frac{1}{4}$ in., and $14\frac{1}{4}$ in. Wider widths and other species may be available upon consultation with the laminator.

1.2.2.9 Stock Glulam Products For many jobs, the engineer (or architect) may specify off-the-shelf products (stock glulam) that are not necessarily project specific. With other considerations equal, the specification of stock products will generally be more economical and time efficient than specialty or custom products.

The prudent design professional is generally cognizant of what particular products are generally available for particular projects or locations. Throughout the United States, 24F-1.8E unbalanced beams in Douglas fir or southern pine are typically stocked by lumber distributors, with the species dependent on the region. Beams with balanced layups may also be available. In addition to beams, it is common for distributors to carry uniform-grade members for use as columns, with grades and species dependent on the region. In some regions, higher strength members of Douglas fir or southern pine up to 30F-2.1E grade beams may be stocked. Depending on the region, Alaska cedar members or pressure-treated southern pine members may be carried in inventory for use where decay resistance is important.

1.2.2.9.1 Widths Stock glulam products are most commonly available in industrial or architectural appearance grades, with finished widths of $3\frac{1}{8}$ in., $5\frac{1}{8}$ in., and $6\frac{3}{4}$ in. in either Douglas fir or southern pine members. In some regions, however, framing appearance grade beams with finished widths of $3\frac{1}{2}$ in., $5\frac{1}{4}$ in., or $5\frac{1}{2}$ in., and 7 in. or $7\frac{1}{4}$ in. may be stocked.

1.2.2.9.2 Depths Depths of stock members are typically multiples of $1\frac{1}{2}$ in. for Douglas fir and $1\frac{3}{8}$ in. for southern pine. Stock beams are typically made in depths of 30 inches or less.

Glulam beams are also commonly manufactured in *I-joist-compatible* (IJC) depths. IJC beams have depths equal to common wood I-joist depths of $9\frac{1}{2}$ in., $11\frac{7}{8}$ in., 14 in., 16 in., 18 in., 20 in., 22 in., or 24 in. for framing within floor spaces. IJC stock beams are typically manufactured in framing or industrial appearance grades.

1.2.2.9.3 Camber Stock members are generally intended for simple-span use and are manufactured with a single radius of curvature. A typical radius for stock beams is 3500 ft; however, different manufacturers may use different standard radius values. In this regard, the design professional seeking to specify stock products will check the suitability of available curvature (camber) values instead of requiring the manufacture of specific cambers for individual members. The present trend of both manufacturers and designers is that of using flat (straight, no camber) or very shallow camber (large radius of curvature) beams. Such members are more easily framed in the field and are have acceptable deflections in service. Beams that span over interior supports or have cantilevered ends are expected to experience significant flexural tension stresses on both top and bottom, and as such, balanced layups are specified. Stock beams with balanced layups are typically manufactured without camber.

1.2.2.9.4 Nonengineered Construction In addition to *engineered* applications, glulam is finding increased use in *nonengineered* construction. Manufacturers typically publish capacity tables and other information (and some provide software) to assist selection of members for simple framing applications.

Nonengineered construction is particularly applicable to residential construction, a great part of which is prescriptive (*conventional light frame construction*). As a framing member, glulam may be substituted (per building official approval) for sawn or built up sawn lumber joists, rafters, headers, and girders. Table 1.2.2.9.4-1 provides 24F-1.8E stock glulam substitutions in both Douglas fir and southern pine for common sawn lumber sizes (single member or multiple-ply) of No. 2 grade Douglas fir-larch or southern pine. The tabulated glulam sizes are also conservative for No. 2 grade hem-fir and spruce-pine-fir. In addition, maximum spans for 24F-1.8E stock glulam beams subject to various loading configurations are included in the *Wood Frame Construction Manual* [13].

1.2.3 Heavy Timber Decking

The term *heavy timber decking* generally refers to lumber sawn with a single or double tongue-and-groove profile on the narrow edges. Heavy timber decking is typically used to form a structural roof in heavy timber systems, and it can also be used for floors. It typically spans 4 ft to 18 ft between timber beams or purlins forming the structural members and serving as the finished ceiling for the

TABLE 1.2.2.9.4-1 24F-1.8E Glulam Beam Sizes to Replace No. 2 Sawn Lumber

Sawn Lumber Nominal Size	24F-1.8E DF Glulam Size to Replace No. 2 DF-L Lumber	24F-1.8E SP Glulam Size to Replace No. 2 SP Lumber
4×8	$3\frac{1}{8} \times 7\frac{1}{2}$	$3\frac{1}{8} \times 8\frac{1}{4}$
4×10	$3\frac{1}{8} \times 10\frac{1}{2}$	$3\frac{1}{8} \times 9\frac{5}{8}$
4×12	$3\frac{1}{8} \times 12$	$3\frac{1}{8} \times 12\frac{3}{8}$
4×14	$3\frac{1}{8} \times 13\frac{1}{2}$	$3\frac{1}{8} \times 13\frac{3}{4}$
4×16	$3\frac{1}{8} \times 16\frac{1}{2}$	$3 \times 16\frac{1}{2}$
6×8	$5\frac{1}{8} \times 7\frac{1}{2}$	$5\frac{1}{8} \times 6\frac{7}{8}$
6×10	$5\frac{1}{8} \times 9$	$5\frac{1}{8} \times 9\frac{5}{8}$
6×12	$5\frac{1}{8} \times 12$	$5\frac{1}{8} \times 11$
6×14	$5\frac{1}{8} \times 13\frac{1}{2}$	$5\frac{1}{8} \times 12\frac{3}{8}$
6×16	$5\frac{1}{8} \times 15$	$5\frac{1}{8} \times 15\frac{1}{8}$
8×10	$6\frac{3}{4} \times 9$	$6\frac{3}{4} \times 9\frac{5}{8}$
8×12	$6\frac{3}{4} \times 12$	$6\frac{3}{4} \times 11$
8×14	$6\frac{3}{4} \times 13\frac{1}{2}$	$6\frac{3}{4} \times 12\frac{3}{8}$
8×16	$6\frac{3}{4} \times 15$	$6\frac{3}{4} \times 15\frac{1}{8}$
(2) 2×8	$3\frac{1}{8} \times 7\frac{1}{2}$	$3\frac{1}{8} \times 8\frac{1}{4}$
(2) 2×10	$3\frac{1}{8} \times 9$	$3\frac{1}{8} \times 9\frac{5}{8}$
(2) 2×12	$3\frac{1}{8} \times 12$	$3\frac{1}{8} \times 11$
(3) 2×8	$5\frac{1}{8} \times 7\frac{1}{2}$	$5\frac{1}{8} \times 6\frac{7}{8}$
(3) 2×10	$5\frac{1}{8} \times 9$	$5\frac{1}{8} \times 9\frac{5}{8}$
(3) 2×12	$5\frac{1}{8} \times 10\frac{1}{2}$	$5\frac{1}{8} \times 11$
(4) 2×8	$6\frac{3}{4} \times 7\frac{1}{2}$	$6\frac{3}{4} \times 6\frac{7}{8}$
(4) 2×10	$6\frac{3}{4} \times 9$	$6\frac{3}{4} \times 9\frac{5}{8}$
(4) 2×12	$6\frac{3}{4} \times 10\frac{1}{2}$	$6\frac{3}{4} \times 11$

space below. Both sawn decking and laminated decking are available. Typical edge joints for decking are shown in Figure 1.2.3-1.

Information on installation and design of two-inch, three-inch, and four-inch nominal thickness tongue-and-groove heavy timber decking may be found in Chapter 10 and in the *International Building Code* [11]. Lumber rules writing agencies publish design values for sawn timber decking.

Glued laminated decking may be manufactured in longer lengths and greater nominal thicknesses and often has higher design values than similar sawn decking. Size, length, and design information for laminated decking should be obtained from the individual manufacturer.

Decking lengths may be specified and ordered to end over supports, where the boards are assumed to act as shallow beams spanning one or more joist

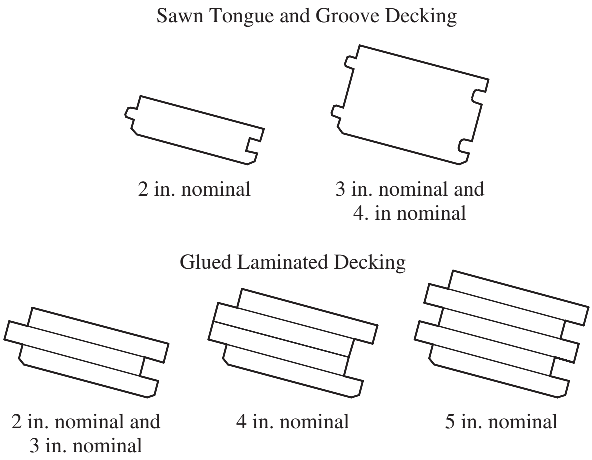

Figure 1.2.3-1 Edge joints for heavy timber decking.

spaces. In many cases, however, it is more economical to specify decking of varied or random lengths. Chapter 10 describes five standard installation patterns for timber decking. Design values for heavy timber decking are established by approved lumber grading agencies. Design values for laminated decking should be obtained from the decking manufacturer.

1.2.4 Structural Panels

Wood structural panels are commonly used for exterior walls and roof surfaces and for floors. Panels with appropriate preservative treatment are sometimes used below grade for wood foundations. Care should be taken to ensure that the selected panels meet the appropriate exposure requirements and satisfy the grade, span rating, and minimum thickness requirements of the local building codes. Structural wood panels should meet the requirements of Voluntary Product Standards PS 1 [14] or PS 2 [15], or those specified by a recognized code evaluation report.

1.2.5 Round Timbers

Modern timber construction most commonly uses members with rectangular cross sections. However, round timber poles and piles continue to be used for some applications. These members are typically left naturally round and tapered, maintaining the shape of the log from which they were cut. Additionally, timbers are occasionally machined to a round or nearly round section.

Poles must conform to ASTM Standard D3200 [16] and piles must conform to ASTM Standard D25 [17] with design values established according to ASTM Standard D2899 [18]. Pole sizes and specifications are per American National Standards Institute (ANSI) Standard O5.1 [19]. Poles and piles must be pressure preservative treated in accordance with the American Wood Protection Association Standards [20] when they are to be used in ground contact or in wet use conditions.

For log construction, grades for round logs and round logs sawn flat on one side are developed in accordance with ASTM Standard D3957 [21]. For members machined to a round cross-section, there is no specific guidance given for grading and assignment of design values. It is recommended that a lumber grading agency be contacted for guidance for assigning grades to members machined to a round cross-section.

1.3 STRUCTURAL SYSTEMS

Structural timber systems take on many forms. Systems discussed in this chapter include: post and beam framing; light frame construction; pole construction, post-frame construction and timber piles; timber trusses; glulam arches; and structural diaphragms.

1.3.1 Post and Beam

Post and beam construction generally consists of roof and floor panels or decking supported by joists or purlins, which are in turn supported by beams or girders, which are supported by columns. Post and beam construction is illustrated in Figure 1.3.1-1. The joists, purlins, beams, and girders are generally framed to carry gravity loads as bending members and the columns resist axial loads. Individual members are designed in accordance with Chapters 4 to 10. Secondary members are typically framed at intervals of 16 in. to 4 ft to accommodate common panel and other material sizes.

Figure 1.3.1-1 Post and beam construction.

Although post and beam framing systems are commonly used for gravity load resistance (roof, snow, and floor loads), they are not inherently suited for lateral load resistance (wind and seismic) without additional elements. For lateral load resistance, bracing is required, and is commonly provided by the addition of cross braces (or "trussing"); let-in bracing, straps, or cables; knee and ankle bracing; and the development of the roof, floor, and wall framing into structural diaphragms and shear walls.

1.3.2 Light Frame Construction

Light frame construction is characterized by repetitive arrangements of small, closely-spaced members installed parallel to each other as wall studs and floor joists. Individual pieces are typically dimension lumber or wood I-joists spaced at intervals of 16–24 inches apart with structural panels spanning across the lumber members forming walls and floors. Light, closely spaced trusses with structural panel sheathing are typically used for roof systems. Larger timber members or built-up members are used as columns and beams where openings are necessary in bearing walls and in floor or roof systems.

Light frame construction is the predominant system used for residential construction in North America. The *Wood Frame Construction Manual* [13] published by the American Wood Council provides design guidance and details for light frame structures including both engineered and prescriptive solutions permitted by the *International Residential Code* [22].

1.3.3 Pole Construction

Pole-type structures generally consist of tapered, round timber poles set in the ground as the main upright supporting members. These poles provide resistance to gravity and lateral loads imposed on the structure.

For resistance of gravity loads, the poles (in some cases referred to as piers) are generally set to bear on undisturbed native soil, engineered fill, or footings. For light gravity loads and/or stronger soils, bearing of a pole on soil may be adequate. For heavier loads and/or weaker soils, the gravity loads must be distributed through spread footings under the poles.

Resistance of lateral loads is achieved by pole bearing laterally on soil or pole embedment in concrete or other fill which bears laterally on surrounding soil. Pole construction relies on the resistance to rotation of the poles provided by pole embedment and backfill. As such, it is critical that the backfill material and placement be suitably specified and its quality assured.

Pole sizes and specifications are per American National Standards Institute (ANSI) Standard O5.1 [19]. Poles must be pressure preservative treated in accordance with the American Wood Protection Association Standards [20]. General considerations applicable to all pole structures include the following:

1. Bracing can be provided at the top of a pole in the form of knee braces or cross bracing in order to reduce bending moments at the base of the pole and to distribute loads; otherwise, the poles must be designed as

vertical cantilevers. The design of buildings supported by poles without bracing requires good knowledge of soil conditions in order to eliminate excessive deflection or side-sway. Where knee braces, cross braces, or other structural elements are attached to the pole and/or roof members, they must be included as integral in the analysis of both vertical and lateral load-resisting systems.

2. Bearing values under butt ends of poles must be checked with regard to the bearing capacity of the supporting soil. Where the bearing capacity of the soil is not sufficient, a structural concrete footing may first be placed under the pole to spread the load. Backfilling the hole with concrete is common practice. With regard to gravity bearing, the concrete backfill can be used to spread the load if a suitable load transfer mechanism is provided from pole to concrete backfill. Friction between pole and concrete should not be relied upon. Studs or dowels may be used; if metal, they must be galvanized or protected against corrosion by some other means. Installation of the stud or dowel in the post must not compromise the pole's resistance to decay. Boring, notching, or other modifications to poles or posts should be done prior to preservative treatment. If boring or notching must be done in the field, the recommendations of the American Wood Protection Association, Standard AWPA M4 [23] must be followed.
3. Where the poles are used to resist lateral loads, it is essential that the backfill material be properly compacted. Sand may be used if placed in shallow, thoroughly compacted (tamped) lifts. Compaction of soil or gravel should be supervised and certified by a geotechnical engineer or other design professional familiar with the site soils conditions and requirements to achieve the needed resistance to lateral movements of the poles. The use of concrete and soil cement backfill will generally result in lesser required embedment depths as the concrete or soil cement provide greater effective pole diameter with regard to lateral bearing.
4. The use of diaphragms and shear walls in pole structures generally results in smaller poles and shallower pole embedment requirements.
5. Pole structures may have excessive deflections for some applications, particularly where there is no bracing, diaphragm, or shear wall action. Deflections of structures with gypsum coverings and glazing should be carefully analyzed.
6. Pole design requires the use of adjustment factors common to wood construction as well as adjustment factors unique to poles. Design values and adjustment factors applicable to timber pole and pile construction are found in the *National Design Specification® for Wood Construction* [6].
7. The intended use of the structure generally determines such features as height, overall length and width, spacing of poles, height at eaves, type of roof framing, and the kind of flooring to be used, as well as any special features such as wide bays, unsymmetrical layouts, or the possible suspending of particular loads from the framing.

1.3.4 Post-Frame Construction

Post-frame construction typically consists of lumber or glulam posts supporting light metal-plate connected trusses and other framing and sheathing or cladding. While the posts in post-frame structures generally resist the gravity loads, lateral forces are typically resisted within the above-ground portion of the structure by a combination of post bending and the diaphragm actions of roof, floors, and walls. Both lateral and vertical forces of the whole superstructure are transferred to the ground via the posts. Posts in post-frame are thus both foundational elements and part of the superstructure.

Post-frame construction has been widely used for agricultural and utility purposes, and has also been used in residential construction. The *Post-Frame Building Design Manual* [24] by the National Frame Builders Association provides guidance for the design of post-frame structures. The primary distinction between pole construction and post-frame construction is in nomenclature, where poles are taken to be tapered with round cross section, and posts are taken to be prismatic and rectangular in section. Post-frame construction generally incorporates the use of metal cladding or structural wood panel sheathing to develop diaphragm action. The stiffness of the diaphragm and posts must be considered together to determine the distribution of loads to posts and end walls. Methods to determine diaphragm action and the distribution of loads to the posts may be found in the *Post-Frame Design Manual* [24] and *Wood Technology in the Design of Structures* [25] with a simplified approach also available [26]. Once the loads on the posts have been determined, the design checks are similar to those described above for pole construction.

1.3.5 Timber Piles

Timber piles are round tapered timber members generally used as foundation elements that are typically driven into the ground. Piles are generally used where soils near the surface are weak or where the structure must be elevated above the surface. Piles may also be used in retaining walls or other structures subject primarily to lateral forces. Piles are typically embedded to greater depths than posts or other types of foundations. Recommendations for the use of timber piles in foundations may be found in *Pile Foundations: Know-How* [27].

Piles may be driven into place or installed in holes prebored by auguring or other means. Tapered timber piles are driven with small end (tip) down. Piles resist vertical forces by a combination of side or skin friction and end bearing. Short piles or piles driven through weak soils until they bear on stronger soils below tend to carry more of the load in end bearing, with the opposite being true of long piles in relatively homogeneous soils.

A number of species are used for piles, with southern pine, Douglas fir, and oak being the most commonly used. Piles must be relatively straight and possess the strength to resist driving stress and support the imposed loads.

1.3.5.1 Pile Driving Equipment used for driving timber piles is of special importance. The energy used to drive the piles must be sufficient to drive the pile, but must not impart excessive forces. Pile butts and tips may be damaged severely by sharp blows. For this reason, it is not desirable to drive timber piles with a drop hammer unless a suitable block is employed to dampen the impact. Air, steam, and diesel hammers are commonly used. Generally, it is desirable to band the butt or driven end of a pile to minimize damage during driving. In some cases where tip damage may occur, a special shoe or fitting is used to protect the tip. Pile driving should be monitored by a quality control professional.

1.3.5.2 Critical Section of Pile Piles may be specified by the circumference of the nominal butt or nominal tip in accordance with ASTM D25 [17]. The ASTM classification allows the designer to specify a pile with adequate dimensions at the critical section. For example, a pile depending on frictional forces along the surface of the pile to support the vertical load will generally have a critical section located away from the tip. On the other hand, an end-bearing pile might have the critical section located at the tip.

1.3.5.3 Preservative Treatment of Piles Preservative treatment of piles should conform to recognized specifications such as American Wood Protection Association (AWPA) Standard U1 Commodity Specification E [20]. Cutoffs at the tops of piles exposing untreated wood should be field treated in accordance with AWPA Standard M4 [23]. Piles used in saltwater are subject to attack by marine borers, and special treatment techniques must be used to minimize degradation.

1.3.5.4 Design of Piles Design of pile foundations and other uses of piles should be based on the recommendations of soils investigations of the sites in question. Design values and adjustment factors are found in the *National Design Specification®* [6]. Such design values typically apply to both wet and dry use. It is generally assumed that piles will be preservative treated and will be used in groups. In cases where no treatment is applied or where piles are used individually, further specific adjustments are applied.

Where the diameter of the pile at the section of critical bending moment exceeds 13.5 in., the bending design value must be multiplied by the size factor given in Equation 3-3, based on the depth of a square section of equivalent cross-sectional area. Except in the case of very slender piles or piles in soils providing little or no lateral support, the column stability factor is not applied. The beam stability factor is not applicable to piles.

1.3.6 Trusses

The subject of timber truss design is quite broad. The discussion in this manual is limited to basic design procedures and the highlighting of features unique to timber truss construction. The design of light metal plate connected wood trusses constructed of dimension lumber is not covered in this manual. Light metal plate connected trusses are generally designed by truss manufacturers utilizing proprietary connection and design techniques.

1.3.6.1 Truss Types Types of timber trusses commonly used are illustrated in Figure 1.3.6.1-1. Architectural considerations generally dictate roof slope and may also dictate truss type. For flat or nearly flat roof trusses, some pitch must be provided for drainage or the trusses must be designed to resist progressive ponding.

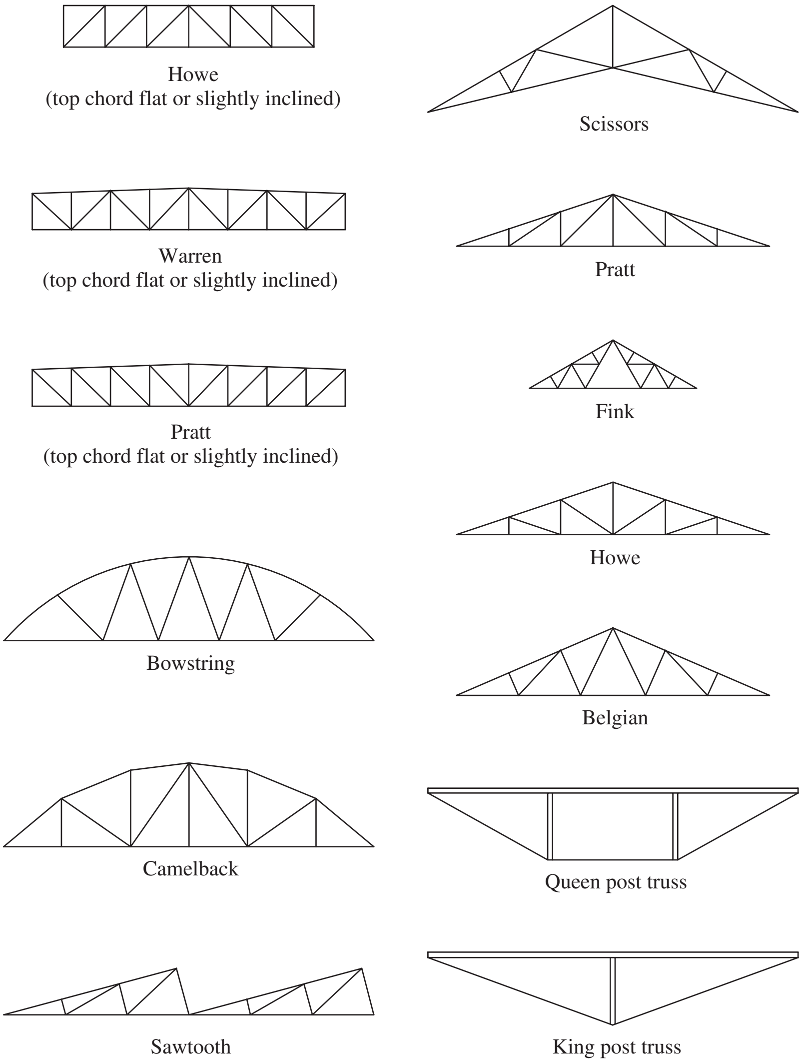

Figure 1.3.6.1-1 Types of timber trusses.

Pratt and Howe trusses are similar except for the orientation of the webs. Pratt trusses have the advantage that for gravity loads, the longer (diagonal) webs are in tension, whereas the shorter (vertical) webs are in compression. These truss names originate from early bridge designers who patented their truss designs. The parallel chord trusses shown in Figure 1.3.6.1-1 were designed for bridge applications with the load applied to the bottom chord, where the triangular trusses of the same names were designed for roof applications with the load applied to the top chord. This accounts for the change in web orientation between the parallel-chord trusses and triangular trusses with the same name.

Bowstring trusses typically have the upper chord shaped to the form of a circular arc with the radius of the top chord equal to the span. Under uniform loading, the chords and heel connections resist the major forces, and the web stresses are small, resulting in light webs and web connections. In addition to normal axial and bending stresses, upper chords of bowstring trusses are subject to moments due to the eccentricity of their curved shape.

Scissor trusses are used to provide more height clearance toward the mid-span. They are commonly used in churches, gymnasiums, various types of assembly halls, and in residential construction. For scissor trusses, horizontal displacement of the truss ends must be considered as part of the design.

Following are recommended span-to-depth ratios for common truss shapes that may be used for determining preliminary truss shape dimensions. Larger span-to-depth ratios may result in excessive member stresses and deflections; smaller ratios may be less economical.

Flat or parallel chord	8–10
Triangular or pitched	6 or less
Bowstring	6–8

1.3.6.2 Truss Members Truss members are designated in three types: top chord, bottom chord, and webs. Webs include all interior vertical or diagonal members between the top and bottom chords. Joints, at which members intersect and connect, are called *panel points.* Chords and webs in all truss types may be constructed as single-leaf, double-leaf, or multi-leaf members. Truss members may be sawn lumber or glued laminated timber. The use of steel rods or other steel shapes for members in timber trusses is acceptable if they fulfill all conditions of design and service.

Glued laminated timber provides many features desirable for truss designs. Glued laminated timber can be made in almost any shape, size, or length, and generally provides higher design values than do sawn timbers. Sawn timbers are limited in maximum length and cross-sectional size and are prone to checking. However, sawn members may provide cost savings. Thus, depending on truss span and loading requirements, trusses can be made of all sawn timber, all glued laminated timber, or a combination of both, and may include some steel tension members. If sawn members are used in conjunction with glued laminated timber, care must be taken to match widths at connections and provide for differential shrinkage.

1.3.6.3 Truss Deflection and Camber The effects of truss deflections must be considered in the design of supporting columns, structural and nonstructural walls, and other fixtures. Timber trusses should be cambered such that total dead load deflection does not produce sag below a straight line between points of support. Additional camber may be appropriate for sustained or heavy live or other loads where sag may impair serviceability or be aesthetically unappealing.

Horizontal deflections of certain trusses must also be computed and accommodated for in the design of the truss support connections. Scissor and crescent trusses may have considerable horizontal deflections. Where horizontal deflection is prevented by the supporting structure, the resulting loads on the truss and support structure must be considered.

1.3.6.4 General Design Procedure For trusses whose members function essentially as pin-connected axial members, member forces may be found by determinate static analysis and deflections by virtual work or other methods. Many trusses, however, incorporate members that are continuous through some connections. For these trusses, static analysis may serve to provide preliminary results, but indeterminate analysis should be used for final member forces and deflections.

Timber truss design typically involves selection of trial member sizes and connection types with iteration until member stress and truss deflection criteria are satisfied. Trial member sizes are generally determined from architectural considerations or engineering judgment, or both. In the absence of other guidance on trial member sizes, preliminary member sizes may be obtained from static analysis considering all joints pinned and the members acting under axial load only. Preliminary deflection information can also be obtained from this idealization.

The availability of proprietary structural analysis and design software enables designers of timber trusses to account for the statically indeterminate features of truss design, unbalanced loads and load reversals, and check combined stresses and deflection quickly and efficiently. Successive iterations of various design features may also result in successive improvements in the truss economy.

For final design, the exact geometry of the truss must be determined—including load points, member sizes, and connection geometry. Where there are knee braces or other structural elements attached to the truss that can lend support or influence load distribution, they must be included as integral with the truss in the overall analysis. If chords are curved, moments resulting from eccentricity of the axial forces must be included in their design.

1.3.6.5 Connections Truss connections should be centric; that is, the centerlines of members at each joint should intersect at a common point so that moments are not induced into the members being connected. Connections should also be detailed in such a way as to allow relative rotation between members (Figures 1.3.6.5-1 and 1.3.6.5-2). If rotation is restrained by the joints, moments in members and connections will result, and the members may split. Single through-bolts connecting the members of multileaf trusses provide true “pin” connections. Slotted or overlapping connecting plates may also be used to allow rotation.

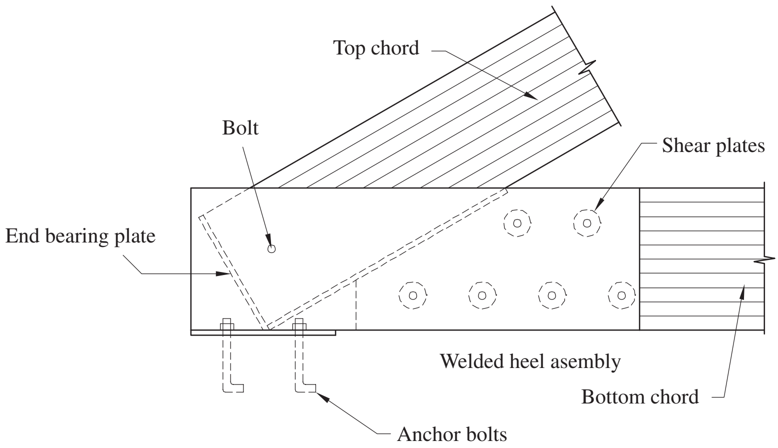

Figure 1.3.6.5-1 Truss heel connection.

Where metal side plates are used to transfer compression loads, buckling of the plates must be considered based on support conditions for the plates. For plates connecting webs to chords, generally the web does not provide lateral stability for the plate but instead the plate is an extension of the web. Therefore, the end of the plate fastened to the web cannot be considered fixed in determining the plate effective length. When the web plates are pinned at the chord, the spacing between bolts in the web should be large enough to provide stability and prevent splitting of the web.

If steel rods are used as tension elements in a truss, written instruction should be given to the truss assembler regarding tightening of the rods. Otherwise, overtightening could occur, which might overstress truss elements when design loads are applied.

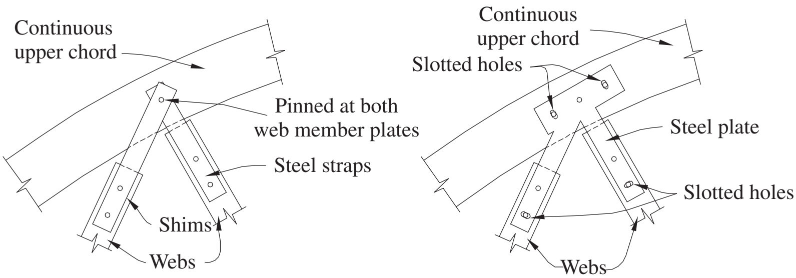

Figure 1.3.6.5-2 Truss chord and web connections.

1.3.6.6 Bracing In structures employing trusses, a system of bracing is required to provide resistance to lateral forces, to hold the trusses true and plumb, and to prevent compression elements from buckling. Both permanent bracing and temporary erection bracing should be designed according to accepted engineering principles to resist all loads that will normally act on the system. Erection bracing is installed during erection to hold the trusses in a safe position until sufficient permanent construction is in place to provide full stability. Permanent bracing forms an integral part of the completed structure. Part or all of the permanent bracing may also act as erection bracing.

1.3.6.6.1 Permanent Bracing Permanent bracing must be provided to resist forces out of the truss plane and provide stability for the truss. Permanent bracing typically consists of a structural diaphragm in the plane of the top chord, horizontal bracing between trusses in the plane of the bottom and top chords, or a combination of both. In addition, individual web members may require permanent bracing to prevent buckling.

A structural diaphragm in the plane of the top chord, acting as a plate girder, transmits forces to end and side walls. This system is the preferred method of providing truss bracing and is usually most economical. It may be necessary to provide additional members acting as the flanges for the diaphragm.

Horizontal bracing between trusses is a positive method of bracing, but it is more costly and should be used only where the strength of a diaphragm described above is insufficient. In effect, such bracing forms an inclined or horizontal truss to resist out of plane loads on the system.

Top chords and web members subject to compressive loads must be adequately braced to satisfy slenderness requirements and resistance to buckling. Similarly, bottom chords and other members subject to compression under wind or other loads may need to be braced. To provide lateral support for truss members subject to compression, the bracing system should be designed to withstand a horizontal force equal to at least 2 percent of the compressive force in the truss chord if the members are aligned.

Even though truss bottom chord forces may be in tension under all loading conditions, there may be circumstances when bottom chord bracing is advised for nonstructural reasons. Truss bottom chords can distort out of plane due to eccentricities introduced by manufacturing variations, unsymmetrical truss loading, and other factors. Distortions out of plane are more likely when chords are non-continuous (spliced) between the support points. The designer should consider including bottom chord bracing when there are sensitive visual sight lines and factors contributing to out of plane distortions.

1.3.6.6.2 Temporary Bracing Temporary or erection bracing is not normally the responsibility of the design engineer. Contract documents should specify who has the responsibility to design and provide temporary bracing systems. Erection truss bracing is installed to hold trusses true and plumb and in a safe condition until permanent truss bracing and other permanent components, such as joists and sheathing contributing to the rigidity of the complete roof structure, are in place. Erection truss bracing may consist of struts, ties, cables, guys, shores, or similar items. Joists, purlins, and other permanent elements may be used as part of the erection bracing.

1.3.7 Structural Glued Laminated Timber Arches

Structural glued laminated timber (glulam) has many advantages over traditional sawn members or other engineered wood products including its ability to be manufactured in a variety of shapes from straight beams and columns to graceful curved members. Glulam can be manufactured with constant cross section along the length or with taper to meet architectural requirements. The glulam arch fully takes advantage of the unique properties of laminated timber construction.

Glulam arches are popular for use in large open structures such as churches and gymnasiums because of their excellent structural performance, inherent fire resistance, and aesthetic appeal. Laminated timber arches are also used for vehicle and pedestrian bridges.

Figure 1.3.7-1 illustrates a number of common arch configurations. Arches may be of either two- or three-hinged design. Tudor arches can generally be used economically for spans of up to 120 feet, and parabolic and radial arches can be used economically for spans of up to 250 feet. The most popular arch configuration in use today is the three-hinged Tudor arch. It provides a vertical wall frame and sloping roof that are commonly used for modern structures. Its appearance is pleasing to most people.

Design of Tudor Arches with Structural Glued Laminated Timber [28] provides detailed guidance for the design of Tudor arches. Manufacturers of arches commonly provide design services for these specialized systems. Chapter 9 of this manual includes a simplified procedure for preliminary design of Tudor arches.

1.3.7.1 Aesthetic Considerations Because structural glued laminated timber arches are typically exposed to view, the aesthetic appeal of the arch is an important design consideration in addition to its structural performance. The building designer and owner should verify that the final geometry meets the aesthetic requirements and any other architectural requirements for the design. Because of the numerous material and geometric parameters involved in arch design, multiple geometries can be utilized to meet the same structural requirements. As with all glued laminated timbers, the specification of the glulam members should clearly include the required appearance grade.

1.3.7.2 Transportation Considerations Arches can pose significant challenges in shipping, particularly with tall wall heights and roofs with low pitch. Critical shipping dimensions of a Tudor arch half are shown in Figure 1.3.7.2-1. To facilitate shipping, it may be necessary to design and manufacture the arch halves with moment splices occurring in the arms (Figure 1.3.7.2-2). These are typically placed at inflection points, or other locations with low bending moments.

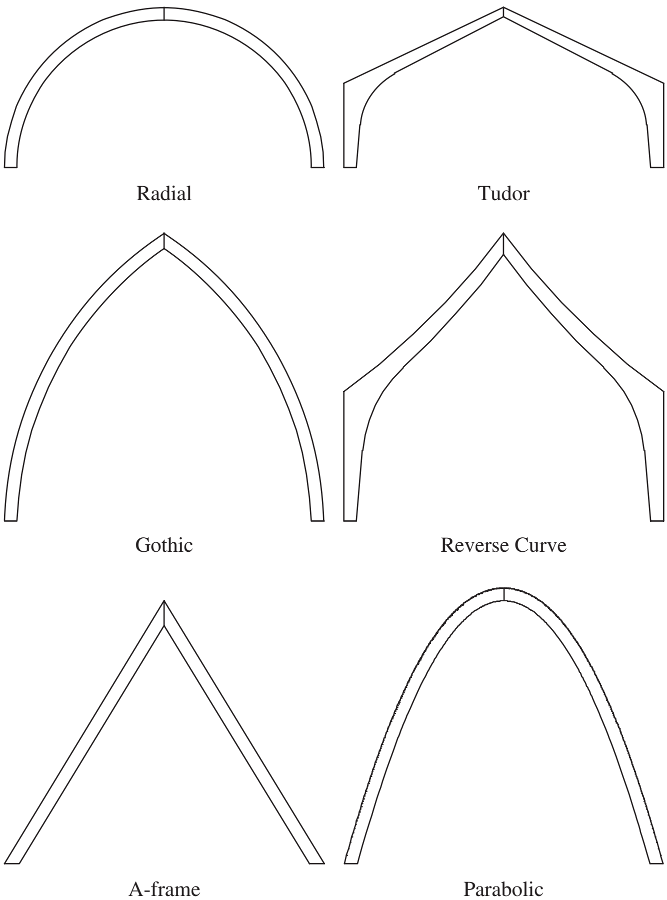

Figure 1.3.7-1 Common arch configurations.

The arch can also be designed and manufactured with a detached haunch to reduce its overall width for shipping (Figure 1.3.7.2-3).

Shipping widths of up to 12 ft can typically be accommodated. Wider loads may be possible depending on the distance from the manufacturing plant to the jobsite and the route the shipment will follow. Glulam manufacturers can provide guidance regarding maximum shipping dimensions for various localities.

For arches with deep haunches, manufacturing constraints may also dictate the use of a detached haunch to facilitate passing the arch through a surface planer. Glulam manufacturers should be contacted early in the design process to determine their maximum recommended haunch depths.

1.3.8 Diaphragms and Shear Walls

Structural diaphragms are relatively thin, usually rectangular, structural systems capable of resisting in-plane shear parallel to their edges. Wood framed roofs,

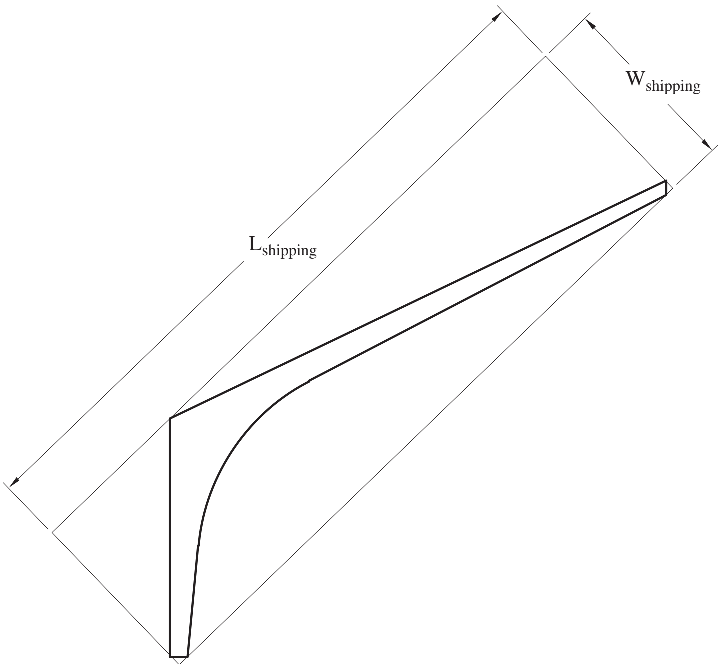

Figure 1.3.7.2-1 Tudor arch critical shipping dimensions.

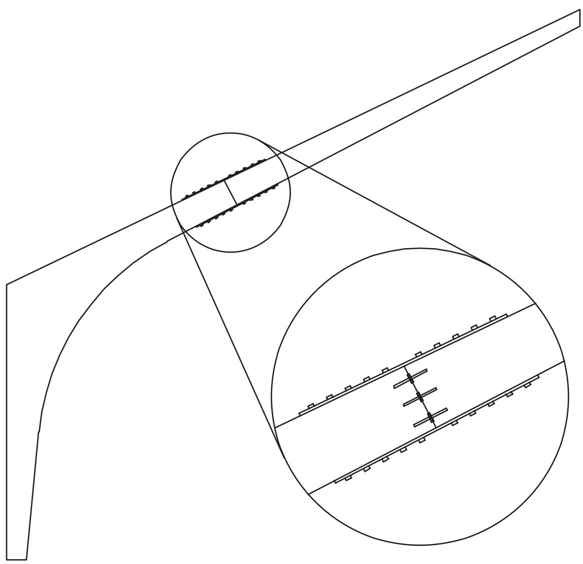

Figure 1.3.7.2-2 Tudor arch with moment splice in arm.

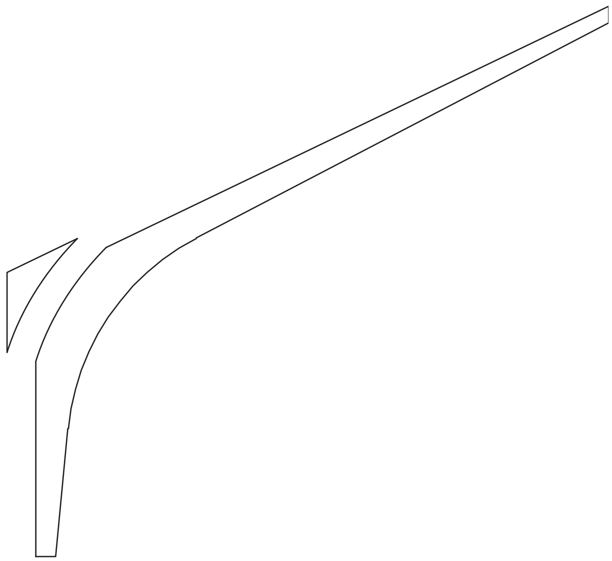

Figure 1.3.7.2-3 Tudor arch with detached haunch.

walls, and floors can generally be made into structural diaphragms with proper detailing and in some cases additional members or connecting hardware. The function of the diaphragm is to brace a structure or parts thereof against lateral forces, such as wind or earthquake loads, and to transmit these forces to the other resisting elements of the structure. Roof and floor systems are often used as horizontal diaphragms. The horizontal diaphragms transfer the lateral forces to vertical diaphragms (shear walls), braced walls of various types, or poles or piles. Common types of diaphragms in wood construction are described below.

1.3.8.1 Wood Structural Panels Structural panel sheathing used to resist out of plane loads (load perpendicular to the panels) can generally be used to also develop diaphragm action by proper detailing of fasteners, boundary members, and attachment to interior support members and blocking. The design of wood structural panel diaphragms is described in *ASD/LRFD Wind & Seismic—Special Design Provisions for Wind and Seismic* [29].

Heavy timber and glued laminated timber decking may be covered with wood structural panel sheathing to develop diaphragm action. Design values for this type of system are considered equivalent to those of blocked structural panel diaphragms of the same sheathing thickness and with the same nailing schedule. The designer must specify and detail the proper panel and boundary nailing conditions for both sheathing and decking.

1.3.8.2 Lumber Sheathing Lumber sheathing, consisting of boards of 1 in. nominal thickness nailed transversely or diagonally at 45° to studs or joists, is sometimes used in wood frame construction. The edges of lumber sheathing may be square, ship-lapped, splined, or tongue-and-groove. When subjected to lateral forces such as wind or earthquakes, lumber sheathing and its supporting framework may act as a diaphragm or shear wall, serving to brace the building against the lateral forces and transmitting these forces to the foundations. Design values for lumber-sheathed diaphragms and shear walls are provided in the *Special Design Provisions for Wind and Seismic* [29], primarily for the evaluation of existing structures. New structures are not typically designed with this type of diaphragm or shear wall.

Lumber sheathing and decking develop only modest amounts of diaphragm action where placed perpendicular to the support members. Diagonal installation of the sheathing lumber a results in considerably greater strength and stiffness than where the sheathing is installed perpendicular across supports. Placing lumber sheathing in two layers of diagonal sheathing, one on top of the other, with the sheathing in one layer perpendicular to the sheathing in the other layer, results in considerably stiffer and stronger diaphragms than single-layer diagonal sheathing.

1.4 ECONOMY

The best economy in timber construction is generally realized when standard-size members can be utilized in a repetitive arrangement with simple connections. However, timber framing, especially glued laminated timber, can be custom fabricated to provide an infinite variety of unique but cost-effective architectural forms and arrangements.

1.4.1 Standard Sizes

The selection of standard sizes and grades in timber construction will result in maximum economy. Standard sizes of glued laminated timber, sawn lumber (boards, dimension lumber, and timbers), are given in Tables 1.4.1-1 and 1.4.1-2. Member length of glued laminated timber is limited, for the most part, only by transportation and handling restrictions. Standard lengths for sawn lumber are generally available in even 2-ft increments, with the maximum length practically limited to 20–30 ft.

1.4.2 Volumetric Measure

The volume of structural timbers is typically measured in terms of board feet (BF). Large volumes of wood are typically measured in thousands of board feet (MBF) and millions of board feet (MMBF). Because price is often stated per thousand board feet, it is important to understand how board footage is measured and to be able to convert into other measures of volume. The wood volume in board feet is calculated based on nominal dimensions; therefore, board foot measure must be converted to actual volume for calculations other than for pricing.

TABLE 1.4.1-1 Standard Sizes for Glued Laminated Timber

Species	Standard Widths for Industrial, Architectural, and Premium Appearance							
Softwoods other than southern pine	$2\frac{1}{8}$	$3\frac{1}{8}$	$5\frac{1}{8}$	$6\frac{3}{4}$	$8\frac{3}{4}$	$10\frac{3}{4}$	$12\frac{1}{4}$[a]	$14\frac{1}{4}$[a]
Southern pine	$2\frac{1}{8}$	3 or $3\frac{1}{8}$	5 or $5\frac{1}{8}$	$6\frac{3}{4}$	$8\frac{1}{2}$	$10\frac{1}{2}$	12[a]	14[a]
	Standard Widths for Framing Appearance[b]							
All softwoods	$2\frac{1}{2}$	$3\frac{1}{2}$	$5\frac{1}{2}$	$7\frac{1}{4}$	—	—	—	—

No. of Laminations	Standard Net Depth of Members, in.		
	Nominal 1 in. Laminations[d]	Nominal 2 in. Laminations	
		$1\frac{1}{2}$ in.[c,d]	$1\frac{3}{8}$ in.[c,d]
4	3	6	$5\frac{1}{2}$
5	$3\frac{1}{4}$	$7\frac{1}{2}$	$6\frac{7}{8}$
6	$4\frac{1}{2}$	9	$8\frac{1}{4}$
7	$5\frac{1}{4}$	$10\frac{1}{2}$	$9\frac{5}{8}$
8	6	12	11
etc.	etc.	etc.	etc.

[a] Laminations wider than 11.25 in. are not generally available. Wider beams are typically manufactured using multiple-piece laminations across the width (Figure 1.4.1-1).
[b] Framing appearance grade members are surfaced "hit or miss" to match conventional framing lumber widths, and are not suitable for applications where appearance is important.
[c] $1\frac{1}{2}$ in. thick laminations are normal for most softwoods; $1\frac{3}{8}$ in. thick laminations are normal for southern pine.
[d] Curved members may use thinner laminations, depending on radius of curvature.

One board foot of sawn lumber or timber is equal to 144 in^3 based on nominal thickness, nominal width, and actual length. For example, a one-foot length of nominal 2 in. × 6 in. or 1 in. × 12 in. lumber measures one board foot. Likewise, a four-inch length of nominal 6 in. × 6 in. timber measures one board foot. The actual volume of a board foot of lumber varies significantly depending on the size of the piece. For example, a board foot of 2 × 6 lumber contains 99 in^3 of wood, while a board foot of 8 × 14 lumber contains 130 in^3 of wood.

Structural glued laminated timber is measured based on the nominal dimensions of the input lumber. For example, a $5\frac{1}{8}$ in. × 12 in. Douglas fir glulam beam is manufactured from eight laminations of nominal 2 in. × 6 in. lumber. Each 2 in. × 6 in. lamination measures one board foot per lineal foot, resulting in a total of 8 board feet per lineal foot for the beam. Similarly, a $5\frac{1}{8}$ in. × $12\frac{3}{8}$ in. Southern pine beam, manufactured from nine laminations of nominal 2 in. × 6 in. lumber measures 9 board feet per lineal foot of beam.

TABLE 1.4.1-2 Standard Sizes for Sawn Lumber

Item	Thickness, in.			Face Widths, in.		
	Nominal	Minimum Dressed		Nominal	Minimum Dressed	
		Dry	Green		Dry	Green
Boards	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{11}{16}$	2	$1\frac{1}{2}$	$1\frac{9}{16}$
	1	$\frac{3}{4}$	$\frac{25}{32}$	3	$2\frac{1}{2}$	$2\frac{9}{16}$
	$1\frac{1}{4}$	1	$1\frac{1}{32}$	4	$3\frac{1}{2}$	$3\frac{9}{16}$
	$1\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{9}{32}$	5	$4\frac{1}{2}$	$4\frac{5}{8}$
				6	$5\frac{1}{2}$	$5\frac{5}{8}$
				7	$6\frac{1}{2}$	$6\frac{5}{8}$
				8	$7\frac{1}{4}$	$7\frac{1}{2}$
				9	$8\frac{1}{4}$	$8\frac{1}{2}$
				10	$9\frac{1}{4}$	$9\frac{1}{2}$
				12	$11\frac{1}{4}$	$11\frac{1}{2}$
				14	$13\frac{1}{4}$	$13\frac{1}{2}$
				16	$15\frac{1}{4}$	$15\frac{1}{2}$
Dimension Lumber	2	$1\frac{9}{16}$	$1\frac{9}{16}$	2	$1\frac{1}{2}$	$1\frac{9}{16}$
	$2\frac{1}{2}$	2	$2\frac{1}{16}$	3	$2\frac{1}{2}$	$2\frac{9}{16}$
	3	$2\frac{1}{2}$	$2\frac{9}{16}$	4	$3\frac{1}{2}$	$3\frac{9}{16}$
	$3\frac{1}{2}$	3	$3\frac{1}{16}$	5	$4\frac{1}{2}$	$4\frac{5}{8}$
	4	$3\frac{1}{2}$	$3\frac{9}{16}$	6	$5\frac{1}{2}$	$5\frac{5}{8}$
	$4\frac{1}{2}$	4	$4\frac{1}{16}$	8	$7\frac{1}{4}$	$7\frac{1}{2}$
				10	$9\frac{1}{4}$	$9\frac{1}{2}$
				12	$11\frac{1}{4}$	$11\frac{1}{2}$
				14	$13\frac{1}{4}$	$13\frac{1}{2}$
				16	$15\frac{1}{4}$	$15\frac{1}{2}$
Timbers	5 and thicker	-	$\frac{1}{2}$ off	5 and wider	-	$\frac{1}{2}$ off

1.4.3 Standard Connection Details

A variety of fasteners and connection hardware is readily available for wood construction. In applications requiring custom design, typical construction details are provided in AITC 104 [30] to assist in the design of safe and durable connections.

1.4.4 Framing Systems

There is great diversity of structural timber framing systems. The relative economy of any one system over another will depend on the particular requirements of a specific job. Consideration of the overall structure, intended use, geographic

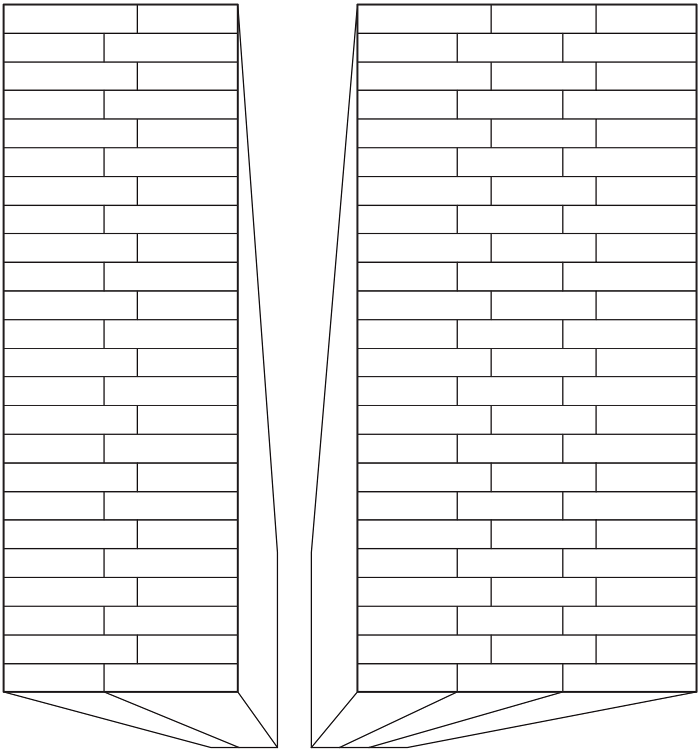

Figure 1.4.1-1 Glulam beams with multiple-piece laminations across the width.

location, required configuration, and other factors play an important part in determining the framing system to be used on a job. Table 1.4.1-1 may be used for preliminary design purposes to determine the economical span ranges for various timber framing systems.

The following additional considerations, when applied to timber framing system design, tend to reduce costs. Connections (joints) should be simple and as few as practically possible. Unnecessary variations in members should be avoided; that is, identical members should be used repetitively where practical, with the number of variations kept to a minimum. Continuous spans and cantilever systems may be used to balance positive and negative moments, reducing required member sizes and costs.

1.4.5 Structural Grades

For projects using sawn lumber and/or “stock” glued laminated members, suppliers should be consulted for the relative availability and economy of various grades and species. For large jobs utilizing numerous glued laminated timbers, and for custom members, better economy may be obtained by specifying the minimum

TABLE 1.4.4-1 Economical Spans for Selected Timber Framing Systems

Primary Framing Systems	Economical Span Range (ft)
Simple Beams	
Sawn Lumber	≤ 32
Glulam	≤ 100
Cantilever Beam Systems	
Sawn Lumber	≤ 24
Glulam	≤ 90
Continuous Beams	
Sawn Lumber	≤ 16
Glulam	≤ 50
Glulam Arches	
Gothic	40–90
Tudor	20–120
A-Frame	20–100
Parabolic	40–250
Radial	40–250
Heavy Trusses	
Flat (parallel chord)	50–150
Triangular (pitched)	50–90
Bowstring	50–200
Light Trusses	
Flat (parallel chord)	20–50
Triangular (pitched)	20–75
Dome	50–500+
Secondary Framing Systems	
1-in. Lumber Sheathing	1–2
2-in. Lumber Decking	4–8
3-in. Lumber Decking	8–14
4 in. Lumber Decking	14–18
Structural Panel Sheathing	1–4
Stressed Skin Panels	8–40
Joists with Sheathing	16–24
Purlins with Sheathing	16–36

required design stresses or stress class for the members, allowing the manufacturer flexibility in choice of laminating combinations.

1.4.6 Appearance Grades for Structural Glued Laminated Timber

The specification of higher appearance grades than needed may significantly increase the cost of the glulam members. It is generally more economical to specify the appearance grade best suited for each job or perhaps different members in a particular job than to require the best appearance grade for all jobs or members.

1.5 PERMANENCE

With proper design details, construction procedures, and usage, wood is a permanent construction material. If proper consideration is given to potential causes of deterioration and their prevention in the design of a project, there will be greater assurance that the structure will be permanent and that maintenance will be minimal. AITC Technical Note 12 [31] provides additional information related to permanence.

1.5.1 Wood Decay

Decay of wood is caused by fungi that grow from microscopic spores. These spores are present wherever wood is used. The fungi use wood substance as their source of nutrition. If deprived of any one of four essentials for life (nutrients, air, moisture, and favorable temperature), decay growth is prevented or stopped and the wood remains sound, retaining its existing strength with no further deterioration. Wood will not be attacked by fungi if it is submerged in water (thereby excluding air), kept continuously below 20% moisture content (excluding sufficient free moisture), or maintained at temperatures below freezing or much above 100°F. Growth can begin or resume whenever conditions are favorable.

The early stages of decay are often accompanied by a discoloration of the wood, which is more evident on freshly exposed surfaces of unseasoned wood than on dry wood. However, many fungi produce early stages of decay that are similar in color to that of normal wood or give the wood a water-soaked appearance.

Later stages of decay produce observable changes in color and texture and in wood volume and density. Decayed wood has reduced strength and fire resistance. In the extreme, the wood appears rotten and crumbly and reduces the member section (Figure 1.5.1-1). *Dry rot* is wood that has decayed in the presence of moisture and has subsequently become dry.

In the design of wood structures, fungal decay is typically prevented by assuring low moisture content or by making the wood toxic to the fungi by pressure preservative treatment (where low moisture content cannot be assured). The *Standard for Preservative Treatment of Structural Glued Laminated Timber*, AITC 109 [32], provides information about preservative treatment of glued laminated timber. The American Wood Protection Association provides information on the treatment of glulam, sawn lumber, and round timbers [20].

1.5.1.1 Detailing to Prevent Decay Proper detailing and construction are important for decay prevention. Rain water and melted snow must be directed away from wood members by adequately sloped framing and appropriate flashing. Roof overhangs with gutters and downspouts are advised. Finish grade around a structure should be sloped to direct runoff away from the structure.

The building envelope should include an appropriate moisture barrier. The American Society of Heating, Refrigeration, and Air-Conditioning Engineers

Figure 1.5.1-1 Advanced decay of unprotected glulam beam.

Fundamentals Handbook [33] can be consulted, as well as the local building authority, for guidance in providing an effective moisture barrier.

Untreated wood should not be installed in direct contact with masonry or concrete. Girder and joist openings in masonry and concrete walls should be large enough to assure that there will be an air space around the sides and ends of these wood members. Where timber members are below the outside soil level, moisture proofing of the outer face of the walls is essential.

Enclosed spaces such as attics and crawl spaces must be adequately ventilated. Moisture from soil floors in crawl spaces can be inhibited from moving into the crawl space by covering the soil with a vapor barrier. Untreated wood must be placed above finish grade (typically a minimum of 6 in.).

1.5.1.2 Use of Preservative Treated or Decay-Resistant Wood Wood has a proven performance of indefinitely long service without special treatments if it is kept below 20% moisture content. However, when wood is exposed to the weather and not properly protected by a roof, eave overhang, or similar covering, or is subjected to other conditions of free water, either preservative treatment is required, or wood that is naturally decay resistant must be used.

Naturally decay-resistant woods include the heartwood of Alaska cedar and redwood. The *Wood Handbook* [34] lists additional domestic woods with heartwood that is naturally resistant to decay.

Special consideration should be taken for structures containing significant sources of moisture such as pools. Special consideration should also be taken for parts of the structure that are outside the building envelope such as decks, porches, and balconies. Prescriptive requirements for wood construction in model building codes generally take into consideration decay potential and reflect many of the above safeguards. Periodic inspection of wood structures is recommended to identify signs of excess moisture, decay, or damage.

1.5.2 Mold and Fungal Stains

Wood may also experience mold and stain. Molds and stains are confined largely to sapwood and are of various colors. Molds generally do not stain the wood but produce surface blemishes varying from white or light colors to black that can often be brushed off. Fungal stains may penetrate the wood and normally cannot be removed by scraping or sanding. The presence of molds and stains are not necessarily signs of decay, as stain-producing fungi do not attack the wood substance appreciably. For most uses in which appearance is not a factor, stains alone are not necessarily unacceptable as wood strength is practically unaffected. Ordinarily, the only effects of stains and mold are confined to those properties that determine shock resistance or toughness. Keeping wood dry is generally sufficient to prevent growth of mold or fungal stains.

1.5.3 Insects

In terms of economic loss, the most destructive insect to attack wood buildings is the subterranean termite. In certain localities, above-ground termites are also very destructive. Other insects attack timber buildings, but, ordinarily, these occurrences are rather rare and their damage is slight. In many cases, these insects can be controlled by the methods used for termites.

1.5.3.1 Subterranean Termites The extent of the occurrence of damage from subterranean and non-subterranean termites is shown in Figure 1.5.3.1-1.

Figure 1.5.3.1-1 Termite damage in the continental United States. A, northern limit of recorded damage done by subterranean termites; B, northern limit of damage done by dry-wood or non-subterranean termites. (From Wood Handbook[34].)

Damage occurrence in general is much greater in southern states where temperature conditions are more favorable. However, damage to individual buildings may be just as great in northern states.

Subterranean termites develop and maintain colonies in the ground from which they build tunnels through the earth and around obstructions to get at the wood they need for food. The worker members of the colony cause the destruction of wood. At certain seasons of the year, male and female winged forms swarm from the colony, fly a short time, lose their wings, mate and, if they succeed in locating suitable places, start new colonies. The occurrence of flying termites (similar in appearance to flying ants) or their shed wings may be an indication of a nearby colony.

Subterranean termites do not establish themselves in buildings by being carried there in lumber, but by entering from the ground nests after the building has been constructed. Termites must have continual access to moisture such as from the soil. Signs of the presence of termites are the earthen tubes, or runways, built by these insects from the ground over the surfaces of foundation walls to reach the wood above. In wood, the termites make galleries that follow the grain, often concealed by a shell of sound wood. Because the galleries seldom show on the wood surface, probing may be necessary to identify termite infestation and damage.

Where subterranean termites are prevalent, the best protection is to prevent their gaining access to the building from the ground. Construction details prescribed by model building codes separating wood from soil and moisture to prevent decay are also useful for preventing termite infestation. In general, foundations must be of preservative treated wood, concrete, or other material through which the termites cannot penetrate. Cement mortar should be used with masonry foundations as termites can work through some other kinds of mortar. Wood that is not impregnated with an effective preservative must be kept away from the ground. Basement floors should preferably be concrete slab on grade. In general, wood floor framing must be treated if within 18 in. of the ground below the floor. Untreated posts must stand off at least 1 in. above concrete slabs unless the slab has been protected from moisture and pest infestation. Moisture condensation on the floor joists and subfloor, which may cause conditions favorable to decay and thus make the wood more attractive to termites, can be avoided by covering the soil with a waterproof membrane. Expansion joint material for slabs must be pest-resistant or treated to resist termites.

All concrete forms, stakes, stumps, and waste wood and other potential sources of infestation must be removed from the building site at the time of construction. Where protection is needed in addition to that obtained by physical methods, the soil adjacent to the foundation walls and piers beneath the building may be thoroughly treated with an appropriate insecticide.

1.5.3.2 Above-Ground Termites Nonsubterranean or dry-wood termites have been found only in a narrow strip of territory extending from central California around the southern edge of the continental United States to Virginia and also in the West Indies and Hawaii (Figure 1.5.3.1-1). Their damage is confined to an area in southern California, to parts of southern Florida, notably Key West, and to Hawaii. The nonsubterranean termites are fewer in number, and their depredations are not rapid, but if they are allowed to work unchecked for a few years, they can occasionally ruin timbers with their tunneling.

In the principal damage areas, careful examination of wood is needed to avoid the occurrence of infestations during the construction of a building. All exterior wood can be protected by placing fine-mesh screen over all holes in the walls or roof of the building. If a building is found to be infested by dry-wood termites, badly damaged wood must be replaced. Further termite activity can be arrested by approved chemical treatments applied under proper supervision that will provide for safety of people, domestic animals, and wildlife. Where practical, fumigation is another method of destroying insects.

1.5.3.3 Other Insects Large wood-boring beetles and wood wasps may infect green wood and complete their development in seasoned wood. The borers can be killed by heating the wood to a center temperature of 130°F for one hour or by fumigation. Once the wood has been cleared of the borers, they will not reinfest seasoned wood. If infested wood is used in a building, the emerging adults may bore $\frac{1}{8}$ in. to $\frac{1}{2}$ in. holes to the surface, penetrating insulation, vapor barriers, siding, or interior surface materials. Infested members may be damaged and require structural or cosmetic repair. If the remaining structure has been built with seasoned wood without initial infestation, infestation of the other members will generally not take place.

Powder-post beetles can infest and reinfest dry wood. The *Lyctus* powder-post beetles, which are encountered most frequently, attack large-pored hardwoods. Their attacks may be recognized by tunnels packed with floury sawdust and numerous emergence holes $\frac{1}{32}$ in. to $\frac{1}{8}$ in. in diameter. Heat or fumigation treatments will kill the beetles but will not prevent reinfestation. Infestation can be prevented by a surface application of an approved insecticide in a light-oil solution. Any finishing material that plugs the surface holes of wood will also protect the wood from *Lyctus* attack. Usually, infestations in buildings result from the use of infested wood, and insecticidal treatment or fumigation may be needed to eliminate them.

Carpenter ants chew nesting galleries in wood. The principal species are large, dark-colored ants, and individuals in the colony may be $\frac{1}{2}$ in. long. They exist throughout the United States. Because the ants require a nearly saturated atmosphere in their nest, an ant infestation may indicate a moisture problem in the wood that could also result in decay damage. Ant infestations can be controlled by insecticides or by keeping the wood dry.

1.5.4 Marine Borers

Fixed or floating wood structures in salt or brackish water are subject to attack by marine borers. Marine borers include shipworms such as *Teredo* and *Bankia*, the pholads *Martesia* and *Zylophaga*, and *Limnoria* and *Sphaeroma*. Almost all marine borers attack wood as free-swimming organisms in the early part of their lives. Shipworms and pholads bore an entrance hole generally at the waterline, attach themselves, and grow in size as they bore tunnels into the wood. *Limnoria* and *Sphaeroma* generally burrow just below the surface of the water.

For areas where shipworm and pholad attack are known or expected and where *Limnoria* attack is not expected, the wood should be pressure treated with a creosote and/or creosote-coal tar solution. For areas where *Limnoria* and pholad attack are known or expected, a dual treatment of waterborne salts and creosote is recommended. Where *Limnoria* attack is known or expected and where pholads are absent, either a dual treatment or waterborne salt preservatives may be used.

1.5.5 Temperature

Wood may be exposed temporarily to temperatures up to 150°F without permanent loss of strength. Where exposed to sustained temperatures in excess of 100°F, wood suffers loss in strength and stiffness as the wood substance is degraded. Strength loss is greater in members simultaneously subject to high moisture content. Design adjustment factors for wood construction take into consideration strength loss at sustained high temperature as well as high temperature and moisture content. Wood at low temperatures tends to have greater strength than at normal temperatures, although this effect is not normally considered in design.

1.5.6 Chemical Environments

Wood is superior to many other common construction materials in its resistance to chemical attack. For this reason, wood is used in storage buildings and for containers for many chemicals and in processing plants in which structural members are subjected to spillage, leakage, or condensation of chemicals. Wooden tanks are commonly employed for the storage of water or chemicals that deteriorate other materials and have the unique feature of being self-sealing due to the expansion of wood where exposed to moisture. Experience has shown that the heartwood of cypress, Douglas fir/larch, southern pine, and redwood is the most suitable for water tanks and that the heartwood of the first three of these species is most suitable for tanks when resistance to chemicals in appreciable concentrations is an important factor. More information on the use of wood in chemical environments is provided in Chapter 2.

1.6 SEASONING

Seasoning, in general, is the drying of wood from its wet or "green" condition when first cut to the end condition in which it is in equilibrium with its surroundings. Since wood shrinks as it dries, it is preferable that wood used during construction be predried to a low moisture content, because the equilibrium moisture content for most end uses in buildings is generally low.

1.6.1 Checking

Wood naturally expands and shrinks with changes in moisture content. In the case of rapid drying, wood at the surface tends to shrink faster than the inner wood, and the surface wood fibers may separate, causing drying "checks." Wood also shrinks at different rates in different directions relative to the growth rings, which can cause checks. Drying checks are common and may be expected in sawn lumber. Drying checks may likewise be expected in glued-laminated members, though to a lesser extent due to the manufacturing process of the members. Glued-laminated members are manufactured using wood with controlled moisture contents generally close to the expected end use conditions of the members.

Proper storage, handling, and final construction details of wood members will, in general, minimize checking. In cases where checking is considered severe, AITC Technical Notes 11 [35] and 18 [36] may be used to evaluate the structural significance of checking in glued-laminated members and ASTM D245 [37] provides some guidance for sawn members.

Where temperature and moisture conditions during construction differ significantly from the building end use (e.g., construction during cold or wet seasons), and where large timber members are exposed to view, it is recommended that the building be brought to end use conditions gradually, to minimize the occurrence of checking.

1.6.2 Shrinkage

Excessive shrinkage of green wood after installation may cause structural and serviceability problems. In its end use, wood used in construction will experience changes in moisture content as surrounding temperature and humidity conditions change. In structures with a good building envelope, these changes tend to be slow, and the wood, fastenings, and properly detailed connections themselves generally accommodate the dimensional changes associated with the changes.

If green wood is used in construction (though not generally recommended), special detailing may be required to accommodate the shrinkage of the members as they dry to equilibrium. This is particularly true if the wood members are large and attached to relatively rigid elements. Equations for estimating wood shrinkage are provided in Chapter 2.

1.7 HANDLING, STORAGE, AND ERECTION

As with any material, care must be taken to protect timber members from damage during the construction process. Proper handling, storage, and erection methods will minimize problems and ensure satisfaction with final product.

1.7.1 Handling

Wood is not a particularly hard material; as such, care must be taken during handling to not damage the members. Forklifts or cranes should be used to lift wood from delivery vehicles to the construction site. Upon delivery, wood members should be tallied and inspected for damage. At the job site, larger members should be handled with fabric slings, because chains and cables tend to mark and damage the wood surfaces. Wood may also be easily marked or scuffed at the site if not protected from soil and traffic.

1.7.2 Storage

Sawn lumber delivered to a job site should be kept off the ground and protected from sunlight and moisture. Wrapped lumber and glued laminated members (generally wrapped) should likewise be stored off the ground with the wrapping intact. While being stored, the underside of the wrapping should be punctured to allow drainage of excess moisture or condensation. For additional protection, the wrapping of glued laminated members should not be removed until the building has been enclosed. Because wood creeps under load, improper storage can result in permanent deformation, so members should not be stored haphazardly or in ways that will introduce undesirable twists or bends.

1.7.3 Assembly

Timber trusses are usually shipped disassembled and are assembled on the ground at the site before erection. Arches, which are generally shipped in halves, may be assembled on the ground or connections may be made after each segment is in position. When trusses and arches are assembled on the ground at the site, they must be assembled on level blocking to permit connections to be fitted properly and tightened securely without damage. The end compression joints should be brought into full bearing and compression plates installed where specified. Field welding of structural connections must be performed in accordance with accepted standards for steel construction and welding [38] [39].

1.7.4 Erection

Before erection, the assembly should be checked for prescribed overall dimensions, prescribed camber, and accuracy of anchorage connections. Erection should be planned and executed in such a way that the close fit and neat appearance of joints and the structure as a whole will not be impaired.

Anchor bolts should be checked prior to the start of erection. Before erection begins, all supports and anchors should be complete, accessible, and free of obstructions. The weights and balance points of the structural timber framing should be determined before lifting begins so that proper equipment and lifting methods may be employed. When long members, spliced members, or timber trusses are raised from a flat to a vertical position preparatory to lifting, stresses entirely different from the normal design stress are introduced. The magnitude and distribution of these stresses will vary, depending on such factors as the weight, dimensions, and type of member. A competent rigger should consider these factors in determining how much stiffening, if any, is required, and where it should be located.

1.7.5 Bracing

All framing must be true and plumb. Temporary erection bracing must be provided to hold the framing in a safe position until sufficient permanent bracing is in place. Erection bracing must accommodate all loads to which the structure may be subjected during erection, including loads from equipment and its operation.

Final tightening of alignment bolts should not be completed until the structure has been properly aligned. Temporary bracing should not be removed until the structure has been properly aligned, diaphragms and permanent bracing have been installed, and connections and fastenings have been finally tightened. The design engineer should be consulted prior to removal of temporary shoring. Retightening of connections prior to final completion or closing in of inaccessible connections is recommended.

1.7.6 Field Cuts

All field cuts in timbers should be coated with an approved moisture sealant if the member was initially coated, unless otherwise specified. If timber framing has been pressure-treated, field cutting after treatment should be avoided where possible. When field cuts in pressure-treated material are unavoidable, additional field-treatment should be provided in accordance with AWPA Standard M4 [23].

1.7.7 Moisture Control

During erection operations, all timber framing, whether sawn or glued laminated timbers, should be protected against moisture absorption. Where practical, fabricated structural materials to be stored for an extended period of time before erection should be assembled into subassemblies for storage purposes. Additional information on handling, storage, and erection of glued laminated timbers is contained in AITC 111 [40].

1.8 CONCLUSION

Timber construction encompasses several different structural systems and materials, giving the designer flexibility to meet his structural and architectural needs. This chapter has presented an overview of timber construction including common wood materials and structural systems. Additional guidance has been given regarding economy, durability, seasoning, handling, storage, and erection of timber materials and systems. Where appropriate, references to other sources of information have been included.

Chapter 2 presents fundamental information regarding the properties of wood. An understanding of these basic wood properties will enable a designer to maximize the benefits of the timber members and systems while minimizing potential weaknesses and problems. Chapters 3 through 15 include detailed information regarding the structural design of timber components and connections using the Allowable Stress Design (ASD) methodology. Chapter 16 provides an overview of Load and Resistance Factor Design (LRFD). Chapters 17–19 discuss the design of timber bridges using both LRFD and ASD provisions. Chapter 20 covers the topic of fire safety in timber construction. Appendices include additional design examples and supplemental information.