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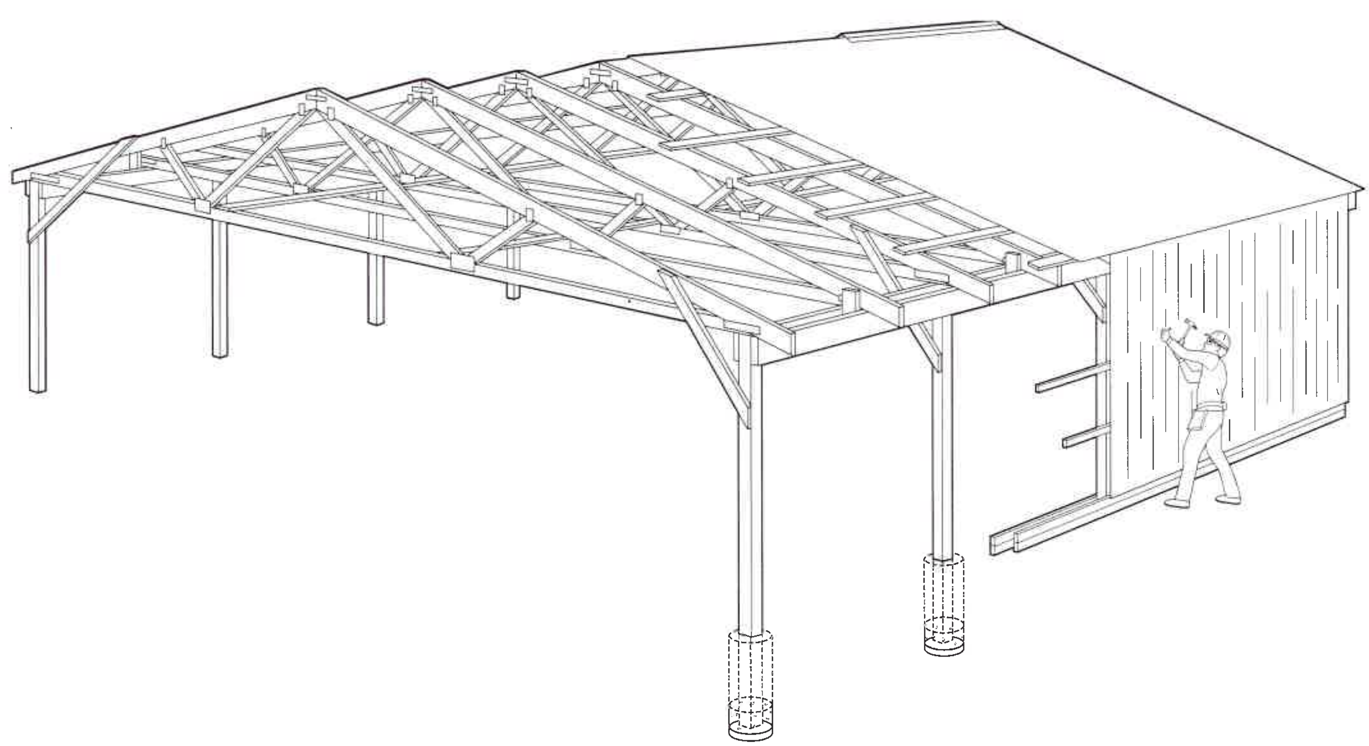
1997 Revision

POST-FRAME BUILDING HANDBOOK

Materials, Design Considerations, Construction Procedures



Natural Resource, Agriculture, and Engineering Service (NRAES)
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Acknowledgments

This publication has been peer-reviewed by the persons listed below. The publication was judged to be technically accurate and useful for cooperative extension programs and the audience.

Robert A. Aldrich
Emeritus Professor
University of Connecticut

Mike Brugger
Associate Professor
Ohio State University
OARDC (Ohio Agricultural Research and Development Center)

Kendall C. Elliott
Professor
West Virginia University

Kifle G. Gebremedhin
Professor
Agricultural and Biological Engineering
Cornell University

Curt A. Gooch, PE
Project Engineer
Agricultural Experiment Station
University of Maryland at College Park

Robert E. Graves
Professor
Agricultural and Biological Engineering
The Pennsylvania State University

James W. Hilton
Associate Professor
The Pennsylvania State University

Jim Lindley
Associate Professor
Agricultural Engineering
North Dakota State University

Harvey B. Manbeck
Professor
Agricultural and Biological Engineering
The Pennsylvania State University

John Porter
Dairy Specialist
Cooperative Extension
University of New Hampshire

Gerald L. Riskowski
Associate Professor
University of Illinois

Larry E. Stewart
Retired
Biological Resources Engineering
University of Maryland

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Post-Frame Building Handbook

Materials, Design Considerations, Construction Procedures

Edited by

Jon M. Carson
Assistant Professor of Engineering
The Pennsylvania State University
Wilkes Barre Campus

Mark Dougherty
Staff Engineer
Natural Resource, Agriculture, and Engineering Service

The authors of the 1984 edition of *Pole and Post Buildings* were:

Wilmot W. Irish
Professor Emeritus
Agricultural and Biological Engineering
Cornell University

Grant D. Wells
Field Specialist
Agricultural Engineering
Iowa State University Extension

Robert A. Parsons
Editor, ASHRAE Handbook
ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.)

Gerald R. Bodman
Professor and Extension Agricultural Engineer
Biological Systems Engineering
University of Nebraska

Natural Resource, Agriculture, and Engineering Service (NRAES)
Cooperative Extension
PO Box 4557
Ithaca, New York 14852-4557

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Natural Resource, Agriculture, and Engineering Service (NRAES)
Cooperative Extension
PO Box 4557
Ithaca, New York 14852-4557

Phone: (607) 255-7654
Fax: (607) 254-8770
E-mail: NRAES@CORNELL.EDU
Web site: WWW.NRAES.ORG

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Introduction

Post-frame utility buildings, formerly called "pole barns," are versatile and economical structures. They can be appropriate for storing machinery or housing livestock. Other uses include residential and commercial buildings, boat sheds, fair exhibit buildings, corn cribs, horizontal silos, hay barns, shops, utility sheds, covered feed bunks, lumber sheds, warehouses, roadside stands, cabins, and airplane hangars.

The National Frame Builder's Association defines a post-frame building as: "A building whose sidewalls have as its basic supporting member wood posts and/or laminated columns integrated into a structural system that acts as the bearing walls, partitions and support for the floor and roof systems." The characteristic and key element of this type of construction is the use of vertical posts or poles that act to carry building loads to the ground (see figure 1 below and figure 2, page 2). Because these wooden columns are in contact with the ground, they must be preservative-treated to resist decay (see section on Preservative Treatment, page 9).

Post-frame buildings can be cost-effective for a variety of uses when compared with buildings constructed with continuous concrete footings, foundations, and stud walls. They can range in size from simple 10-foot-by-12-foot shelters to large, clear-span buildings 100 feet wide and several hundred feet long.

One or more sides of a post-frame building may be left open for a simple, low-cost shelter. During cold weather, heavy-duty curtains can be used on open-sided structures.

This handbook will help you understand design considerations involved in the construction of a post-frame building. In some cases, particularly in rural areas where professional design help is not readily available, the information in this handbook may be used to complete the preliminary design of an agricultural building, storage shed, or other uninhabited structure. *English units of measurement will be used throughout this handbook; however, metric and other conversion factors have been included in appendix A on page 71.*

Due to the complex effects of combined loading in a post-frame structure, you should always have plans reviewed by an experienced professional designer. Table values given in this handbook are presented for guidance only and should not be used in place of assistance from an experienced design professional.

An experienced consulting engineer or other design professional will usually be able to reduce both construction costs and the risk of building failure while incorporating your specific needs into a completed building design. In addition, the design professional can be contracted to provide the following specific services:

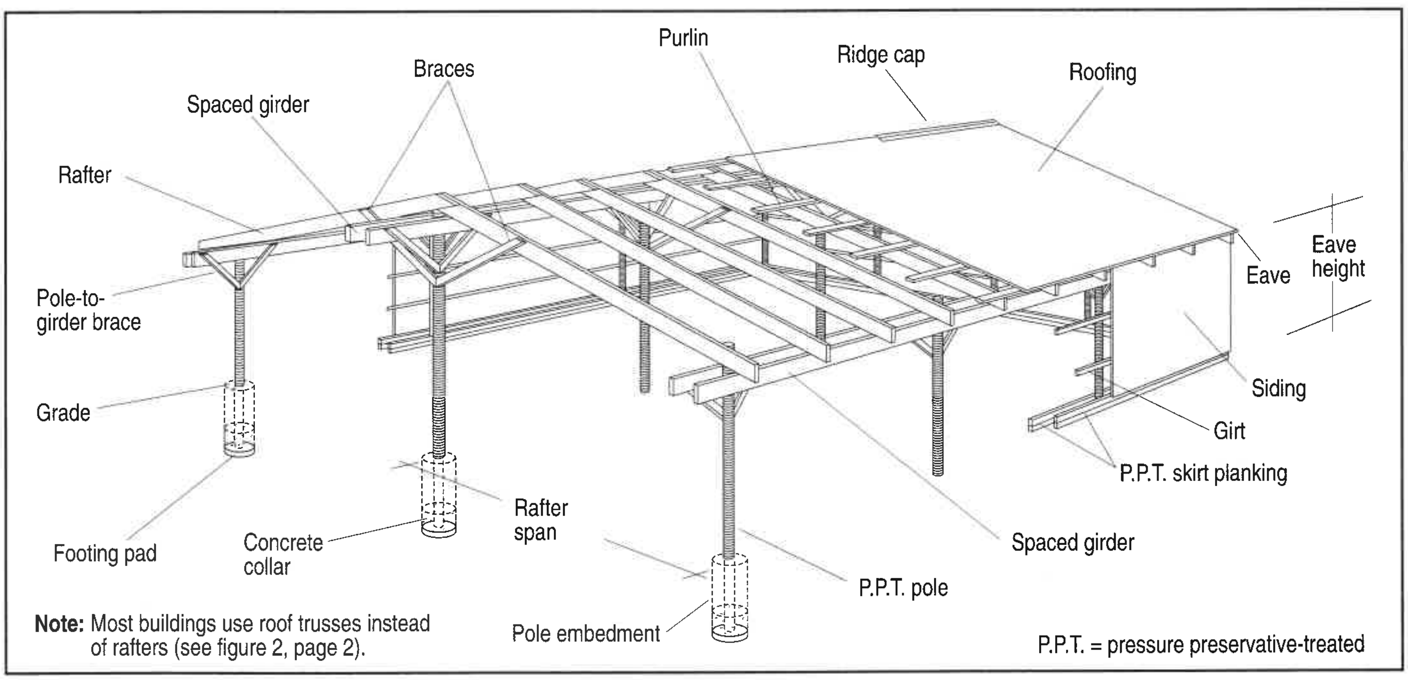


Figure 1. Traditional "pole barn" with common rafters.

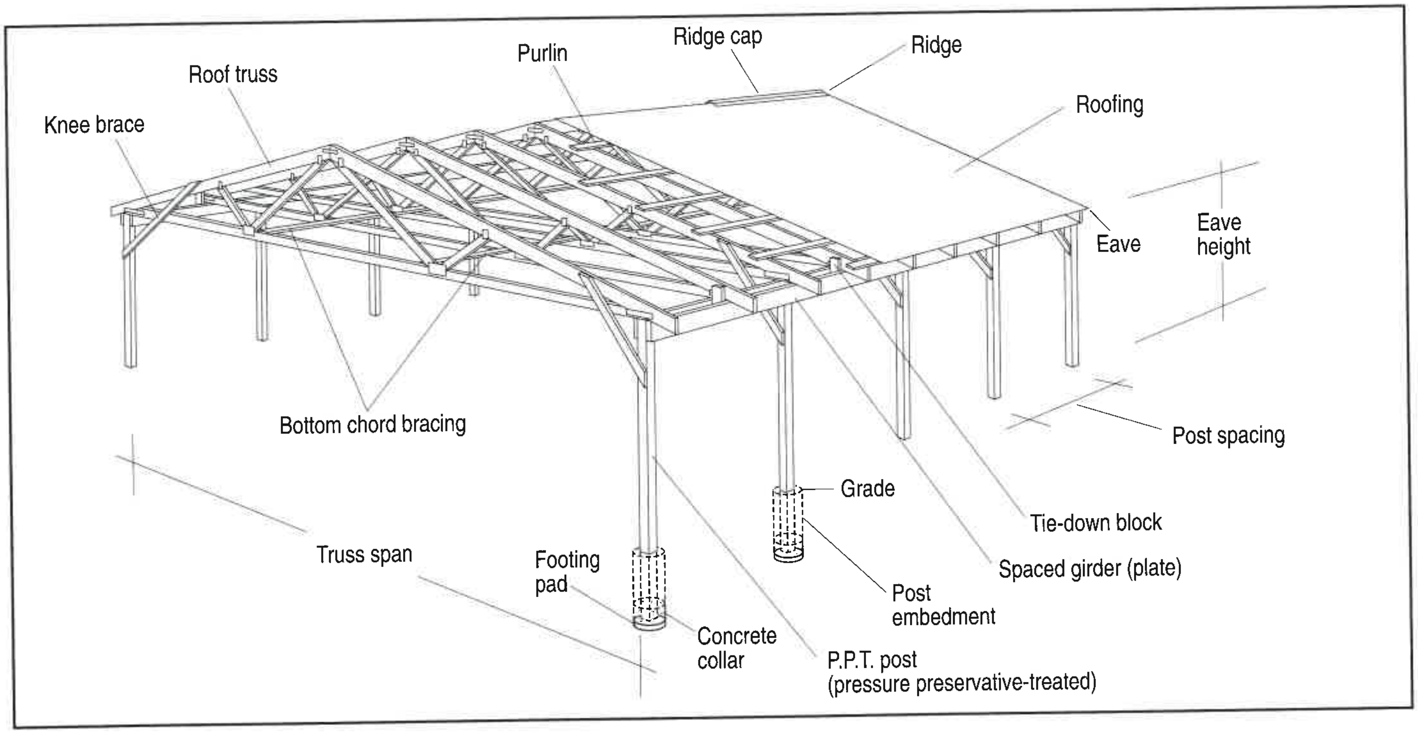


Figure 2. Post-frame building with trusses.

- drawings of and specifications for the building,
- cost estimates and construction financing plans,
- assurance of compliance with local zoning and regional codes (see section on Building Codes, page 3),
- assembly of bid packages,
- construction management (including arranging for a contractor),
- construction review to assure that the building is erected according to design plans, and
- advisability and cost of any changes to the original building plans due to specific site requirements or unexpected contingencies.

When planning a post-frame structure of any type, the following information will be required by the building designer:

- a site plan of all existing and proposed facilities,
- the intended use of the building,
- the capacity requirements of the building (square feet of storage, number of animals, tons of feed, etc.),
- special building use needs (such as animal or manure handling facilities, equipment clearances, etc.), and
- anticipated expansions or connections to existing buildings within the next twenty to thirty years.

Advantages and Limitations of Post-Frame Construction

Some of the advantages gained by selecting a post-frame structure over other types of construction are:

- Post-frame construction is generally simpler, faster, and less expensive than other types of construction.
- No massive or continuous foundation is needed.
- Site preparation is relatively simple when a level and well-drained site is chosen.
- Post-frame buildings are assembled in units (bays or bents) that can be easily added to the end of the building as more space is needed.
- A wide variety of building widths and configurations are available (figure 3). Also, since posts support the roof, sides can be left open for easy access.
- The common use of engineered structural members such as laminated posts has allowed for more flexible design alternatives (see section on Engineered Structural Wood Products, page 9).
- Business, family, or local labor can often be used for construction.
- Small post-frame structures are suitable as do-it-yourself projects.

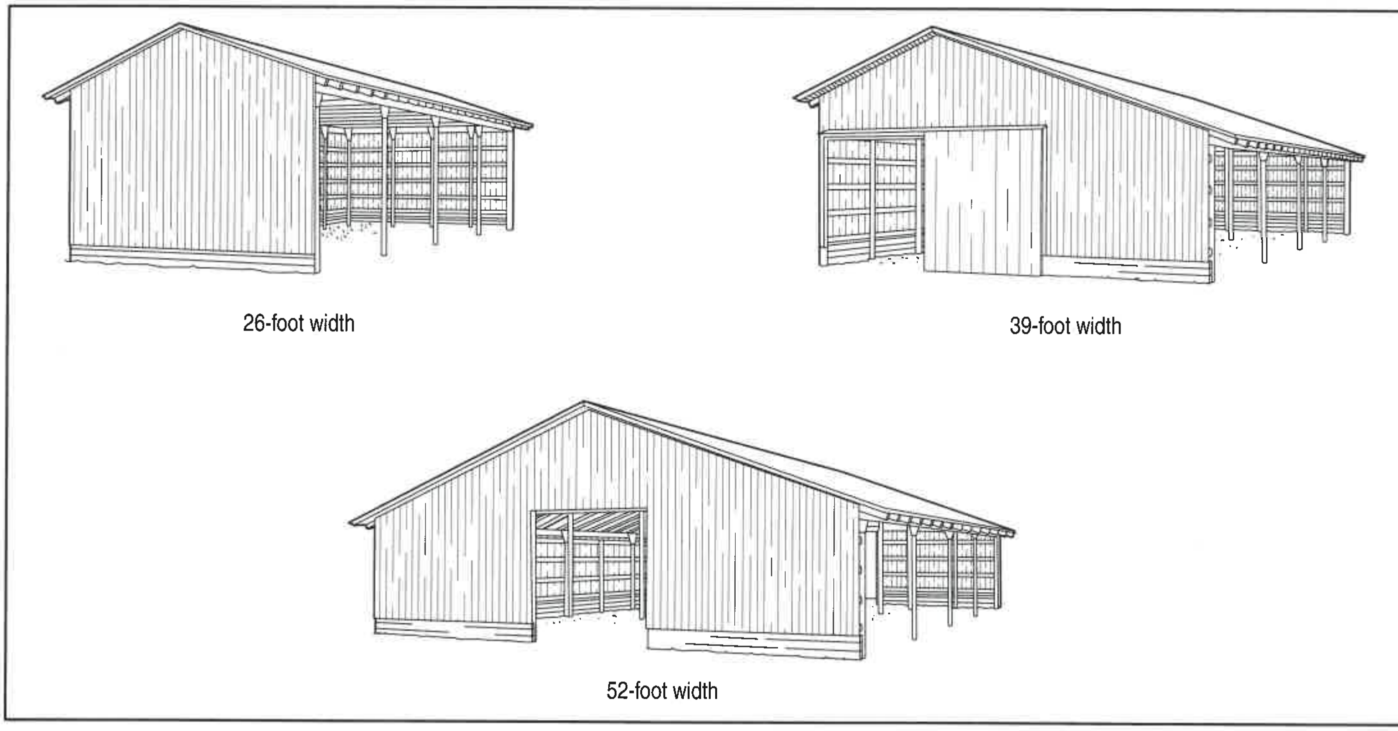


Figure 3. Selected post-frame building widths and configurations.

- Rectangular or square cross-sectional posts can be used for an even-sided, neat appearance.

Some of the limitations inherent in many post-frame structures are:

- Site conditions such as rock outcroppings can limit the depth of posts and may make other foundation types desirable or necessary.
- Post-frame utility buildings are rarely more than one story high.
- Generally, the use of wood posts (laminated or solid-sawn) and wood roof trusses limits the sidewall height to 20 feet and clear spans to 100 feet. Heights and spans greater than this require more rigorous professional design, along with builders experienced in these larger structures. Subsequently, construction costs per square foot may increase.
- Insulated post-frame buildings with interior wall finishes can be as expensive as conventionally-constructed buildings with stud walls and continuous concrete foundations.
- Round poles, if used in place of square or rectangular posts, may give a wavy or uneven appearance to the sidewalls.

Building Codes

Model building codes are legal documents that set forth the minimum requirements to protect the public health, safety, and general welfare as they relate to the construction and occupancy of buildings and structures. Most building codes are consensus documents, continually studied and periodically revised by building officials, industry representatives, and other interested parties. The content and administration of building codes vary among states and municipalities; however, most building codes regulate construction based on building occupancy and use. Building codes are usually administered at the local level, as are zoning laws.

Zoning laws are established to control construction activities and regulate land use in terms of types of occupancy, building height, and density of population and activity. Typically, land is zoned for residential, commercial, industrial, or agricultural use. Both zoning ordinances and building codes are enforced by the granting of building permits and inspection of construction work in progress. *Before planning a new post-frame building, check with local officials about specific building ordinances.*

The three primary building codes in the United States are the Uniform Building Code (UBC); the National (Basic) Building Code, published by the Building Officials and Code Administrators (BOCA); and the

Standard Building Code (SBC). Figure 4 shows the areas of model building code influence in the United States. Note that Wisconsin and New York building codes are developed on a statewide basis and are not necessarily equivalent to current model codes.

Information in this handbook is based on standard engineering practice and experience with agricultural buildings and is not intended to meet the requirements of all building codes. Historically, building codes have not applied to agricultural buildings, since the risk to life and property was perceived to be relatively small. However, code enforcement of agricultural buildings, including post-frame structures, is increasing.

The building owner must carefully consider the inherent probability of failure as a managed risk. In general, the more conservative the post-frame building design, the more expensive the initial cost. Therefore, risk and economy are inversely related. Risk of post-frame building failure can be successfully managed through the engineering design process and through building codes.

Chapter 1. Materials

The performance of any building is dependent on the materials used in the construction.

Wooden members in a post-frame building such as posts, poles, girts, purlins, braces, and trusses must be able to resist all applied loads. The ability of wooden members to resist loads is dependent on the shape, length, species, moisture content, and quality of the members, and on the fastening method. All wood that is in contact with the ground or concrete—such as posts, poles, and bottom skirting—must be preservative-treated.

Early "pole" buildings used preservative-treated poles (figure 1, page 1)—round, unsawn wooden members similar to the poles used by electric and telephone utilities. The trees used for poles are machined to remove bark and trim knots flush to the surface.

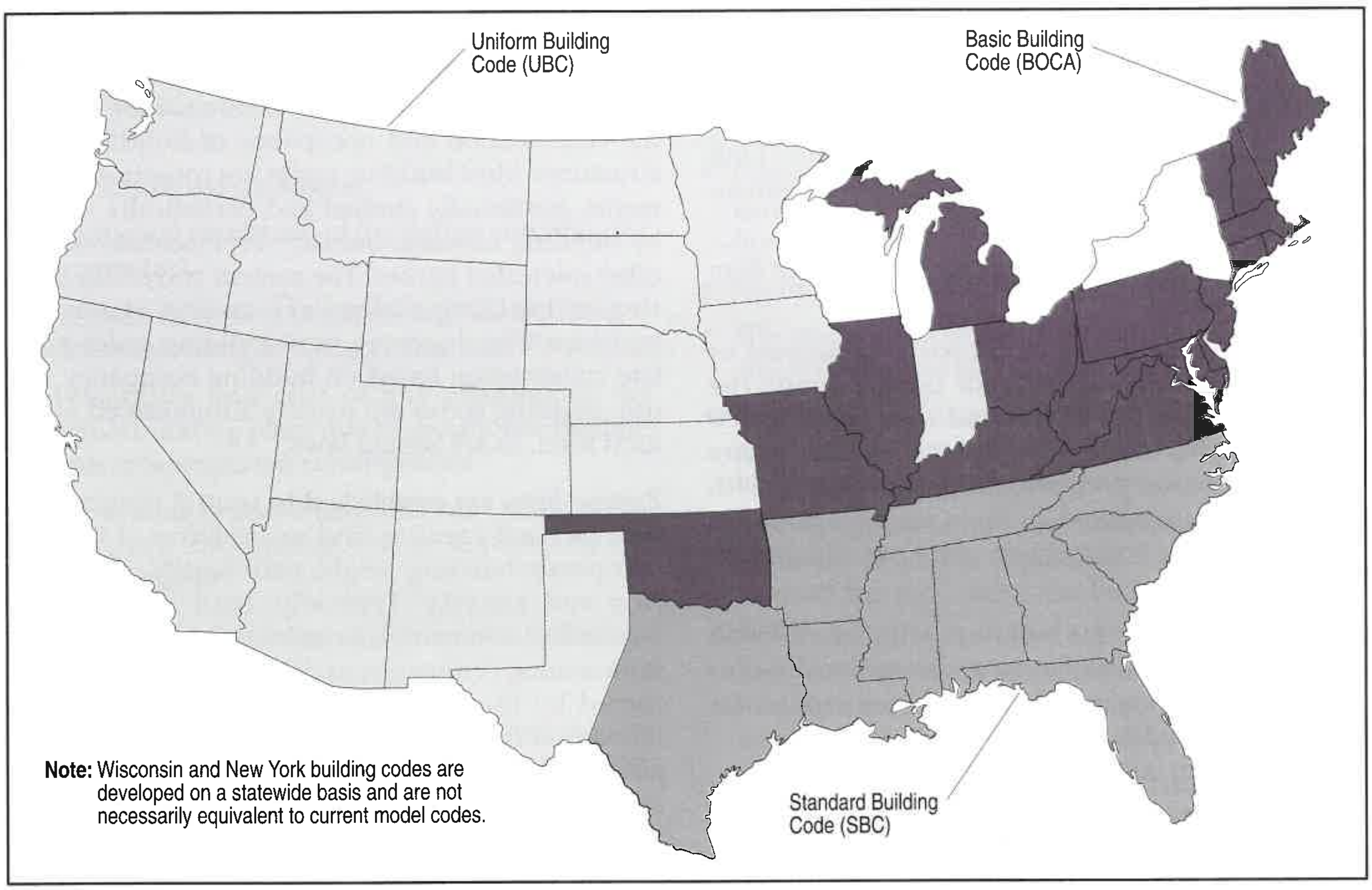


Figure 4. Model building code map. *(Reprinted with permission from Walker and Woeste,* Post-Frame Building Design, *1992.)*

The poles retain their natural taper, which provides a larger area for bearing at the bottom of the pole and a larger cross-sectional area where the greatest bending stress occurs. Poles are seldom uniform in size and taper. Solid-sawn rectangular posts and engineered posts made by laminating dimensional lumber are being used in most new buildings (figure 2, page 2). Figure 5 shows the differences among a pole, a solid-sawn post, and a glued-laminated post.

The decision of a building owner to use poles or posts will depend on availability, cost, and the desired use of the finished building. Because poles are seldom used anymore, this handbook will emphasize the use of posts (both solid-sawn and laminated) for post-frame design and construction.

The roofing that keeps wind, rain, and snow out of the building must be supported by the roof framing. The selection of roofing and siding materials will be influenced by cost, length of service, and desired application, including aesthetics. Roof framing directly or indirectly transfers roof loads to the posts, and the posts carry the load to the ground.

Lumber

Wood is a natural material with characteristics including strength, ease in machining, and good fastener-holding ability that make it desirable for post-frame buildings. Wood characteristics that create design challenges include differences in strength due to species, grade, moisture content, temperature, and orientation to a load. The American Forest & Paper Association (AFPA) has a recommended practice called the *National Design Specification for Wood Construction*, or *NDS*. The *NDS* has recommended procedures for the proper design of structural wood members. Accepted practices of design using graded lumber, structural glued-laminated timbers, timber piles, and standard fasteners are included in the specification.

A supplement to the *NDS*, *Design Values for Wood Construction*, is also available from AFPA. This publication provides design values for wood construction using graded wood products of various species and dimensions. Design values in the *NDS Supplement* are based on grade, species, size, and moisture content, as well as a variety of specific modification factors (see section on Structural Lumber Grades on page 6).

Size

Lumber is usually sold by nominal, or rough-sawn, size. Most commercial lumber is dressed or planed smooth so it is ½ to ¾ inch smaller than the nominal size. Lumber that is designated as S4S has been "surfaced on four sides." Table 1 lists sizes of commonly available construction lumber. Appendix B in the back of this handbook lists standard dressed sizes and design properties of S4S sawn lumber.

The standard unit of measurement for a quantity of lumber is the board foot, also referred to as the board measure. The measurement represents a 1-inch-thick board 12 inches wide by 12 inches long. The board measure, in feet, for each 10 and 12 feet of length for selected lumber sizes is given in table 1. Prices are quoted in dollars per thousand board feet (or thousand board measure, M.B.M.), dollars per board foot

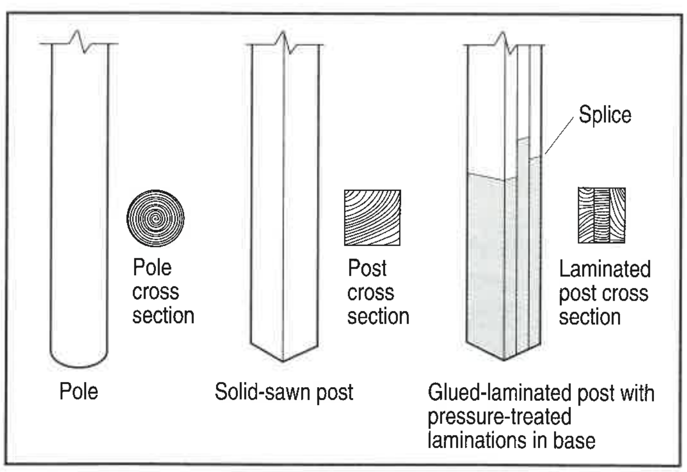


Figure 5. Poles, posts, and laminated posts.

Table 1. Nominal size, surfaced size, and board measure of dimension lumber and timbers.

	Dimension Lumber & Timber Size			
	Nominal Size, inches	Actual Size, inches	Board Feet per 10-foot length	Board Feet per 12-foot length
Dimension Lumber	2x4	1½ x 3½	6⅔	8
	2x6	1½ x 5½	10	12
	2x8	1½ x 7¼	13⅓	16
	2x10	1½ x 9¼	16⅔	20
	2x12	1½ x 11¼	20	24
Posts & Timbers	4x4	3½ x 3½	13⅓	16
	4x6	3½ x 5½	20	24
	6x6	5½ x 5½	30	36
	6x8	5½ x 7½	40	48
	6x10	5½ x 9½	50	60
	8x8	7½ x 7½	53⅓	64

Adapted from American Forest and Paper Association, *Design Values for Wood Construction, NDS Supplement*, Revised 1991 Edition, p. 10.

Board Feet (or Board Measure) = [Nominal Width (inches) x Nominal Thickness (inches) x Actual Length (feet)] / 12.

(or board measure, B.M.), lineal feet (L.F.), or by the piece. To determine the amount of board feet in a piece of lumber, multiply the nominal width in inches by the nominal thickness in inches by the length in feet and divide by 12, as follows:

board feet = [nominal width (inches)
x nominal thickness (inches)
x length (feet)] ÷ 12

Lumber is commonly available in 8- to 20-foot lengths in 2-foot increments. Longer lengths are available by special order. Some common definitions for lumber, as used in the industry, are:

Boards – lumber with a nominal thickness between 1 and 1½ inches and a width of 2 to 16 inches

Dimension Lumber – lumber with a nominal thickness between 2 and 4 inches and a width of 2 to 16 inches

Timbers – lumber that is 5 inches or thicker in the smaller dimension

Structural, sawn dimension lumber is used as framing lumber for girders, rafters, girts, purlins, and bracing, where strength, stiffness, and uniform size are important. Usually only one or two of the general-purpose construction woods such as Southern Pine, Douglas Fir, Hemlock, or Spruce-Pine-Fir are stocked in retail yards.

Structural Lumber Grades

Assigned values for lumber strength are required to properly size a wooden member so it will resist anticipated loads. Grading of structural lumber accounts for the fact that the strength of each piece of lumber is affected by knots, growth patterns, and species of tree. Most solid-sawn structural lumber is graded as either visually stress-rated (VSR) or machine stress-rated (MSR).

Lumber is graded following standards established by agencies such as the Northeastern Lumber Manufacturers Association (NELMA), the Southern Pine Inspection Bureau (SPIB), the Western Wood Products Association (WWPA), the National Softwood Lumber Bureau (NSLB), and others. Certification is provided by the American Lumber Standards Committee Board of Review.

VSR and MSR Lumber

Typical VSR grades include Select Structural, No. 1, No. 2, No. 3, Stud, Construction, and Utility grade. MSR lumber uses grades that are based on the lumber's bending strength and modulus of elasticity. All lumber used in the framing of a post-frame building should be structurally graded, with the grade stamped onto each piece of lumber. Table 2 lists design values for visually graded Spruce-Pine-Fir, according to grade. Note that values in table 2 are also based on the thickness and width of the lumber. Design values for bending, tension, shear, compression, and stiffness (modulus of elasticity) are available for most lumber grades and species.

Machine stress-rated (MSR) lumber is lumber that has been non-destructively tested using mechanical methods to measure stiffness. While visually graded lumber adequately meets the needs of most residential use applications, MSR lumber can be cost-competitive for members such as glued-laminated tension members with more demanding engineering specifications. Bending strengths and deflections of lumber pieces are predicted based on their modulus of elasticity (see section on Stresses in Wood, page 32).

MSR lumber is visually graded as well and is sorted into modulus of elasticity classes before being assigned engineering values. To properly specify MSR lumber for an engineered structural application,

Table 2. Design values for visually graded Spruce-Pine-Fir dimension lumber.

Commercial Grade	Size Classification	Design values in pounds per square inch (psi)					
		Bending, Fb*	Tension parallel to grain, Ft*	Shear parallel to grain, Fv	Compression perpendicular to grain, Fc ⊥	Compression parallel to grain, Fc*	Modulus of elasticity, E
Select Structural	2"–4" thick	1250	675	70	425	1400	1,500,000
No. 1 / No. 2	and	875	425	70	425	1100	1,400,000
No. 3	2" and wider	500	250	70	425	625	1,200,000
Stud		675	325	70	425	675	1,200,000
Construction	2"–4" thick	975	475	70	425	1350	1,300,000
Standard	and	550	275	70	425	1100	1,200,000
Utility	2"–4" wide	250	125	70	425	725	1,100,000

Source: American Forest and Paper Association, *Design Values for Wood Construction, NDS Supplement*, Revised 1991 Edition, p. 22.

* Tabulated design values must be multiplied by the appropriate size, repetitive member, and flat use factors.

Table design values are for normal load duration (ten years) and dry service conditions (< 19% moisture content).

request grade-stamped, machine-rated lumber and specify the bending strength, Fb, corresponding modulus of elasticity, E, and nominal sizes and lengths required. A typical E-rated grade of MSR lumber is 2000f-1.8E, which indicates lumber with a bending strength of 2,000 pounds per square inch and a modulus of elasticity (stiffness) of 1.8 million pounds per square inch.

Grades for glued-laminated (glulam) members are similar to those for solid-sawn lumber. Typical visual grades are 20f-V1 and 24f-V1, where 20f indicates a beam with a bending strength of 2,000 pounds per square inch when used as a simply supported beam (i.e., with one support under each end). Likewise, 24f indicates a simply supported beam with a bending strength of 2,400 pounds per square inch. The V designation indicates that the individual laminations have been visually graded. The number after the V identifies a specific combination of lumber with assigned design stresses. Each glulam member should have a grade stamp affixed and should also have the top side of the cross section clearly marked to assure that it is installed properly. Otherwise, the glulam member could fail due to loads it was not designed to carry.

Ungraded Lumber

Local woodlots are often overlooked as a source of high-quality, low-cost wood products for flooring, furniture, construction, crating, specialty forest products, woodworking projects, and more. There are many opportunities to purchase lumber from local sawmills or have lumber sawn from standing timber. However, if the sawmill does not have facilities and personnel to dry, surface, and grade structural lumber, the lumber will be classified as ungraded.

Ungraded lumber should not be used as a direct substitution for graded lumber and should not be used for structural framing of post-frame buildings. The greater variability of ungraded lumber makes it less reliable where strength is important. Because non-stress-graded lumber lacks assigned strength properties, it is generally used in construction as boards, battens, siding, shelving, or paneling. Ungraded lumber can also be used for trim, fencing, gates, and windbreaks. For more information on the use of tree species native to the eastern United States, refer to *Lumber from Local Woodlots*, NRAES–27. (A list of suggested readings, along with ordering information, appears on page 78.)

Posts

Posts in a post-frame building act to transfer building loads to the ground. The size (cross-sectional area), shape (square or rectangular), length, and material all influence post performance. The weight of the building, loads inside the building, and snow and wind loads all act to either compress or bend the post. All structural members, including the supporting posts in a post-frame building, must be properly designed to resist all applied loads, as well as damage from insects and decay.

Posts have uniform rectangular or square cross sections and are either solid-sawn members or an assembly of laminated members. Laminated posts are usually built up using nominal 2-inch lumber and are laminated with adhesive (glue) or mechanical fasteners. Glued-laminated posts are factory-made with laminations that are glued together. Mechanically laminated posts use bolts, screws, nails, or other fasteners to hold the individual wood laminations together. Mechanically laminated posts can be made at the construction site.

Solid-Sawn Posts

Solid-sawn posts in common nominal sizes such as 4-by-6 (3.5 inches by 5.5 inches), 6-by-6 (5.5 inches by 5.5 inches), and 6-by-8 (5.5 inches by 7.5 inches) are in stock in lengths up to 20 feet at many lumber yards. Because rectangular posts are more uniform in size and straighter than poles, posts are much easier to build with compared to poles. Cost-effective building designs using solid-sawn posts have been used for many years by industry and agriculture. Research has verified the strength properties of the various grades and species of solid-sawn posts. Graded, solid-sawn lumber for post construction is not always readily available.

Laminated Posts

Laminated posts, whether glued-laminated or mechanically laminated, have several advantages over solid-sawn posts, including both strength and versatility. Since laminated posts are engineered products, their relative strength is a function of design. Laminated post strength is dependent on the type of lamination, the presence or absence of splices (figure 6, page 8), the type and number of fasteners, and the type and direction of applied loads. Various grades of lumber can be used in a laminated post by placing the strongest lumber in the position where the post

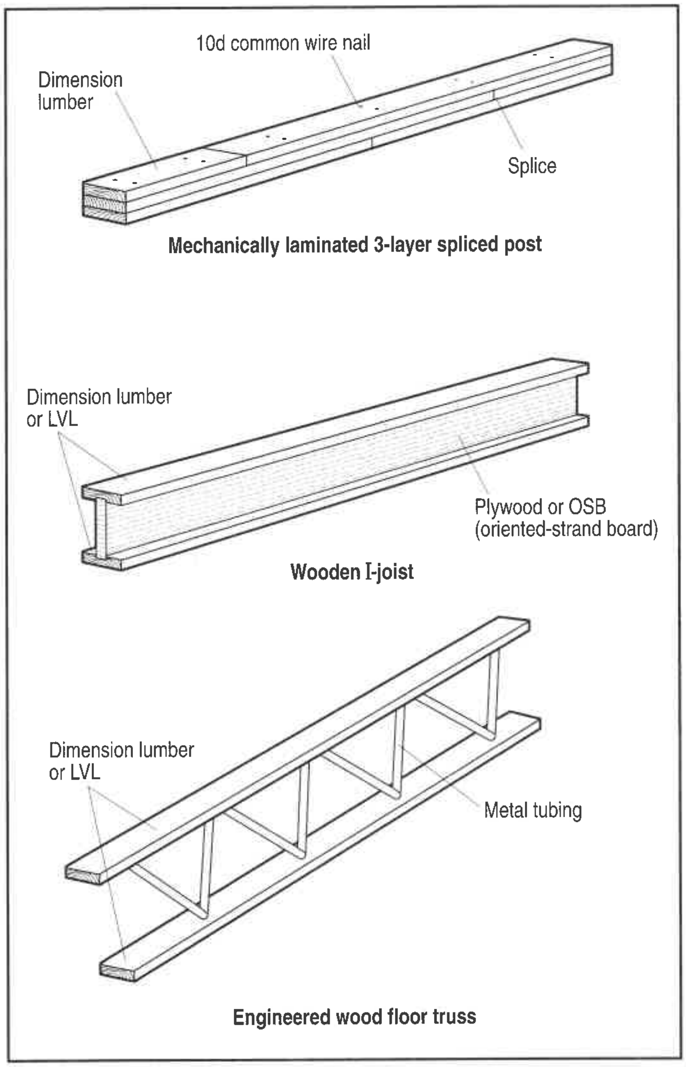


Figure 6. Engineered structural wood products.

will be stressed the most. Preservative-treated lumber can also be used with untreated lumber to create laminated posts with treatment only on the end that will be in the ground, as shown in figure 5, page 5.

Structures using glued-laminated or mechanically laminated posts can be designed to better fit with trusses. Figure 7 shows how the heel (end) of a roof truss can be sandwiched between the outside layers of a three-layer laminated assembly. By leaving a portion of the center layer out until post erection, placement of the truss between the outer layers assures a better truss-to-post connection, which is essential to maintain rigidity in the structure.

Glued-Laminated Posts

An important advantage that glued-laminated members have over solid-sawn members is more uniform strength and stiffness. This is because laminating acts to distribute the natural and seasoning defects inherent within the individual wood laminations. Glued

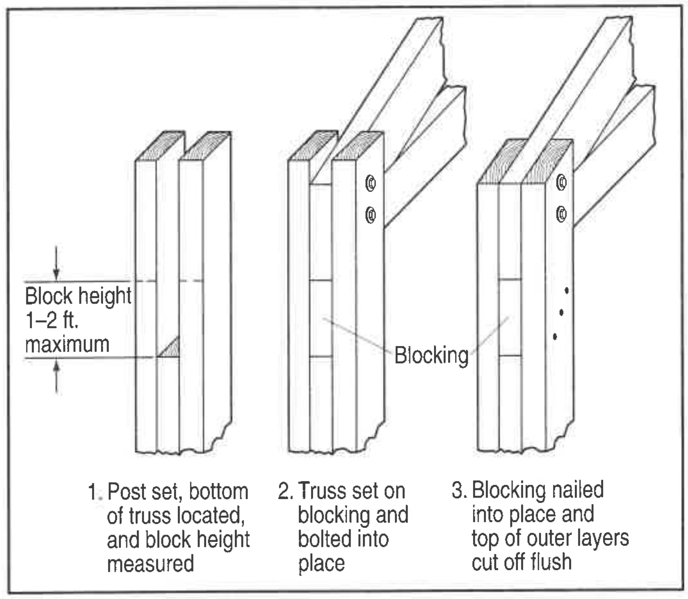


Figure 7. Placement of a truss between the outer layers of a three-layer assembly. *(Reprinted with permission from Walker and Woeste,* Post-Frame Building Design, *1992.)*

laminations reduce the effects of knots and other defects on member strength. The resulting higher strength of factory glued-laminated members permits higher allowable design stress values than those for similar solid-sawn members.

Smaller-sized glulam members can often be used in place of solid-sawn members in a variety of applications, including posts. For shorter members, graded glued-laminated posts may cost more than solid-sawn posts. However, the greater strength and longer available lengths of glulam members make their use appealing for a wide variety of construction applications.

Mechanically Laminated Posts

Mechanically laminated posts use nails, bolts, or other fasteners and may be fabricated wholly or partly at the construction site. When nails are used to join individual layers, the assembly is usually referred to as a nail-laminated joint. With proper design and on-site assembly of mechanically laminated posts, hauling of long timbers over the highway may be avoided. However, special care must be taken during assembly to follow the design specifications for the proper type, size, location, and number of fasteners.

Mechanical fasteners used above grade to join waterborne preservative-treated lumber should be AISI (American Iron and Steel Institute) Type 304 or 316 stainless steel, silicon bronze, copper, or double hot-dipped galvanized (zinc-coated) steel nails. Mechanical fasteners used below grade should be AISI Type 304 or 316 stainless steel. *The length or number of* *post laminations must not be modified in the field without reanalyzing the original post design application.* ASAE has drafted a new engineering practice titled "Design Requirements and Bending Properties for Mechanically-Laminated Posts" for use by designers and fabricators of mechanically laminated posts.

CAUTION: Glued-laminated and mechanically laminated posts can behave quite differently from each other under load. While there can be considerable slip between the layers in a mechanically laminated post, there is little or no slip in a glued-laminated post. In this regard, glued-laminated posts behave more like solid-sawn posts. Slip between mechanically laminated layers is even greater when there is a splice joint between treated and untreated portions of a nail-laminated post.

Engineered Structural Wood Products

There are numerous methods and materials used for rafters, girders, or joists. Since dimension lumber can be most easily found in lengths less than 20 feet, designs that call for longer lengths may require special material. Structural glued-laminated (glulam) timber is made by gluing layers of dimension lumber together to create long, deep members of practically any dimension and length. Glulam beam cross-sections may be as large as 12 inches wide and 50 inches deep. Glulam beams can be over 100 feet long. Mechanically laminated members, joined with nails, bolts, and/or other mechanical fasteners are also available. Both mechanically laminated and glued-laminated members are used as sidewall and endwall posts in post-frame buildings.

Laminated veneer lumber (LVL) is another type of engineered structural wood product. LVL consists of dimension lumber (up to 4 inches thick, 14 inches wide, and 100 feet long) manufactured from thin veneers ($\frac{1}{10}$ to $\frac{1}{8}$ inch thick). Laminated strand lumber (LSL) is similar to LVL, except that it is manufactured by gluing small wood strands approximately $\frac{1}{4}$ inch wide and 4 to 6 inches long together to form continuous 2-by-4 to 4-by-14 members up to 100 feet in length.

Plywood is also an engineered wood product, made from alternating sheets of pressed veneer. Graded plywood panels 8 feet long are commonly used for roofing, siding, and floor support (see section on Types of Roofing and Siding, page 16). Oriented strand board (OSB) is another type of engineered panel. OSB is made of pressed small wood strands formed into a mat. OSB panels can be manufactured in sizes up to 28 feet long because of the large presses used in their manufacture.

Engineered structural wood products are used to form continuous members in a variety of cross-sections, including those in the shape of wooden "I" beams or joists. Engineered wood trusses are available that utilize metal tubing, or solid rectangular components such as OSB or plywood. Figure 6 presents examples of engineered structural wood products. Allowable load and span tables for most engineered structural wood products are available from the manufacturer.

Probably the greatest advantage of engineered lumber is that continuous members of almost any length can be fabricated. The decision to use laminated posts or other engineered structural wood products in place of solid-sawn lumber is largely dependent on the labor and equipment costs associated with their fabrication, as well as the design requirements of the structure. Before choosing an engineered structural wood product, make sure that the materials used in its manufacture (including glues) are compatible with the conditions where it will be used (see section on Fasteners, page 48). Since verifiable allowable stress values are required by the designer, only graded lumber products can be used for structural engineering applications.

Preservative Treatment

Wood in contact with the ground or used in a high-moisture environment must be treated with a preservative to prevent degradation from decay and insects. Wood decay, or rotting, is caused by various fungi that use the wood for food. Insects damage wood structures when they use the wood for food and/or shelter. Deterioration of wood by fungal decay or insect damage reduces the strength of the wood and leads to structural failure. Preservative treatment makes wood toxic to fungi and insects, so the wood's original internal structure and ability to resist applied loads is retained.

Two major types of wood preservative treatments are available: (1) waterborne preservatives, which include inorganic arsenicals and (2) organic and organometallic preservatives, which include creosote, creosote solutions, copper naphthenate, and pentachlorophenol. These chemicals are approved by the U.S. Environmental Protection Agency (EPA) for safety and by the American Wood Preservers' Association (AWPA) for effectiveness. Wood that has been

Table 3. Selected uses for preservative-treated wood.

Application	Inorganic Arsenicals	Penta	Creosote
Production Agriculture			
Poles and timbers (structural)	yes	yes*	yes*
Animal pen or stall dividers	yes	no	no
Ground contact	yes	yes*	yes*
Splash boards, skirt boards	yes	yes*	yes*
Residential/Commercial			
Interior use	yes	no	no
Ground contact (residential)	yes	yes*	no
Ground contact (commercial)	yes	yes*	yes*
Laminated beams	yes	yes*	no
Log cabins/homes	yes	no	no
Trim and siding	yes	yes	no
Sills, plates, and headers	yes	no	no
Wood block flooring	yes	no	yes*
Bridge timbers	no	yes	yes

Adapted from Walker and Woeste, *Post-Frame Building Design,* 1992, p. 181.

*Penta- and creosote-treated wood require two coats of sealer in these applications. Urethane, epoxy, and shellac are accepted sealers for both penta- and creosote-treated wood. Enamel, latex, and varnish are acceptable sealers for penta-treated wood.

preservative-treated is not a restricted-use material but should not come in contact with feed or foodstuffs. When used properly, preservative-treated lumber poses no significant threat to the user or the environment. Still, preservative-treated (often called "pressure-treated") wood should only be used where protection from decay or insect damage is necessary. Table 3 presents selected uses for preservative-treated wood in construction applications.

The effectiveness of preservative treatment is dependent on the penetration of the chemical into the wood and the amount of the chemical retained inside the wooden member. For effective penetration, the chemical must be injected throughout the entire piece of wood using large pressure vessels. Soaking the wood in the chemical or applying the chemical with a brush are not effective methods of applying preservative treatment.

Table 4 summarizes the amounts of preservative that should be retained in wood used on farms as recommended by AWPA Standards C16-90 (Wood Used on Farms) and C15-90 (Commercial Residential Use). In some cases, lumber meeting recommended preservative treatment standards may need to be special ordered. For quality assurance, obtain preservative certification from the lumber supplier or purchase only stamped wood. The American Lumber Standard Committee has accredited eight agencies (and their individual logos) for certification of preservative-treated wood. Stamps from accredited agencies assure compliance with industry standards (figure 8). Presently, most waterborne salt-treated lumber is stamped.

Table 4. Recommended minimum preservative retention for wood use on farms, pounds per cubic foot.

	Organic & Organometallic		Waterborne		
	Creosote	Penta.	ACA	ACZA	CCA
Posts, sawn four sides as structural members					
All Softwood species	12.0	0.60	0.60	0.60	0.60
Round poles, as structural members					
Southern Pine, Ponderosa Pine	7.5	0.38	0.60	0.60	0.60
Red Pine	10.5	0.53	0.60	0.60	0.60
Coastal Douglas-Fir	9.0	0.45	0.60	0.60	0.60
Jack Pine, Lodgepole Pine	12.0	0.60	0.60	0.60	0.60
Western Red Cedar, Western Larch, Inter Mountain Douglas Fir	16.0	0.80	0.60	0.60	0.60
Lumber, all softwood species					
In contact with soil	10.0	0.50	0.40	0.40	0.40
Not in contact with soil	8.0	0.40	0.25	0.25	0.25
Plywood					
In contact with soil	10.0	0.50	0.40	0.40	0.40
Not in contact with soil	8.0	0.40	0.25	0.25	0.25
Foundation	NR	NR	0.60	0.60	0.60
Greenhouse					
Above ground	NR	NR	0.25	0.25	0.25
Soil contact	NR	NR	0.40	0.40	0.40
Structural posts	NR	NR	0.60	0.60	0.60

Adapted with permission from Walker and Woeste, *Post-Frame Building Design,* 1992, p. 178.

As recommended by the American Wood Preservers' Association.

Standard C16-90, Wood Used on Farms.

Standard C15-90, Commercial Residential Use

NR = Not recommended

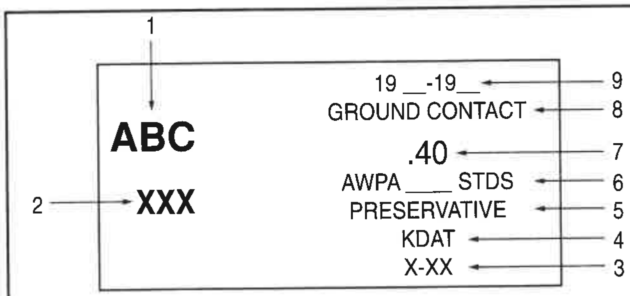
Creosote = Creosote & creosote solutions

Penta. = Pentachlorophenol

ACA = Ammoniacal copper arsenate

ACZA = Ammoniacal copper zinc arsenate

CCA = Chromated copper arsenate



1 - The identifying symbol, logo, or name of the accredited agency.
2 - The company name and location of home office; or company name and number; or company number.
3 - If applicable, length and/or class.
4 - If applicable, moisture content after treatment.
5 - The preservative used, which may be abbreviated.
6 - The applicable American Wood Preservers' Association (AWPA) commodity standard.
7 - The preservative retention, in pounds per cubic foot.
8 - The exposure category (e.g. Above Ground, Ground Contact, etc.).
9 - The year of treatment, if required by AWPA standard.

Figure 8. Typical quality mark for preservative-treated lumber. *(Courtesy of American Lumber Standard Committee, Inc.)*

Waterborne Preservatives

The three waterborne preservatives approved by AWPA for structural posts and poles are ammoniacal copper arsenate (ACA), ammoniacal copper zinc arsenate (ACZA), and chromated copper arsenate (CCA). These three waterborne preservatives have a high resistance to leaching and have excellent service records. The service life of test stakes treated with 0.40 pound per cubic foot retention of CCA showed no failures after forty years. Waterborne preservative chemicals react with wood to form tightly fixed insoluble complexes, which reduces or eliminates the risk of exposure to people and animals. All wood treated with waterborne preservatives can be painted when the wood dries.

The most widely used waterborne preservative in the United States and Canada is CCA, where it is used for treatment of solid-sawn lumber. Waterborne preservatives ACA and ACZA are commonly used for preservative treatment of coastal Douglas Fir and some Hemlock Firs. ACA is used in Canada and ACZA is used in the United States.

Organic and Organometallic Preservatives

Creosote is a black or brown oil derived from the distillation of coal or other tars. It is the oldest major wood preservative. Creosote is highly toxic to wood-destroying organisms, is easily applied, and has a relatively low cost. Objections to the use of creosote include its strong odor and the possibility of skin burn upon contact. Creosote vapors are harmful to growing plants. The average service life of a creosoted utility pole is thirty to thirty-five years, with some railroad crossties lasting up to fifty years. Creosote is the least used of all wood preservatives for lumber and structural posts and poles.

Copper naphthenate is an organometallic preservative that is carried into the wood by an oil. Copper naphthenate is listed by AWPA Commodity Standard C2-90 for lumber in contact with the soil at 0.60 pound per cubic foot retention. AWPA Standards C14-90 (Highway Construction) and C16-90 (Wood Used on Farms) list copper naphthenate for treatment of coastal Douglas Fir and Southern Pine at 0.075 pound per cubic foot retention.

Pentachlorophenol, called penta, is a chlorinated phenolic compound in an oil carrier used for preservative treatment of woods. Because the heavy oils that remain in the wood are generally unpaintable, light solvents such as mineral spirits are often used as an alternative carrier for ground contact members in post-frame construction. Penta compounds are fat-soluble and can be absorbed through the skin; therefore, excessive contact should be avoided. Penta is an irritant to the skin, eyes, nose, and throat and has toxic effects in cattle and plants. Neither penta nor creosote should be used in residential interiors or where they may come in contact with animal feed. Penta-treated test stakes have had no reported failures after twenty-four years of continuous ground contact. Penta's primary use is in the treatment of utility poles.

Precautions and Construction Recommendations

Wood preservatives must be toxic to protect the wood. Under certain conditions, exposure to freshly treated wood can be hazardous. The main concerns about using pressure-treated wood are human and animal exposure. *Before handling, be sure that preservative-treated wood has been dried and has no surface residue.* Some other common precautions that should be used with treated wood products are:

1. Do not use preservative-treated wood where the potential exists for contamination of food or animal feed. For example, do not use pressure-treated wood in cutting boards, beehives, or structures for storing silage or grain.
2. Do not burn preservative-treated wood scraps. Dispose of them by ordinary trash collection.
3. Avoid contact or inhalation of sawdust from preservative-treated wood.
4. After working with preservative-treated wood, wash before eating.
5. Wash clothes that have come in contact with preservative-treated wood separate from other laundry.
6. Penta- or creosote-treated wood should not be used in the interior of buildings, where it may come in contact with skin, or where livestock can chew or lick the wood.

Corrosion of metal fasteners in treated wood is an important consideration in the design of post-frame buildings. Most woods are slightly acidic, having a pH of 3 to 6. Corrosion of steel and galvanized steel in acidic conditions increases when wood moisture content increases above 18%. Salts from waterborne preservatives such as CCA can accelerate corrosion, especially if treated wood is not dried before use. Use only treated lumber that has been properly dried to at least 19% moisture content *after treatment.*

Corrosion of metal fasteners can be especially severe in high-humidity conditions where two dissimilar metals are in contact with each other. For protection, select nails and screws for pressure-treated wood that are double hot-dipped, zinc-coated galvanized, or Type 304 or 316 stainless steel. The Engineered Wood Association (formerly the American Plywood Association) recommends stainless steel nails for below-grade plywood construction. Corrosion of metal fasteners in wood treated with oil-type preservatives (such as penta and copper naphthenate) is usually not a problem because the heavy oils tend to coat metal surfaces.

To ensure long service life and avoid decay in wood construction, the following design and construction recommendations are provided:

1. Use only dry lumber that is free from decay and mold.
2. Design wood structures to keep wood dry and allow for proper drainage.
3. Use wood treated to the proper retention (table 4, page 10).
4. Use lumber that has been dried to 19% moisture content *after treatment* (18% for plywood).
5. Keep wood stacked off the ground and protected from weather until it is used.
6. Use preservative-treated wood for ground contact applications, or for wood in contact with concrete, especially at or near grade.
7. When preservative-treated laminations are used for soil embedment (as in posts), all treated laminations should extend a minimum of 16 inches above the exterior gradeline.
8. Avoid sawing or drilling holes in treated wood, unless exposures can be field-treated with several coats of copper naphthenate (minimum 2% copper). Otherwise, sawing and drilling almost always leaves untreated wood exposed.
9. After construction, remove all wood pieces, sawdust, and other debris from interior walls and other construction areas.

Roof Trusses

Roof trusses are an important part of an engineered wood structure. Trusses consist of structural dimension lumber fastened together in various configurations to allow economical clear spans from 20 feet to 60 feet wide. The components of a truss are identified in figure 9. *Proper truss-to-post connections are essential if the truss is to carry the roof load to the posts.* Proper truss anchoring is also required to withstand wind uplift forces that may occur. Figure 10 shows a typical truss-to-post connection using two ½-inch bolts.

Trusses are just one part of the building structure. Although they are strong in resisting vertical loads, trusses can collapse from loads perpendicular to the plane of the truss if not braced properly. For example, roof trusses subjected to high winds can collapse together if not properly braced. Bracing between trusses assures that the structure can resist wind or impact loads that "push" against the building both during and after construction (see section on Bracing on page 46).

Typical lumber grades for truss components are Select Structural or No. 1 in the chords of the truss and No. 2 for truss webs. Trusses may be fabricated at the building site, but from a structural and

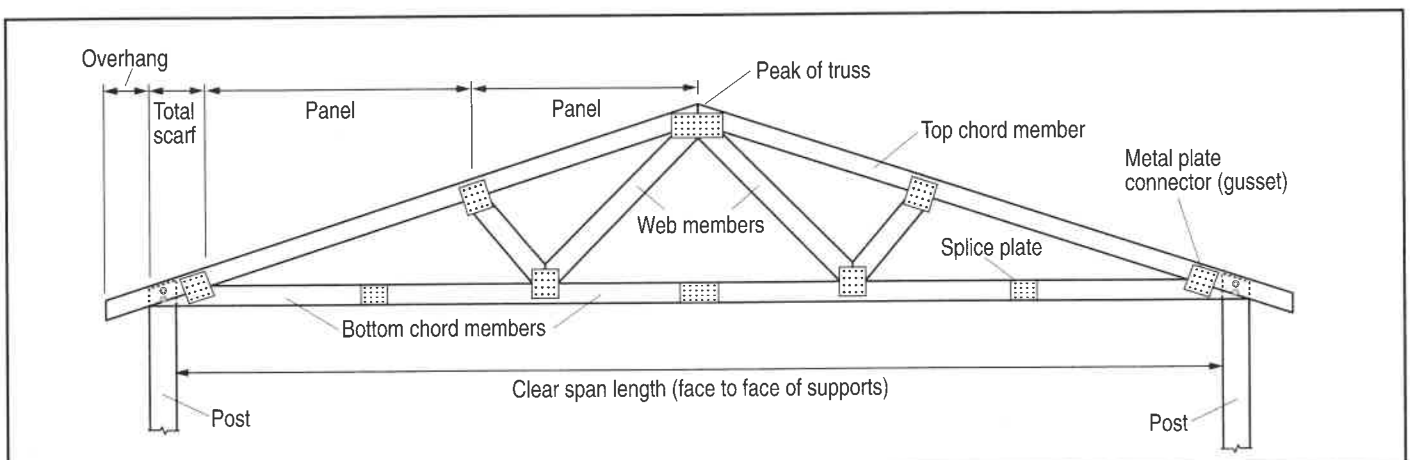


Figure 9. Components of a truss. (*Adapted from* National Design Standard for Metal-Plate-Connected Wood Truss Construction, *ANSI/TPI 1-1995, Truss Plate Institute.*)

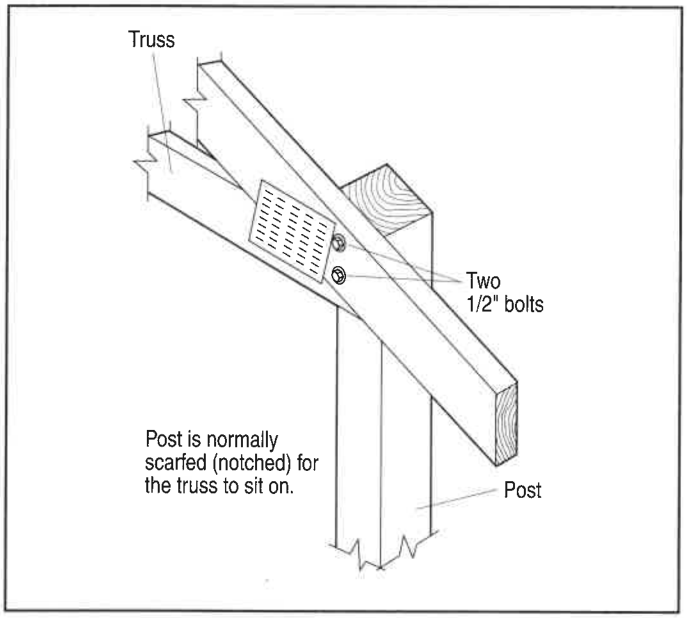


Figure 10. Typical truss-to-post connection. (*Adapted with permission from Western Wood Products Association)*

economic standpoint, this is **not** recommended. Trusses that are designed for prescribed roof loads (say 30 pounds per square foot) and manufactured under controlled factory conditions offer much greater quality and reliability, especially at the joints. *Because of the complex interaction of forces in the members of a roof truss, their design and construction is best completed by professionals using specialized computer programs and standardized test procedures for new products.*

The greatest advantage of a truss is in providing a clear span for the interior of a building. All gravity loads that the truss supports must be transferred to the ground through the post foundation system. Larger spans will require larger posts to carry the additional load from an increased contributing roof area. Trusses with large spans are difficult to handle, and a crane may be required to properly unload them and set them in place (see chapter 3, Construction Procedures, page 64).

If a wide building span is desired, the combination of a center gable truss with a single-slope truss on one or both sides may be applicable, as shown in figure 11. Interior posts will be required for truss support, but these posts can also be used as supports for livestock gates or other interior partitions. ***CAUTION: Gable trusses cannot be inverted or installed upside down without high risk of failure. Instead, use a properly designed single-slope shed truss for the required roof load.***

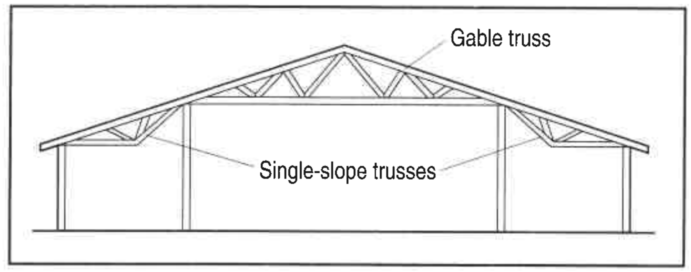


Figure 11. Truss combination for wide buildings.

Slopes and Spacing

Roof slope is described as the vertical rise in feet to a horizontal run of 12 feet. Roof slopes of 2.5:12, 3:12, 3.5:12, 4:12, 5:12, etc. are common (figure 12, page 14). The slope for a roof is determined principally by the structural design of the truss, as well as the intended use of the building. Modern, cost-effective roofing materials can accommodate a wide range of acceptable roof slopes (see section on Roofing and Siding, page 14).

In post-frame buildings, roof trusses are commonly spaced 4 feet or 8 feet on-center (o.c.). Residential frame construction normally uses a 2-foot truss spacing. A wider truss spacing requires stronger trusses and roof purlins to support the increased total roof load that is carried between individual trusses. *As with all structural components, professional truss design is recommended. Each truss is designed for a specific span and load, based on a specific design truss spacing. No alteration of design spacing should be allowed.*

Truss Fasteners

Trusses are an integral part of the post-frame structure. Consequently, the methods and materials used to fasten truss chord members together are extremely important. Usually, truss fasteners or connectors are the weakest part of the truss. Therefore, the truss manufacturer will give assurances that the methods and materials used to fasten chord members satisfy building design requirements. *Assurance from a truss manufacturer is important because the size, type, coating, and method of connection will strongly influence the holding ability of the fasteners.*

Typical fasteners used to transfer loads to and from wooden truss members are nails, bolts, screws, and gusset plates (wood or metal). ***CAUTION: No deviation from truss fastener geometry, spacing, or number should be made. Connection failures are one of the most common causes of building failure!***

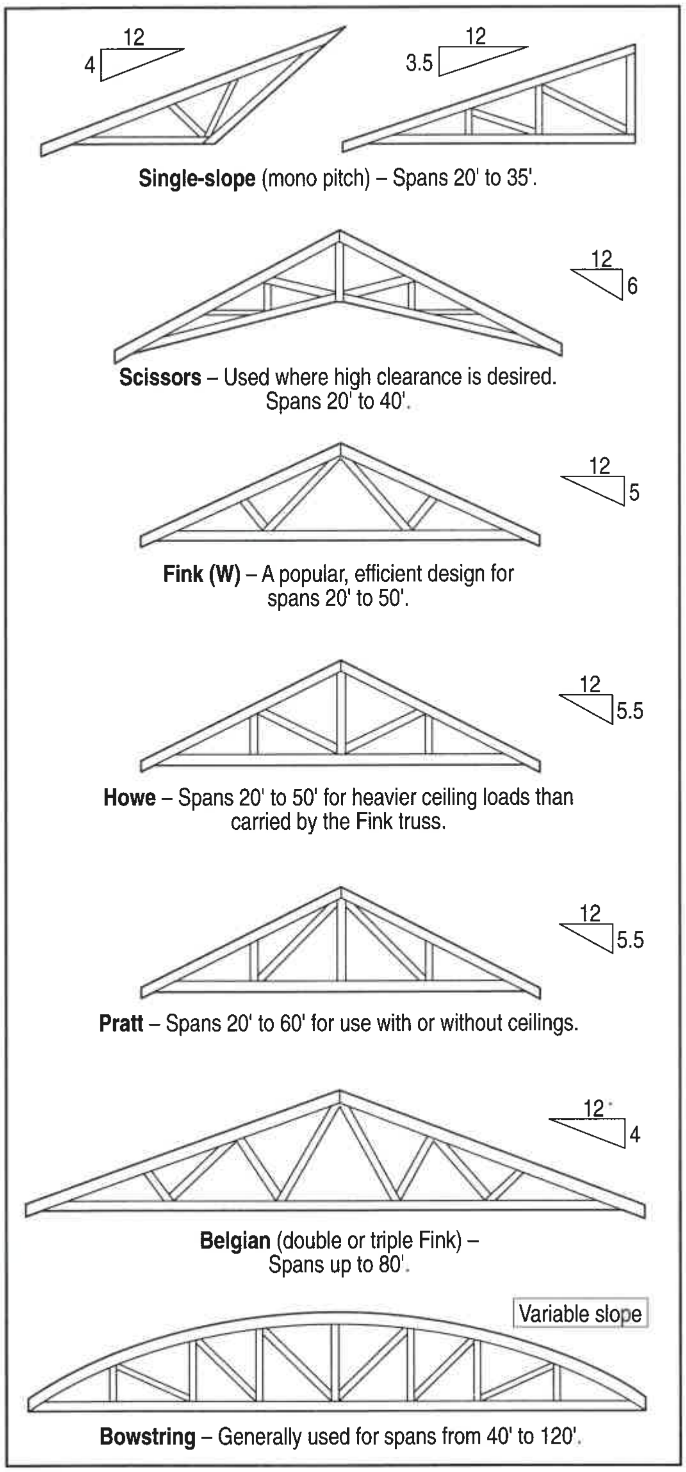


Figure 12. Common truss configurations and slopes.

When the common triangular-shaped (gable) wood truss is in place, the upper chord members are normally in compression, while the bottom chord members are usually in tension. **Never** cut, bore through, or notch any truss member. Trusses with larger chord members, like larger girders or beams, are stronger than trusses using smaller members of similar materials. However, larger members do not assure increased truss strength if adequate joint connections are not provided. For this reason, larger and stiffer gussets or splice plates are usually specified when strengthening a specific truss design.

Metal truss plates and fasteners must be protected from moisture and corrosive gases. Protection can be accomplished with various paints or coatings, or through the use of stainless steel materials. *Do not use unprotected light-gauge steel components as truss fasteners in an animal housing facility. For corrosion protection, specify hot-dipped zinc coatings in place of electroplating or mechanical plating of zinc. Hot-dipped zinc coatings are thicker and consequently last longer.*

Ordering and Storage of Trusses

When ordering trusses, specify the design roof loads to be carried (see section on Structural Loads, page 25); service conditions (wet, dry, corrosive, etc.); and critical dimensions such as truss span (length), overhang, roof slope, and desired spacing between trusses. Request documentation that the trusses meet or exceed your design requirements and are manufactured following standards set by the Truss Plate Institute (TPI). TPI is an industrial association concerned with the design, analysis, fabrication, and installation of metal-plate-connected wood trusses.

Tell the supplier if the truss is to support loads that may require a stronger truss design; for example, ceilings with insulation, a roof deck with asphalt shingles, suspended equipment, or other loads anticipated during the useful life of the building. Also specify how the building will be used. Livestock buildings, for example, often have a moist, corrosive atmosphere that may weaken trusses over time.

Upon delivery, trusses must be inspected carefully for loosened joints and defective lumber. *Reject any questionable trusses.* Trusses to be stored horizontally should be supported by blocking to prevent excessive lateral (side) bending and lessen moisture gain (figure 13). Trusses stored vertically should be blocked and braced to prevent toppling or tipping (figure 14).

Roofing and Siding

Post-frame building construction takes advantage of the strength of properly spaced individual wood frames. Roofing and siding material encloses the post-frame structure and protects the contents of the building. Roofing and siding materials that are used to cover large areas of the structure also act to distribute loads over the spaced roof purlins and wall girts. Aluminum and galvanized steel sheets are often chosen to cover the wood frame in a post-frame building.

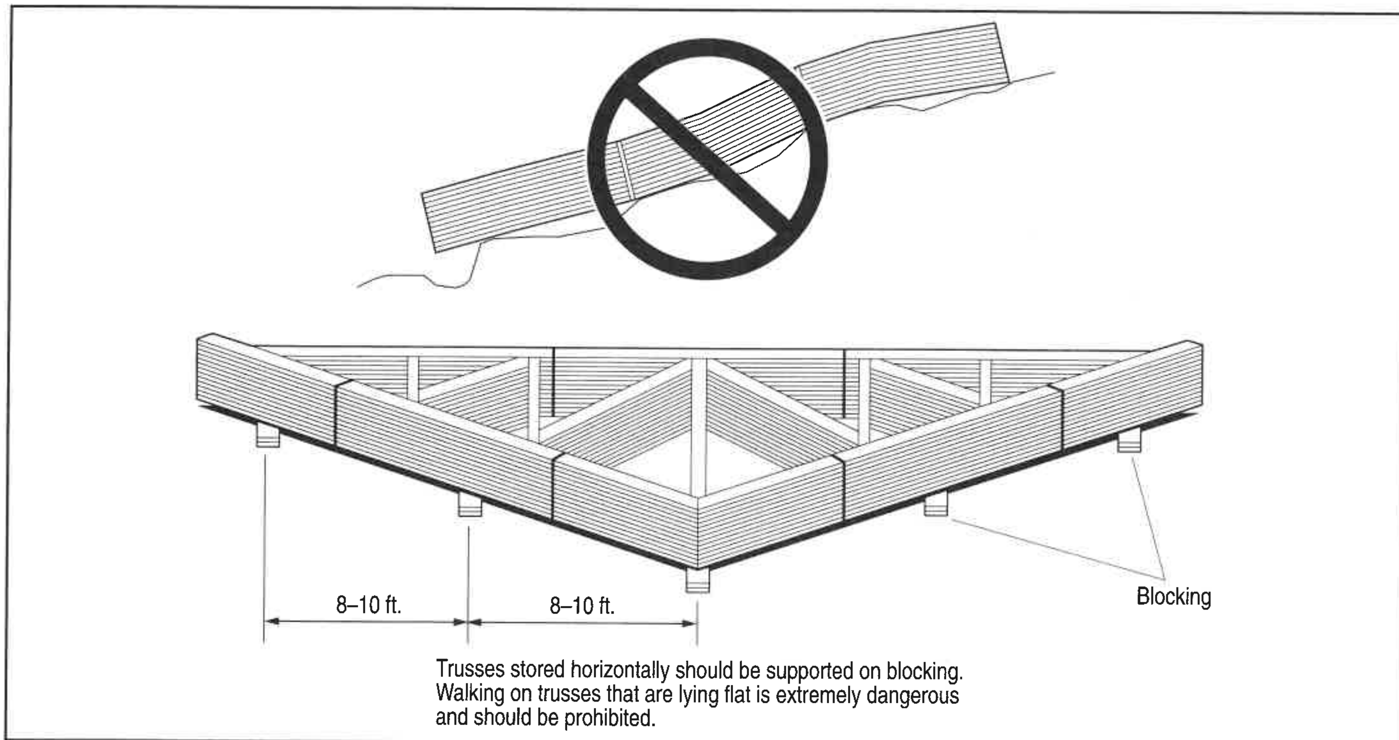


Figure 13. Horizontal storage of trusses. (*Source:* Commentary and Recommendations for Handling, Installing, and Bracing Metal-Plate-Connected Wood Trusses, *HIB-91 Summary Sheet, Truss Plate Institute*)

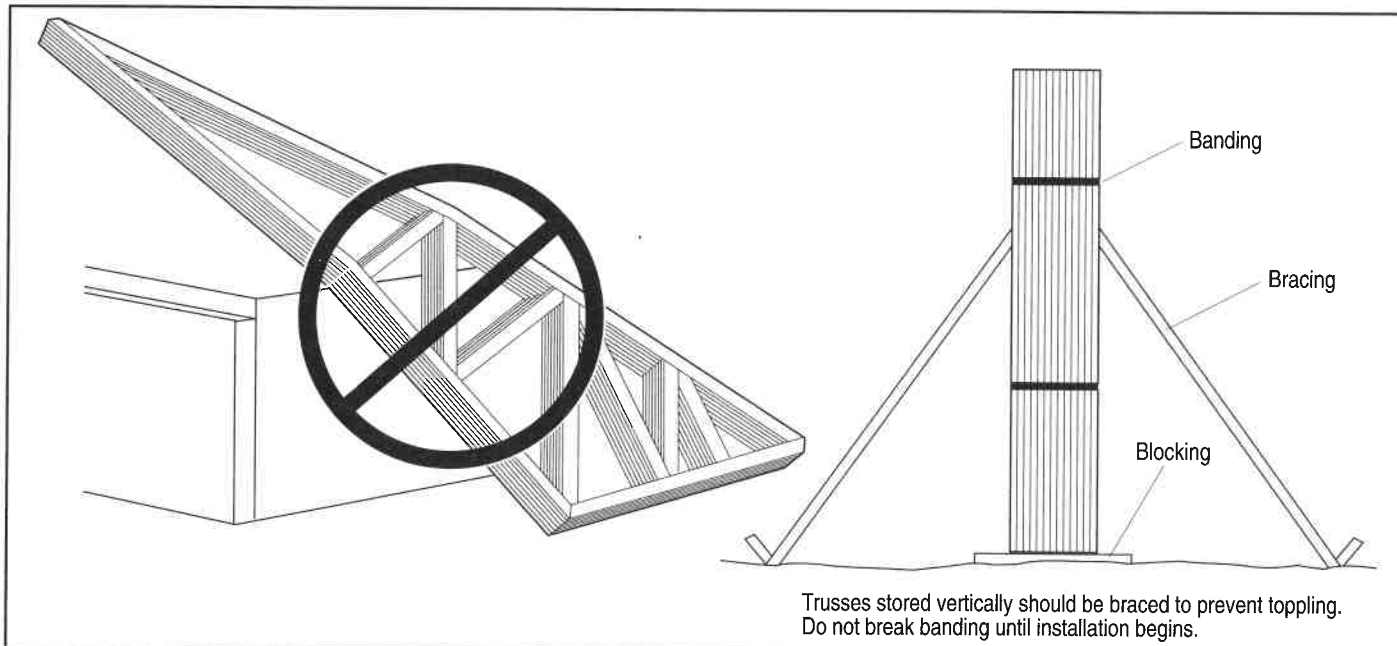


Figure 14. Vertical storage of trusses. (*Source:* Commentary and Recommendations for Handling, Installing, and Bracing Metal-Plate-Connected Wood Trusses, *HIB-91 Summary Sheet, Truss Plate Institute*)

Other materials such as asphalt or wood roof shingles are generally more expensive because a strengthened building frame is usually necessary to support the added weight of the shingles.

Usually roofing and siding materials are sold based on final coverage, so necessary overlaps are already included. For most owners, selection of roofing and siding materials is based on economy (cost-effectiveness), aesthetics, and anticipated use of the building.

Nearly all asphalt roofing and siding materials are sold by the "bundle," with three to four bundles making up a "square" (100 square feet). Metal roofing and siding materials are usually found in 24- or 36-inch widths and are sold by the foot in standard lengths of 8 to 16 feet.

Exterior Maintenance

Because of the importance of controlling leaks, roofs have traditionally been a high-maintenance item in buildings. However, the majority of post-frame roofs built today use corrugated metal panels that have an expected life of twenty-five to thirty years. Leaks in these metal roofs (which usually occur at a pipe or vent protrusion) can generally be stopped with an inexpensive caulk or sealant. Since newer caulks and sealants have a relatively long service life, routine roof maintenance is reduced. Exterior and interior siding materials in modern post-frame structures are also relatively maintenance-free because of the limited amount of exposed wood.

Types of Roofing and Siding

There are three general types of roofing and siding to choose from: (1) metal sheets, (2) wood products, and (3) asphalt products. The most common type of covering in post-frame buildings is corrugated metal sheets or panels. Wood shingles and shakes are rarely used in post-frame construction. Plywood is commonly used in residential construction, and in some post-frame applications (such as suspended floors and bulk storage of commodities). Rough-cut lumber can make an attractive, inexpensive siding material. Asphalt products are rarely used in post-frame construction.

Metal Sheets

Metal sheets are formed from rolls or coils of galvanized steel or aluminum. Stock is passed through a series of rollers that can create a variety of cross-sectional profiles (figure 15). The ribs or corrugations that are formed by the rollers give the metal sheets greater resistance to bending and allow the sheets to support loads over wider-spaced roof purlins or wall girts than would otherwise be possible. Aluminum and galvanized steel sheets up to 40 feet long are available. Smooth-finished or embossed metal sheets are available with either a straight galvanized finish (silvery gray) or color baked-enamel coating. Metal sheets come in several gauges or thicknesses (for example, 29-gauge, 30-gauge, 0.028-inch, 0.032-inch, etc.).

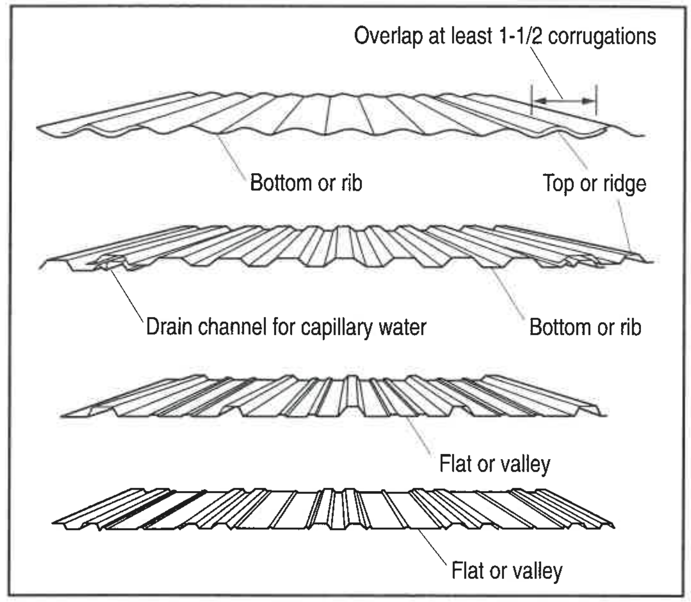


Figure 15. Typical sheet metal configurations.

Exterior wall sheathing (cladding) must be designed to withstand design wind loads between 10 and 30 pounds per square foot, depending on building configuration, location, and intended use. Cladding used on the roof must be able to support design snow loads up to 100 pounds per square foot, depending on locality (see sections on Wind Loads and Snow Loads, pages 26 and 28).

The rib profile, metal thickness, metal strength, and distance between framing supports determine the weight or load that the roofing or siding can resist. Cladding manufacturers publish span or allowable load tables for each standard thickness of material. *Before buying metal cladding, obtain certification that the cladding supplied has load ratings equal to or greater than the design requirements of the building being constructed.*

An advantage of using long metal sheets for roofing and siding is faster application with fewer joints. Large sheets can also add to the stiffness of the building by carrying in-plane shear loads (see section on Diaphragm Action, page 34). Disadvantages of large sheets include difficulties in handling and expansion/contraction of the continuous sheets during wide temperature fluctuations. Metal sheets will contract as the temperature decreases and expand as the temperature increases. This contraction and expansion of the metal is much greater than the supporting wooden frame of the building. Subsequently, the joints between overlapping sheets must provide the necessary differential movement between adjacent sheets. Fasteners must be properly designed and installed to absorb the movement between sheets.

The ribs in metal sheets are commonly ½ to ¾ inch deep. Sheets with deeper ribs carry rain away better on long slopes and can support greater loads, allowing greater support spacing. *For the best performance, install corrugated metal sheets on roofs with a 3:12 slope or greater.* This reduces flooding of corrugation ribs and seepage through the side or end joints during heavy rainfall or snow melt. Lap metal sheets for roofing at least one and a half corrugations (figure 15). Metal roofing manufacturers can provide increased end-lap recommendations for lower slopes.

Standing-seam roofs (metal roofing that uses single or double crimping in lieu of overlapping corrugations) can also be used to prevent roof seepage on low-slope roofs. Standing-seam roofs are not very common because they are more expensive than a conventional metal roof. Because the individual sheets in a standing-seam roof have some slip between them, they do not provide the same stiffness to a building as conventional metal roofing (see section on Diaphragm Action, page 34).

Steel alloy sheets are stronger, heavier, and expand less due to temperature change than aluminum alloy sheets. Steel does require durable coatings to prevent rusting. Zinc galvanizing protects steel from corrosion and varies in thickness. Minimum zinc-galvanized coating standards from the Zinc Institute, Inc. are 1.25 ounces of zinc per square foot of sheet. Two ounces of zinc per square foot of sheet are required to qualify for a "Seal of Quality" designation.

Exposure tests in rural atmospheres show a useful life before "first signs of rust" of seven years for 1.25-ounce and fifteen years for 2-ounce zinc coatings. In industrial areas, the useful life is reduced. Because zinc thickness cannot be measured by visual inspection, look for the Zinc Institute seal or request a written certification from the manufacturer. Aluminum plating, polyesters, and other factory-applied enamel finishes are also available to protect steel with performance warranties of up to twenty years.

Aluminum alloys oxidize and become less reflective with age but do not require additional coatings for weather protection. Roofing sheets made from high-strength aluminum or steel alloys tend to be brittle. This brittleness causes some alloys to crack or split rather than dent or bend if hit too hard or if stepped on incorrectly.

Generally, aluminum and galvanized steel roofs require little maintenance, but care should be used to keep lead, zinc, manure, salt, and other corrosive materials away from them. Dissimilar metals such as steel or aluminum that contact each other corrode rapidly. *To avoid corrosion, use galvanized nails or screws with galvanized steel sheets, and use aluminum fasteners with aluminum sheets* (see chapter 3, Construction Procedures, page 64).

Pre-formed flashing and trim with finishes that compliment the metal sheeting are available to give the building a finished appearance and protect the building frame and sheeting edges. Check with the metal sheeting supplier for the trim and flashing profiles that are available to match siding and roofing materials. Common flashing and trim items include:

- ridge caps that match the sheeting profile,
- corners to cover the rake (the edge of a pitched roof at the gable end), outside corners, and inside corners,
- special profiles to trim and flash around overhead doors, sliding doors, and swinging doors,
- trim to trim and flash windows, and
- special flashing to seal around any roof or wall penetrations such as plumbing vents, furnace flues, or chimneys.

Wood Products

Wood shingles and shakes have been a traditional roofing material for centuries. The endurance of the material is evident based on the existing roofs on old barns. A thirty- or forty-year life for a good wood shingle roof was common. Wood shingles and shakes are best placed on spaced nailers (purlins). The spacing allows air circulation to reduce the accumulation of moisture that can lead to premature rolling and excessive warping of the shingles. Wood shingles generally perform well on roof slopes of 6:12 or greater. With flatter slopes, the shingle overlap should be increased (to prevent leaks due to roof flooding).

Although wood shingles and shakes can provide an effective alternative roofing system, more purlins are required as compared to metal roofing, which makes the overall cost of wood shingle roofing for post-frame buildings prohibitively expensive. Another problem with wood shingles and shakes is that they are not fire-resistant unless the wood is treated.

Where asphalt shingles are used (see following section on Asphalt Products), shingles must be adequately supported to prevent sag or failure from snow loads. Plywood decking is normally used for this application. Graded plywood is an engineered product that is manufactured with three to five layers consisting of one or more sheets of veneer (thin sheets of wood). Layers are glued together in a hot press with the grain of adjacent layers at right angles (figure 16). After removal from the press, panels are trimmed to size, and some grades are sanded. The multilayer construction of plywood provides greater dimensional stability than for solid-sawn wood but alters panel strength in perpendicular directions of loading. Because plywood is much stronger in the direction parallel to the face grain, plywood should be used with the face grain running perpendicular to the wall or roof supports.

Plywood is commonly found in 4-foot-by-8-foot sheets designated by an identification index (a pair of numbers separated by a slash). The first number gives the maximum spacing, in inches, for roof decking with the face grain across the supports. The second number gives the maximum spacing for residential subflooring supports. For example, a 48/24 designation indicates that a plywood panel can carry the basic roof loads over a 48-inch support spacing or the basic floor load over a 24-inch support spacing provided the face grain is oriented perpendicular to the supports. Typical ½-inch plywood requires roof supports every 32 inches or less, while ⅜-inch plywood generally requires roof supports every 24 inches or less.

Exterior-grade plywood should always be specified for high-moisture-content applications. Exposure 1 plywood may be used for applications that are not permanently exposed to the weather. Exposure 2 or IMG (intermediate glue) plywood may be used for protected applications that are not continuously exposed to high humidity conditions. Exposure 2 or IMG panels are not readily available. For permanently protected interior applications, interior plywood may be used. Panels in grades other than those mentioned above are designated by:

- panel thickness,
- veneer-grade classification of face and back veneers, and
- the species group of the veneers.

Rough-cut green lumber makes an attractive, inexpensive board and batten siding. Boards are positioned vertically over the nailing girts and nailed in place along one edge only. After one year of curing, batten strips are nailed over the cracks, resulting in a weather-tight building. Individual vertical boards (with or without battens over joints), plywood, textured plywood, drop siding, and shiplap are all alternative wood siding materials.

Asphalt Products

Asphalt shingles and roll roofing are not commonly used on post-frame buildings, because a continuous decking or wood sheathing is required. Asphalt shingles are asphalt-saturated felt or fiberglass that are surfaced with colored granules on the exposed side. Light-colored shingles reflect solar heat better

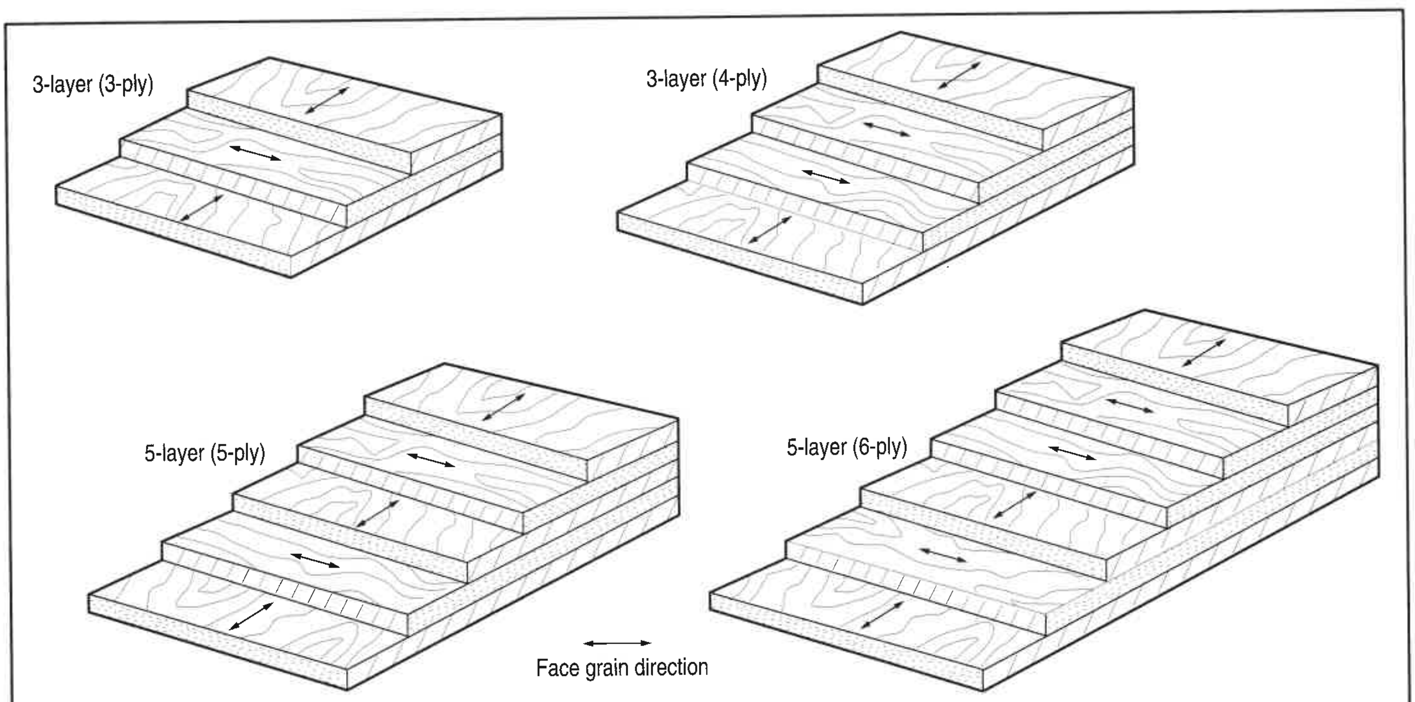


Figure 16. Typical three- and five-layer plywood construction. (*Courtesy of APA, The Engineered Wood Association*)

and last longer than dark ones. Interlocking or self-sealing shingles are best for areas with high wind. Roofs with less than a 3:12 slope require more care during installation, less shingle tab exposure, and a roofing underlayment (usually asphalt-saturated felt).

High-quality shingles weigh about 300 pounds per square and can last more than twenty years. If shingles are chosen for a post-frame building, at least 240-pound shingles should be used. However, the additional weight of a continuous decking or felt underlayment must be considered when sizing structural components such as trusses, purlins, posts, and foundations (see section on Dead Loads, page 25).

Corrugated asphalt sheets can be installed on spaced purlins or spaced sidewall girts. These sheets are available in widths of 32 inches and lengths of 6½ feet. If corrugated asphalt sheets are used on roofs where the slope is less than 3:12 or in areas with high temperatures and intense sun, roof purlins should be spaced 12 inches on-center to reduce sag.

Doors

Durable doors, door frames, and hardware are needed to resist the rough service, moisture, impact, and corrosion that typically occur in agricultural buildings. To protect door jambs and overhead door tracks from animals or equipment, set ballard posts (6-inch-diameter steel pipe filled with concrete) close to the doorway. Gates inside the barn help protect the inside of doors and allow better ventilation during warm weather. Install insulated doors and/or a storm door on buildings that will be kept above freezing in cold climates.

Hinged, sliding, or overhead doors are common in agricultural buildings (figure 17). The choice depends largely upon use, size, and cost. Table 5 summarizes the minimum and recommended sizes, types, and uses of doors. Prefabricated metal or wood doors for personnel or single animals are readily available, but buy only durable units. Lightweight aluminum storm and screen doors or hollow-core wood doors often need replacement within two years. A durable door can be built on-site from exterior-grade plywood with "Z" framing. The "Dutch" door is an example that is often used in horse barns (figure 18, page 20).

Rolling or sliding doors are hung from two trolleys on a track and are easier to secure against wind gusts than large hinged doors. Guides at the lower corners of doorways and latches help prevent wind damage. Rolling doors are usually built on-site with plywood or metal sheathing on a wood or metal frame. Large doors (over 16 feet wide) can be divided for easier operation with the track on both sides of the doorway. Sliding doors can be protected from freezing (so they will slide easier) by self-storage in a 6-inch interior "pocket wall." Supporting posts for large doors should be reinforced with extra concrete below grade (see section on Foundations, page 40).

Prefabricated overhead doors are easier to operate but more expensive than rolling doors. Curved side tracks on overhead doors guide hinged panels beneath ceilings or roof trusses as the door is raised. When closed, the door wedges tightly against the door jamb. Protect the door track and posts with ballard posts set in concrete and consider electric door openers where vehicles move in and out several times daily. Overhead doors require space above the door. Standard overhead doors require 16 inches of clear space above the top of the door. Purchase overhead doors that have a built-in safety feature to prevent accidental closure on top of objects or children.

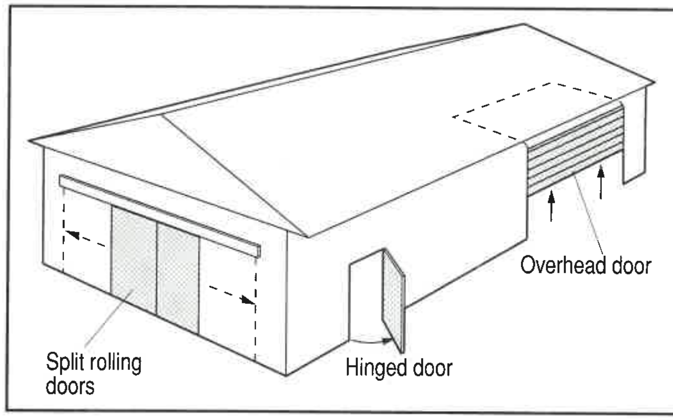


Figure 17. Common doors in agricultural buildings.

Table 5. Minimum and recommended sizes, types, and uses of doors.

User	Size (Width by Height)		
	Minimum	Recommended	Door Type
Personnel & small animals*	2' x 6'-8"	3' x 6'-8"	Swing
Single cows & horses	3' x 7'	4' x 8'	Swing or sliding
Two lines of cows & horses, medium-sized tractors, autos, pick-up trucks	7' x 7'	8' x 8'	Sliding or overhead
Mixer or side-unloading wagons	10' x 10'	12' x 13'	Overhead with automatic opener
Tractors with cabs, trailer trucks, field equipment**	10' x 13'	12' x 13'	Sliding or overhead

* Typical widths for standard personnel doors are 24, 30, 32, and 36 inches.
**Large field equipment may require doorways 16 feet to 24 feet wide, and small airplanes may need 40-foot-wide doors.

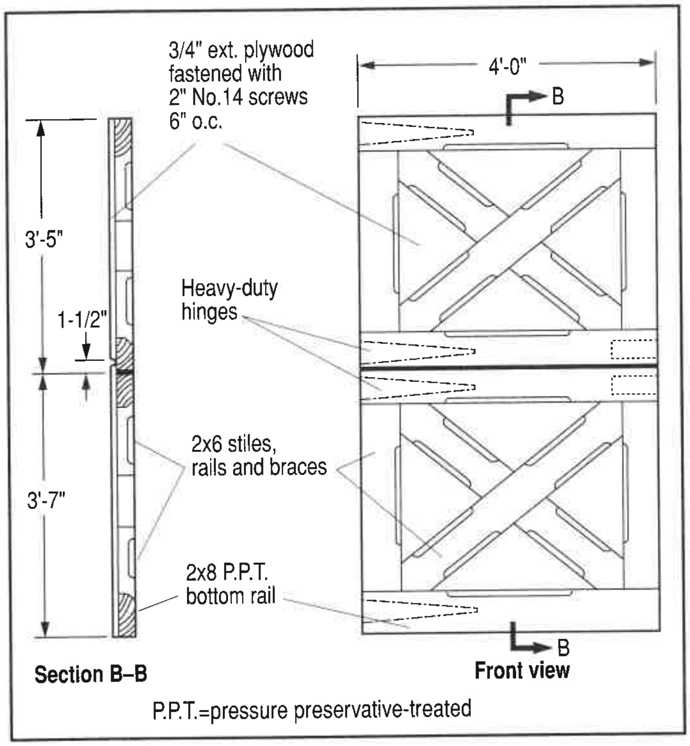


Figure 18. Horse barn "Dutch" door detail. (*USDA Plan No. 6285*)

Skylights and Windows

Fiberglass-reinforced plastic (FRP) panels shaped to match metal roofing and siding panels are available for use as skylights in several colors—commonly green, yellow, and white (figure 19). These opaque panels generally transmit enough daylight to improve building interior appearance and working conditions. FRP panels are thicker and several times more costly than metal panels. Unfortunately, roof skylights can be a high-maintenance item, as metal sheeting and FRP panels have different thermal expansion characteristics. Temperature variations in the two dissimilar materials create movement between the panels, leading to fastener failure and/or leaks. For this reason, sidewall light panels are usually preferred.

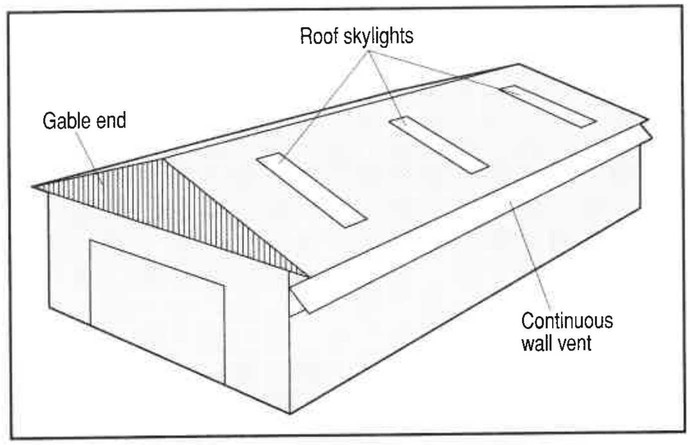


Figure 19. Skylights and vents.

With proper placement, skylights and windows may eliminate or reduce the need for artificial lighting. FRP panels installed in gable ends and sidewalls can be used to reduce water leaks and excessive solar gain from roof skylights. FRP panels may also improve the appearance and function of agricultural buildings. Some windows are available that are ready to be installed in a post-frame building. However, since most windows are manufactured for stud frame walls, additional framing will be required to install these windows. In animal housing structures, adjustable curtains often serve as windows while allowing increased natural ventilation.

Chapter 2. Design Considerations

No building should be constructed without a complete set of drawings and written specifications. The drawings and specifications together describe the building construction. At a minimum, construction drawings (plans) should cover the following items:

- building location relative to existing facilities,
- site grading, drainage, and finished floor elevation,
- building dimensions, measurements, and sizes,
- details of framing, building enclosure, and member connections,
- placement of windows, doors, and equipment,
- type, grade, or class of material used, and
- all existing and future utility locations and connections.

Construction specifications contain the written description of those items not detailed on the plans (usually due to lack of space). Written specifications should complement and complete the description of the building presented in the construction drawings. Written specifications can include the following items:

- minimum acceptable level of workmanship,
- minimum acceptable quality of materials,
- specified materials (such as paints, protective coatings, lumber, concrete, etc.), and
- capacity requirements and minimum quality of equipment.

Although building codes and standards give guidance on the minimum requirements for safe building design, judgment is required. All buildings must be designed to support the loads that can be expected to occur during the service life of the building. The estimation of which loads and materials should be used in a building is not simple. Various uncertainties in structural loads and in the performance of building materials make engineering design necessary. For these reasons, it is important that buildings be designed by qualified professionals, especially where failure poses risks to human life or property.

Site Selection

Site selection is critical for the satisfactory use of any building; therefore, it should be given great care and consideration. Aspects of selecting a site include orientation and spatial relationships with other buildings and facilities. Local zoning and environmental laws may control the site selection. For example, wetland designation of a prospective construction site will normally prevent any type of site development. The location and orientation of a post-frame building can be chosen for a variety of reasons, including: wind protection, to capture winter sun or summer breezes, or to screen animal exercise and feed lots from view. Figure 20 presents an example of a farmstead plan, showing existing and proposed structures.

Other factors that must be considered in building site selection are: existing and future utility lines, surface drainage patterns, machine and livestock travel lanes, potential odors, fire danger, and neighbors. New buildings should be located on a well-drained, nearly level site that is easily accessible and convenient to other buildings. Avoid sites with rock or rock outcroppings, otherwise special excavation equipment or building anchorage may be required. Digging a few holes 4 feet deep can determine if the site is appropriate for a post-frame building.

Consider drifting snow as well as wind protection when locating a new building. In many areas buildings are oriented to protect against winter storms that come from the northwest. Check local conditions, as severe storms may come from other directions.

For more detailed information about site selection for farm and shop structures, the following publications are recommended: *Dairy Freestall Housing and Equipment*, MWPS–7 and *Farm Shop Plans Book*, MWPS–26. (A list of suggested readings appears on page 78.)

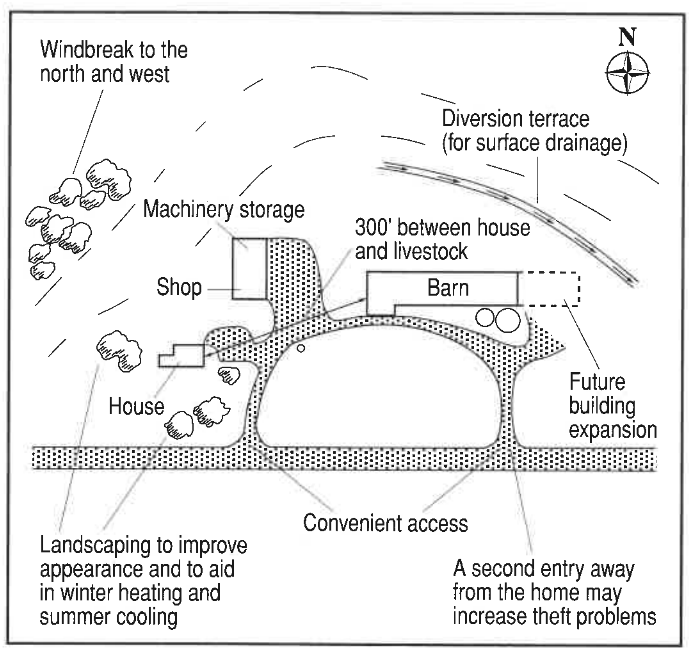


Figure 20. Farmstead plan.

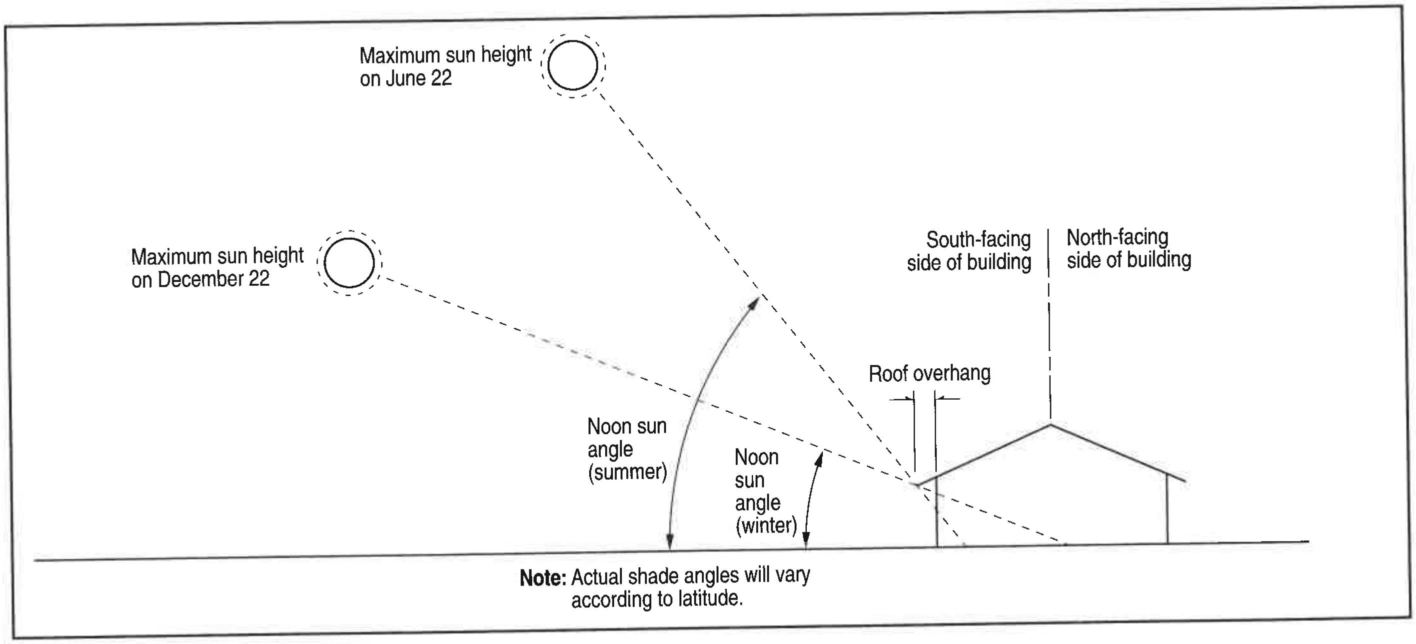


Figure 21. Relative solar shade angles.

In the Northern Hemisphere, the sun will always be in the southern and western sky during the afternoon. To take advantage of the winter sun, face the building southward, with the roof ridge oriented east-west. A roof overhang can be designed to allow winter sunlight to penetrate the building, yet provide shade from the summer sun (figure 21). In areas with prevailing southwest winds, open-front buildings can be oriented with the ridge northeast-southwest to accommodate both summer sun and winter wind exposure.

When choosing a site, allow adequate space for access and future expansion (which may double the size of the building). Space major buildings at least 100 feet apart to reduce the spread of fire and to give room to fight a fire. For more information about reducing the risk of fire in livestock buildings, refer to *Fire Control in Livestock Buildings*, NRAES–39, which is listed in the suggested readings section on page 78. In some cases, building insurance rates can be reduced by meeting minimum spacing distances. Zoning laws may restrict construction in flood plains, the use of the building, and how close buildings can be constructed relative to property lines or other buildings. Check with the local zoning office for regulations.

Site Drainage

On an ideal building site, water drains naturally away from the building. Keep the building higher than the surrounding site to allow proper drainage. Otherwise, surface grading will be necessary to carry surface water away from the building. Keeping the finished floor of the building higher than the surrounding site will reduce the possibility of a flooded building during heavy rainfall. In some cases, heavy equipment may be needed to properly grade the site to drain away from the building.

Site preparation should include removing and stockpiling topsoil for later use as a finish grading material. Subsoils that are removed from around the building should be replaced with a well-graded, granulated fill to facilitate drainage of subsurface water away from the building. All fill should be free of large debris and placed around the site in 6-inch layers that are compacted by an appropriate method before adding more layers.

Grade the surrounding area with a 1 to 5% slope (figure 22) to drain surface water away from the building in all directions. Percent slope is calculated as the vertical change (in feet) per 100 feet of horizontal distance. For example, a piece of land that drops 4½ feet over a 100-foot horizontal distance would have a 4.5% slope. A pipe laid on a grade of 1% would drop 1 foot over a 100-foot horizontal distance, or 2 feet over a 200-foot distance. Diversion terraces can also be installed to divert surface drainage from the building site (figure 20, page 21). Locate the terrace 50 feet or more from a building so it does not interfere with existing or proposed traffic patterns.

Install gutters or eave troughs if roof water is to be collected for storage, or to protect doorways and foundations from flooding. A 5-inch gutter with 3-inch-diameter downspout for every 1,000 square feet of roof area is usually satisfactory. Position the gutter to avoid damage from sliding ice and snow and fasten according to manufacturers' instructions.

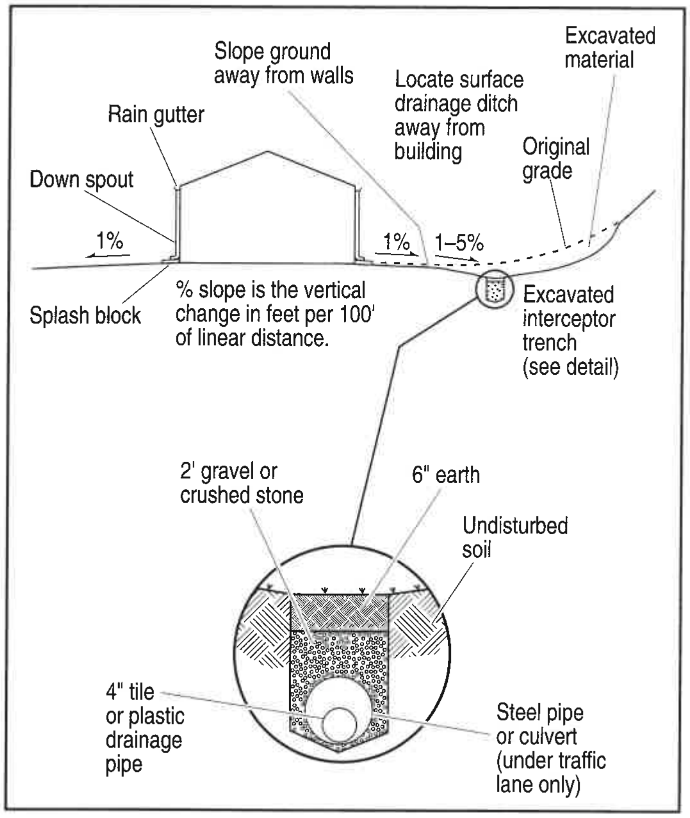


Figure 22. Site drainage and grading.

At the base of the downspouts, install an elbow and extension pipe or splash block to divert water at least 30 inches away from the building (figure 22). Prevent the discharge of water where it could cross sidewalks or driveways, creating icy spots in freezing weather.

Clean roof runoff may be directed to the nearest ditch or stream. Roof runoff should be directed away from areas containing potential pollutants (such as pesticides, animal manures, or refuse). Runoff from contaminated areas must be diverted to separate holding areas for further treatment or land application. For further information about diversion, storage, and treatment of contaminated runoff, refer to the *Livestock Waste Facilities Handbook*, MWPS–18, which is listed in the suggested readings section on page 78.

Often roof gutters are omitted on utility buildings since a distributed roof drip is preferred over the concentrated flow from a downspout. In colder regions with heavy snowfall, gutters are often omitted because snow and ice dams can form along the gutter near the edge of the roof (especially in heated buildings with uninsulated roofs).

Water seepage from an excavated hillside can be diverted with an interceptor trench (figure 22). The design of an interceptor trench depends on the building foundation depth, soil type, and the distance of the drainage pipe from the building. One example may be a 3-foot-deep trench, sloped 1%, with 4-inch tile or plastic drainage pipe laid in gravel or crushed stone (see detail, figure 22). The gravel base is used to support the drainage line and maintain a constant design slope. Use steel culverts or cast iron pipe where drainage lines are crossed by heavy equipment or traffic lanes.

It is possible to construct post-frame buildings on steeply sloped (over 10%) sites as long as there is no danger from landslides (see figure 45 on page 56). Have a soil expert check the site to be sure it is safe for building. Wet silty or clay soil often slides at a 50% (1:2) slope, but sandy and gravel soil may be stable at a 100% (1:1) slope. Slides and erosion can be prevented with careful construction and drainage control. Protect natural vegetation and drainage patterns around the structure to reduce erosion.

Functional Planning

A post-frame building represents a large capital cost. If properly protected, these buildings have a normal life of about fifty years. It is much easier and less costly to optimize the floor plan of a building in the design phase, before construction. After construction, it is often too late and too costly to modify major structural components. The best way to complete a good floor plan is to decide on the building's function prior to construction.

If the building's function is machine storage, make the building long, wide, and tall enough to store the equipment. Place doors so that equipment can be moved in and out without interference. If the building's function is livestock housing, design the building with adequate room for stalls, feeding areas, animal movement, and equipment maneuvering. Consider the building's illumination as well as ventilation requirements (see the following section on Heating and Ventilation). Visit existing facilities to gather both good and bad ideas. *Do not hesitate to seek professional assistance!*

The building site will have a significant effect on the final building design and function. Match the design to the site. Site conditions that influence structural design include soil conditions for post foundations, size of level area for the building, and access to the site (see Site Selection on page 21). Consider all concepts on paper before committing the resources required to complete the project (see Construction Checklist on page 70).

Ultimately, a good design is one that achieves the objectives of the user. Post-frame buildings that represent a low risk to human life (such as an agricultural building) can have the following objectives:

1. have relatively low operating, maintenance, and capital costs,
2. protect equipment, livestock, crops, or other valuable items from detrimental weather,
3. provide easy entry and exits for livestock, deliveries, and equipment, and
4. increase the value of the property.

Heating and Ventilation

The type of building exterior can greatly affect the air movement into and out of the finished building. Therefore, the heating and ventilation requirements of a new building should be considered when choosing the type of roofing and siding. Heating and ventilation requirements for post-frame buildings will vary widely, depending on the end use. Ventilation systems in agricultural post-frame buildings are commonly used to:

- remove moisture from inside the building,
- provide fresh air,
- remove excess heat,
- remove odors and gases,
- remove airborne dust and disease organisms, and
- remove the combustion products of supplemental heaters.

Without a properly designed and operating ventilation system, indoor air quality will be compromised. One consequence could be increased corrosion of structural metal components, such as metal truss plates (especially in the highly corrosive atmosphere of an animal housing facility). If metal truss plates are not adequately protected from high moisture and corrosive gases, the structural integrity of the roof system could be jeopardized.

Naturally ventilated buildings are often used in agricultural applications (figure 23). There are two basic types of naturally ventilated buildings: "cold" buildings and "modified-environment" buildings. "Cold" buildings are normally uninsulated or slightly insulated, with open fronts. Such buildings are often used to house large animals. "Modified-environment" buildings are well insulated to maintain higher winter temperatures than in cold buildings.

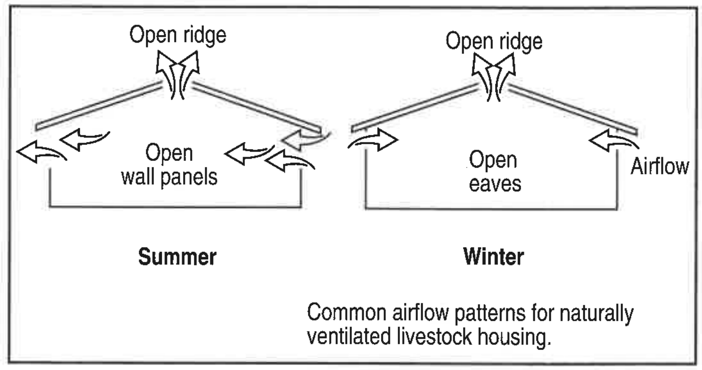


Figure 23. Airflow with natural ventilation. (*Source: MidWest Plan Service*)

In addition to natural ventilation, numerous mechanical ventilation systems utilizing power-driven fans are available. Ventilation fans can be used to force air into or out of a building through openings such as gable louvers and ridge ventilators. Figure 24 shows one possible configuration for mechanical ventilation. To maintain mechanical efficiencies, regular dust removal from fan blades, motors, fan housings, shutters, and controls is required.

For more detailed information about ventilation and insulation of agricultural buildings, the following publications are recommended: *Mechanical Ventilating Systems for Livestock Housing*, MWPS–32; *Natural Ventilating Systems for Livestock Housing*, MWPS–33; and *Heating, Cooling, and Tempering Air for Livestock Housing*, MWPS–34. For more information about the performance and efficiencies of agricultural ventilation fans, *Agricultural Ventilation Fans: Performance and Efficiencies*, IL–97, is recommended. (A list of suggested readings appears on page 78; ordering information can be found on the inside back cover.)

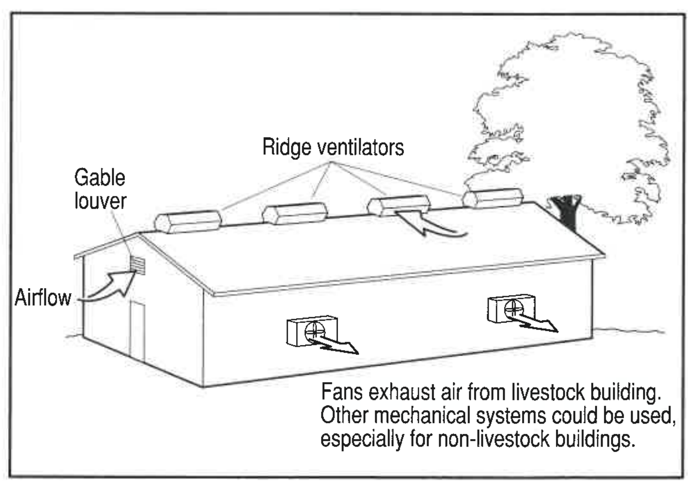


Figure 24. Airflow with mechanical ventilation. (*Source: MidWest Plan Service*)

Structural Loads

The size of a building will directly affect its structural design. Structural analysis of a building is completed to determine the ability of the structural components to resist forces called design loads, such as snow, wind, the weight of the building itself, and the occupants of the structure. In a post-frame building, all of these loads are transferred to the ground directly or through the post-frame and cladding. The magnitude of the loads will vary depending on the geographic location and end use of the building. A complete structural design assures that the structure can safely support all loads without exceeding the allowable stresses of the individual load-bearing members.

For structural analysis, design loads are commonly divided into live loads and dead loads. Live loads are those in the building that are not fixed in place, or are applied intermittently. Live loads are caused by people, livestock, foodstuffs, and moveable equipment in a building. Dead loads are those gravity loads that are considered a permanent part of the building, including the weight of the building construction materials as well as any fixed equipment in the building such as plumbing, heating, electric, or ventilation equipment.

Other loads that the building may need to resist include snow, wind, and earthquake loads. The building will likely see a great variation of these loads over its design life. Extensive research has been conducted to characterize building loads. Calculation procedures for minimum design loads are given in the model building codes and the American Society of Civil Engineers (ASCE) Standard 7-95, *Minimum Design Loads for Buildings and Other Structures*. ASCE is the primary technical source used in the model codes with regard to dead, live, snow, wind, rain, and earthquake loads. Model building codes present the more rigorous ASCE procedures in a simpler, easy-to-use format.

ASAE also publishes a snow and wind load standard, EP288.5, which is intended for agricultural buildings. Differences in the minimum design loadings between agricultural and other types of buildings are due to the relatively lower risk to people and property in agricultural buildings.

Dead Loads

Dead loads are the gravity loads that are constant in magnitude and location throughout the life of the building. Dead loads are due to the combined weight of all permanent structural and nonstructural components of the building, such as sheathing, trusses, purlins, girts, and fixed service equipment. Table 6 presents minimum design dead loads, in pounds per square foot, for various roof and ceiling components. Floor dead load is often assumed to be 10 pounds per square foot. Dead weight of floors may be more accurately calculated from the weight of flooring materials used.

Using excessive design dead loads may lead to conservative designs for trusses, purlins, posts, and post-bearing pads. If a conservative design is desired, it is permitted to use design dead loads that exceed the actual weight of construction materials and permanent fixtures, except to determine building stability under wind loading (see Caution below).

CAUTION: Dead load design values for wind uplift must not exceed the actual dead load of the construction materials, otherwise potentially dangerous errors could be introduced into the building design. The design of anchorage to counteract uplift, overturn, and sliding forces due to wind loads is beyond the scope of this handbook. Professional design assistance should be sought.

Table 6. Minimum design dead loads for various ceiling and roofing materials.*

Component	Load (psf)
Ceilings	
Gypsum board (per 1/8-inch thickness)	0.55
Mechanical duct allowance	4
Plaster on wood lath	8
Suspended steel channel system	2
Wood furring suspension system	2.5
Coverings, roof, and wall	
Asphalt shingles	2
Copper or tin	1
Corrugated cement roofing	4
Deck, metal, 20 gauge	2.5
Deck, metal, 18 gauge	3
Decking, 2-inch wood (Douglas fir)	5
Decking, 3-inch wood (Douglas fir)	8
Fiberboard, 1/2-inch	0.75
Gypsum sheathing, 1/2-inch	2
Insulation, roof boards (per inch thickness):	
Cellular glass	0.7
Fibrous glass	1.1
Fiberboard	1.5
Perlite	0.8
Polystyrene foam	0.2
Urethane foam with skin	0.5
Plywood (per 1/8-inch thickness)	0.4
Rigid insulation, 1/2-inch	0.75
Skylight metal frame, 3/8-inch wire glass	8
Wood sheathing (per inch thickness)	3
Wood shingles	3

* Values given are averages. In some cases, there is considerable range of weight for the same construction. All values are from American Society of Civil Engineers, *Minimum Design Loads for Buildings and Other Structures*, ASCE 7-95.

Live Loads

Live loads are usually estimated based on building code requirements or accepted standards of practice. The minimum allowable live load for agricultural buildings listed in ASAE Standard EP378.3, Floor and Suspended Loads on Agricultural Structures Due to Use, is 20 pounds per square foot (for poultry floor housing). In all localities, if the governing building code applies to agricultural buildings, then the design load criteria in the applicable code must be followed. Table 7 presents selected distributed floor live loads. *Only those loads that are specific to the desired application should be used in the structural design of a building.* Loads from grain and other bulk storage are given in the section on Bulk Storage of Commodities on page 58.

Wind, Snow, and Earthquake Loads

Wind loads are the loads from wind coming from any direction but are most often considered to act in a horizontal direction, as against a wall. Methods for determining design wind loads in this handbook do not include values for tornado wind loads. Snow loads are the vertical loads from the weight of snow applied to the horizontal projection of a roof. Earthquake loads are the accelerated ground motions caused by a seismic event. Wind, snow, and earthquake loads produce displacements and stresses in structural frames. Design values for these loads are strongly influenced by the type of occupancy of the building. ASCE has classified buildings into four categories, based on the relative importance of the structure (table 8). Most agricultural post-frame buildings fall under Category I, which means they present a low hazard to human life.

Table 7. Selected distributed floor live loads. *

Use	Floor Load pounds per square foot (psf)
Livestock, calves to 300 pounds[1]	50
Cattle or horses[1]	100
Sheep[1]	40
Swine to 200 pounds[1]	50
Poultry	20
Greenhouses	50
Shops, maintenance, or craft [2,3]	70
Non-residential attics, storage [4]	80
Hay or grain storage[4]	300
Farm vehicle storage[2]	
Automobiles, light trucks	100
Field machinery (limited access)	150
Large tractors, trucks (> 13,000 lbs.)	200
Residential dwellings	40
Public rooms and corridors	100

* Adapted from ASAE EP378.3; American Society of Civil Engineers, *Minimum Design Loads for Buildings and Other Structures*, ASCE 7-93; and Building Officials and Code Administrators, *The BOCA National Building Code/1987.*

1 Increase solid floor load 25% for floors supporting crowded animals (such as in a crowding pen, a holding pen, or handling alleys).

2 Special design is required for concentrated loads of heavy equipment, vehicles, hoists, etc.

3 Increase minimum design loads by 50% where impact and vibrations of machinery or equipment occur.

4 Use weight of actual stored material when greater.

Table 8. Classification of buildings for wind, snow, and earthquake loads.*

Nature of Occupancy	Category
Buildings and structures that represent a low hazard to human life in the event of failure, such as agricultural buildings, certain temporary facilities, and minor storage facilities	I
All buildings and structures except those listed in Categories I, III, and IV	II
Buildings and structures that represent a substantial hazard to human life in the event of failure, including, but not limited to: buildings or other structures where more than 300 people congregate in one area, schools and daycare centers, health care facilities, jails and detention centers, and certain toxic or explosive storages	III
Buildings and structures designated as essential facilities, including, but not limited to: Hospitals Communication centers Power stations Fire or rescue Critical national defense	IV

* Source: American Society of Civil Engineers, *Minimum Design Loads for Buildings and Other Structures*, ASCE 7-95.

Wind Loads

Wind loading on structures is a complex phenomenon. The wind forces that act on a building are influenced by numerous factors, including: basic wind speed, building orientation and geometry, number and size of building openings, and building exposure. *The proper determination of all wind forces on a building (including potentially dangerous wind uplift) requires professional experience.*

The wind map in figure 25 shows basic wind speeds in the United States. The map presents the expected 3-second gust speed at 33 feet above the ground in open country, based on a probability of recurrence every fifty years. Winds flowing over mountains or through valleys in special wind regions (see figure 25) could have much higher speeds than those shown. Designers are cautioned to use local weather records in areas susceptible to unusual wind events.

Design values for wind load (P_w) are obtained by converting the appropriate wind velocity (V) from figure 25 to an effective velocity pressure (q), then multiplying by an appropriate gust effect factor (G) and pressure coefficient (C_p). The effective velocity pressure (q) is determined by using the following equation:

$$q = 0.00256\ K_z\ V^2\ I_w,\ \text{psf} \qquad \text{Equation (1)}$$

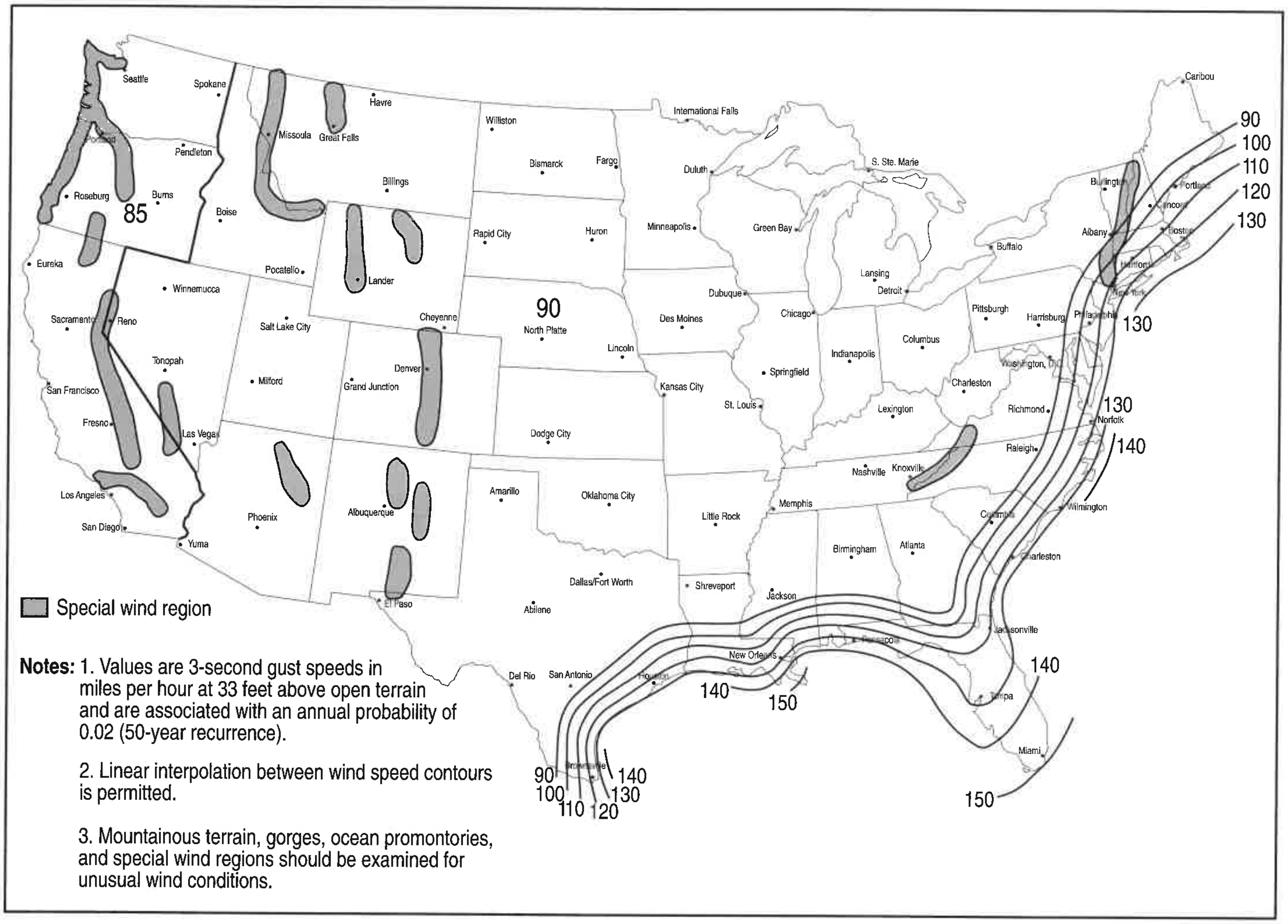


Figure 25. Basic wind speed, V, in mph. (*Source: American Society of Civil Engineers,* Minimum Design Loads for Buildings and Other Structures, *ASCE 7-95*)

where K_z is the exposure coefficient (from table 9),

V is the wind velocity for extreme winds at 33 feet above ground at a fifty-year recurrence interval (from figure 25), and

I_w is the importance factor for wind loads (from table 10, page 28).

For buildings located in flat, open country with few obstructions, the gust effect factor (G) is equal to 0.85. For buildings located in wooded areas, or with numerous obstructions, G = 0.80.

The building pressure coefficient, C_p, is influenced by the height and shape of the building, the roof slope, and the section of building being designed (i.e., roof, sidewalls, or endwalls). A closed building is one that has a perimeter of solid walls, including protected openings such as bay doors or large windows. A gable-roofed building is one with endwalls that extend vertically from the eave to the peak of the roof.

Table 9. Velocity pressure exposure coefficients, (K_Z).

Design height above ground level, Z[1] (ft.)	K_Z for exposure categories[2]		
	B	C	D
0-15	0.57	0.85	1.03
20	0.62	0.90	1.08
25	0.66	0.94	1.12

Source: American Society of Civil Engineers, *Minimum Design Loads for Buildings and Other Structures,* ASCE 7-95.

[1] For windward walls, the design height is equal to the eave height. For leeward walls, sidewalls, and roof, the design height is equal to the mid-elevation of the roof (i.e., eave height plus one-half roof height at the peak).

[2] Exposure categories reflect ground surface irregularities, as follows:

- A – (Not shown) Large city centers with tall buildings (> 70 ft.)
- B – Urban and suburban areas, wooded areas, or other terrain with numerous closely spaced obstructions the size of single-family dwellings or larger.
- C – Open terrain with scattered obstructions less than 30 ft. tall. This category includes flat open country and grasslands.
- D – Flat, unobstructed areas exposed to wind flowing over open water for at least one mile. Exposure D extends inland from the shoreline a distance of 1500 ft. or 10 times the height of the building or structure, whichever is greater.

The sidewalls of a closed gable-roofed building have a maximum C_p = 0.7.

Table 10. Importance factor (I_W) for wind loads.

Category[1]	I_w
I	0.87
II	1.00
III	1.15
IV	1.15

Source: American Society of Civil Engineers, *Minimum Design Loads for Buildings and Other Structures*, ASCE 7-95.

[1] See table 8, page 26.

A building is classified as an open building if all walls are at least 80% open. The sidewalls of an open gable-roofed building have a maximum $C_p = 1.3$. The roofs of buildings that are completely open on both sides (umbrella roof) have a $C_p = 0.6$. Monoslope buildings typically have one sidewall taller than the other, with a single-slope roof between them. Monoslope buildings with one sidewall open, such as a commodity storage shed, have a maximum $C_p = 1.3$.

All structures (including completely open buildings) experience complex internal and external wind pressures, resulting in both positive and negative values for C_p. For more detailed information concerning building shapes and wind pressure coefficients, refer to ASAE Engineering Practice EP288.5 DEC92, Agricultural Building Snow and Wind Loads, or ASCE 7-95, *Minimum Design Loads for Buildings and Other Structures*. Both are listed in the reference section of this handbook.

Snow Loads

Snow loads vary greatly and are difficult to predict. Nearby obstructions, wind, roof slope, and the type of storm all affect snow loading. Light, freshly fallen snow may have only one-twentieth the density of water, while wetter late-season snow packs may have a density one-third that of water. As a rule of thumb, 1 inch of snow accumulation results in approximately 1 pound per square foot of snow load. Roof snow loads are also influenced by building interior temperature, friction characteristics of the roofing material, and roof wind exposure.

Drifting snow causes uncertain and unbalanced loads that have collapsed buildings. Two to four times normal loads may occur where drifts, ice dams, or sliding snow build up:

- near projections above the general roof level,
- at intersecting roofs,
- at sheds below and beside a higher roof or silo, or
- on projecting eaves.

Example: Design wind load

Determine the design wind load for the sidewalls of a low-risk building located in the southwest corner of Iowa. The building is in an exposed location and has the following dimensions: it is 48 feet wide, has a 4:12 sloped roof, and has 16-foot-high sidewalls. The building is closed and has a gable roof.

From figure 25 on page 27, the basic wind speed, V, is 90 miles per hour in southwestern Iowa. From table 10, the importance factor for wind loads, I_w, for Class I (low-risk) buildings is 0.87. From note 1 of table 9 (page 27) the design height for leeward walls is equal to the eave height plus one-half the roof height at the peak (to be conservative, use the design height for the leeward wall because it is taller). For a 48-foot-wide building with a 4:12 roof slope, the total height of the roof peak above the eave is 8 feet (24 feet x 4 ÷ 12). Therefore, the design height is 20 feet (16-foot eave height plus ½ x 8-foot roof height). From table 9, the exposure coefficient (K_z) for an exposed building (category C) with a 20-foot design height is 0.90. Filling in all values for equation (1), the effective velocity pressure, q, is:

$q = 0.00256\ K_z V^2 I_w$, pounds per square foot,

$K_z = 0.90$ for a mid-roof height of 20 feet,

$V = 90$ miles per hour (from figure 25, page 27),

$I_w = 0.87$ (from table 10),

$q = 0.00256 \times 0.90 \times (90)^2 \times 0.87$,

$= 16.2$ pounds per square foot

For the sidewall of a closed gable-roofed building, the maximum pressure coefficient (C_p) is 0.7. For buildings in flat, open country, the gust effect factor (G) is 0.85 (see text, page 27). The design wind load for the sidewall, P_w, equals $q \times C_p \times G$; or 16.2 pounds per square foot x 0.7 x 0.85 = 9.6 pounds per square foot.

Design values for snow load are obtained by first determining the ground snow loads (p_g) in pounds per square foot from figure 26. The map snow loads are based on a probability of recurrence every fifty years.

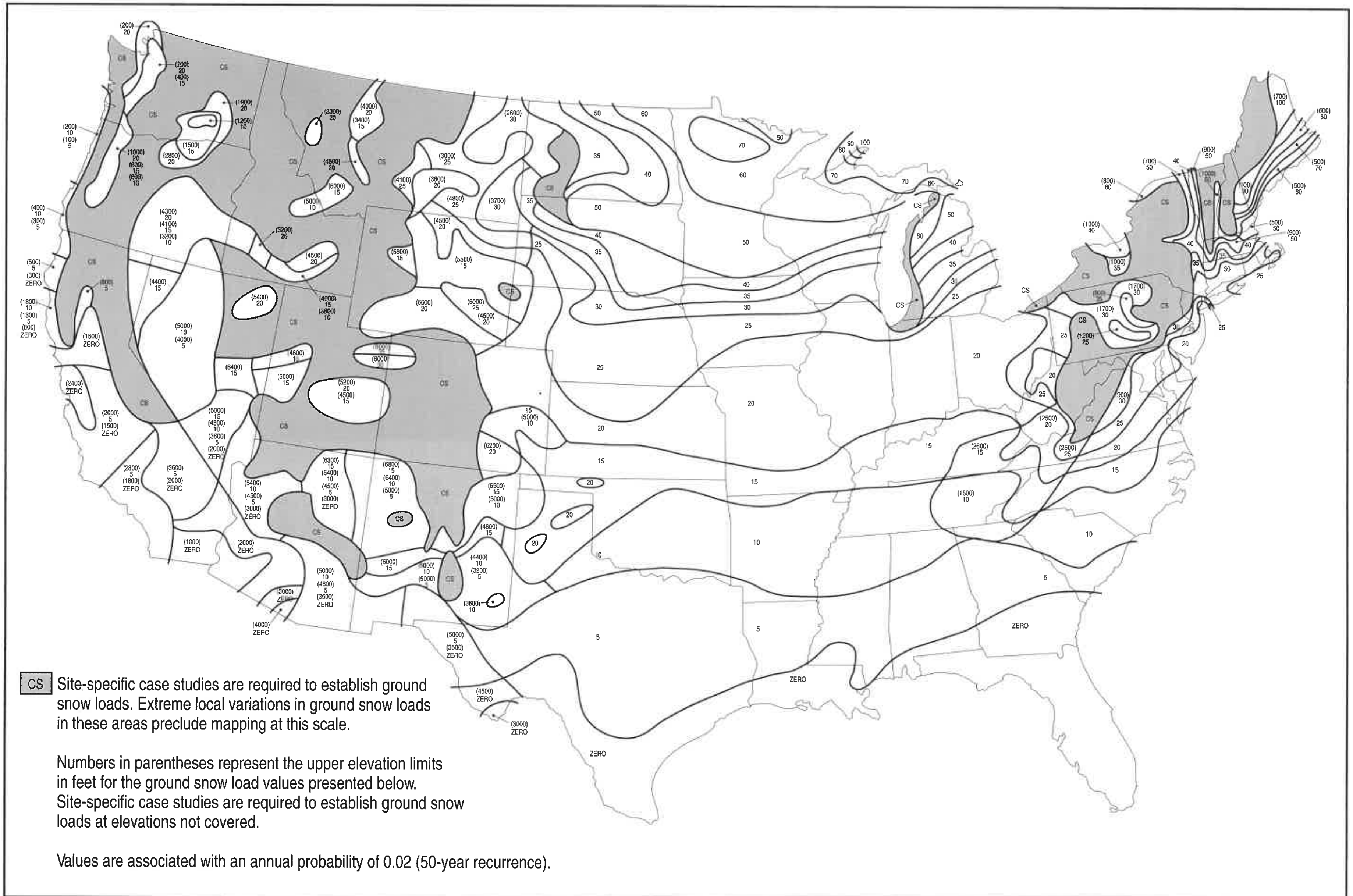


Figure 26. Ground snow loads, p_g, in psf. (*Source: American Society of Civil Engineers,* Minimum Design Loads for Buildings and Other Structures, *ASCE 7-95*)

Snow load values for shaded areas on the map vary widely with local topography. In these areas, ground snow loads should be estimated using local sources. Ground snow loads from figure 26 (page 29) are converted to design snow loads (P_s), in pounds per square foot, on an unobstructed roof using the following equation:

$$P_s = R\ C_e\ I_s\ C_s\ C_t\ p_g,\ \text{psf} \qquad \text{Equation (2)}$$

where R is the roof snow factor

= 1.0 for ground snowpack of 15 pounds per square foot or less

= 0.7 for ground snowpack of 20 pounds per square foot or more,

C_e is the building exposure factor

= 0.8 in windy areas with the roof completely exposed on all sides

= 1.0 where wind cannot be relied on to reduce roof snow loads due to terrain, higher structures, or nearby trees

= 1.1 where terrain, higher structures, or trees will shelter the building, increasing the potential for drifting,

I_s is the importance factor for snow loads (from table 11),

C_s is the roof slope factor (see table 12 to convert roof slope from rise:run to degrees from horizontal)

= 1.0 for 0° to 15° slope

= 1.0 - [(slope - 15) ÷ 55] for 15° to 70° slope

= 0 for slopes > 70°,

C_t is the thermal factor (from table 13), and

p_g is the ground snow load, in pounds per square foot, associated with a fifty-year recurrence interval (from figure 26, page 29).

For a more detailed presentation of building snow loads, including unbalanced loads from drifts, sliding snow, and roof projections, refer to ASAE EP288.5 DEC92, Agricultural Building Snow and Wind Loads, or ASCE 7-95, *Minimum Design Loads for Buildings and Other Structures*, both of which are listed in the reference section of this handbook.

Table 11. Importance factor (I_S) for snow loads.

Category[1]	I_s
I	0.8
II	1.0
III	1.1
IV	1.2

Source: American Society of Civil Engineers, *Minimum Design Loads for Buildings and Other Structures*, ASCE 7-95.

[1] See table 9, page 27.

Table 12. Conversion of roof slopes in rise:run to degrees for use in equation (2).

Roof slope in rise:run	ø, Roof slope in degrees from horizontal *
2:12	9.5°
2.5:12	11.8°
3:12	14.0°
3.5:12	16.3°
4:12	18.4°
4.5:12	20.6°
5:12	22.6°
5.5:12	24.6°
6:12	26.6°

* tan ø = rise/run

Example: Design snow load

Determine the design snow load on an unheated low-risk agricultural building located in the southwest corner of Iowa with a 4:12 sloped roof in a highly sheltered area (that is, it is subject to drifting).

Using figure 26 (page 29), ground snow load (p_g) is 25 pounds per square foot. Subsequently, the roof snow factor (R) is 0.7. The building exposure factor (C_e) and importance factor for snow load (I_s) (from table 11), are 1.1 and 0.8, respectively. From table 12, the slope of a 4:12 roof is equal to 18.4°. The roof slope factor (C_s) is calculated as follows: C_s = 1.0 - [(18.4 - 15) ÷ 55] = 0.94. The thermal factor (C_t) for an unheated structure (from table 13), is 1.2. Filling in all values for equation (2), the design snow load (P_s) is:

$$P_s = R\ C_e\ I_s\ C_s\ C_t\ p_g,\ \text{pounds per square foot,}$$

$$P_s = 0.7 \times 1.1 \times 0.8 \times 0.94 \times 1.2 \times 25,$$

$$= 17.4\ \text{pounds per square foot}$$

Table 13. Thermal factor (C_t) for snow loads.

Thermal condition[1]	C_t
Heated structure	1.0
Structure kept just above freezing	1.1
Unheated structure	1.2

Source: American Society of Civil Engineers, *Minimum Design Loads for Buildings and Other Structures*, ASCE 7-95.

[1] These conditions should be representative of those that are likely to exist during winters for the life of the structure.

Earthquake (Seismic) Loads

Earthquake loads are geographically dependent. Although it is always important to consider the potential for injury, ASCE 7-95 recommends that buildings with a low hazard to human life be exempt from the stringent building requirements for earthquake loading. Most agricultural storage buildings intended for incidental human occupancy are classified as Category I structures (see table 8 on page 26) and are generally exempt from ASCE provisions for buildings subject to earthquake ground motions. *As with all proposed building construction, check with local building code requirements before initial design.*

Combination of Loads

Every building element should be designed to resist the most critical load combination specified by the governing building code. Combinations of loads are used because maximum design loads on a building will probably not all occur at the same time. For example, it is unlikely that the maximum wind load will occur at the same time as the maximum snow load. Except when applicable codes require otherwise, the following load combinations should be considered (as a minimum). The combination that results in the most conservative design for each building element should be used. These load combinations are:

1. Dead + Snow
2. Dead + Wind
3. Dead + Wind + ½ Snow
4. Dead + ½ Wind + Snow

The above load combinations are used by design professionals to determine the critical size of structural members and components. For example, whereas load combination 3 usually governs the design of posts and roof diaphragms in post-frame buildings, load combination 1 frequently controls truss design. However, depending on the geometry of the building, unbalanced snow loads due to drifting and sliding may become critical for truss design.

In addition, wind load combinations should be checked for possible stress reversals in members (such as truss webs, where a tension web may become stressed in compression). Wind uplift is checked using load combination 2. It is important not to overestimate dead loads for building resistance to wind uplift, since this could provide unrealistic design assumptions (see section on Dead Loads, page 25).

Roof purlins and wall girts are also usually controlled by wind loads; however, roof purlins must also be checked for maximum gravity loads. Due to excessive loads from wind near the edges of the building, design of connections is critical (see section on Fasteners, page 48).

Post design is often controlled by full wind plus a portion of gravity loads (load combination 3) rather than maximum gravity load (load combination 1). Similarly, post foundation depth is controlled by load combination 3 but is also checked for bearing and uplift using load combinations 1 and 2. Since most post-frame buildings are single-story, floor loads do not usually act on the post-frame structure. Suspended floors require special design consideration (see section on Suspended Floors, page 56).

The following is a procedure for post load determination. *The same procedure can be used to determine the loads acting on all structural siding, roof, and truss components in a post-frame building.*

1. The dead load is best determined by adding the weight of all the construction materials that act on the structural member. An estimate of 3½ to 5 pounds per square foot is often used for initial estimates of post-frame building roof dead load.
2. Live loads acting on the building are determined from the activities in (or on top of) the proposed building. Roof construction live loads ranging from 12 to 20 pounds per square foot are often used to estimate the weight of workers and equipment used to assemble roof components. *Typically, one-story post-frame buildings have few other live loads acting on the building frame since live loads are usually carried by an interior concrete or earthen floor system. A major exception is the live product storage loads acting outward on the sidewalls of a post-frame storage facility (see section on Sidewall Loading Due to Bulk Storage, page 60).*
3. The design wind load for the building member is determined using equation (1) on page 26.

4. The snow load is determined using equation (2) on page 30. *Use the larger of snow load or minimum roof live load, but not both.*

5. Determine the critical loads or combination of loads that must be resisted by the structural member, as outlined in the beginning of this section. *It is recommended that an experienced design professional be secured to determine the critical load combinations for all post-frame structural members.*

Stresses in Wood

Posts in a post-frame building act both as columns and vertical beams. As columns, they must resist both crushing and buckling. Crushing of wooden posts in post-frame buildings is not common because bending (flexural) loads predominate on typical sidewall posts. Also, the wood fibers running the length of the column (axially) are inherently strong in resistance to compressive loads. Buckling, however, can occur when a relatively long unsupported column fails due to compressive forces, such as a snow load on the roof. To prevent buckling, the column cross-section can be increased (by using a larger size post), or bracing can be used. Bracing reduces the unsupported length of the post "column" and controls buckling by providing lateral support. Wall girts can act as post bracing in a post-frame building.

In addition to acting as a column, a post can act as a vertical beam when horizontal forces push against it. Wind on the side of the building, stored products that act outward against the sidewall, and soil pressure (as in an embankment or retaining wall) are loads that must be resisted by the vertical "beam." The bending stresses that result from these horizontal loads must be resisted by the post in addition to the compression stresses caused by snow and other downward-acting gravity loads. Since the post is subjected to both vertical (compressive) and lateral (bending) loads, it is referred to as a beam-column.

The basic stresses that any wood member must resist include: compression, tension, bending, and shear. Design tables for structural lumber, glued-laminated timbers, and other structural wood products provide the numerical value of the stresses that a wooden member can safely withstand. The following design stresses, which are given in pounds per square inch, are used to classify the strength of structural wood products:

Fc Compression parallel to grain,

Fc⊥ Compression perpendicular to grain,

Ft Tension parallel to grain,

Fb Extreme fiber in bending,

Fv Horizontal shear (or shear parallel to grain), and

E Modulus of elasticity.

Table 14 presents design values for visually graded Spruce-Pine-Fir posts and timbers (5-inch-by-5-inch and larger) from the American Forest & Paper Association's *NDS Supplement*, revised 1991 edition. The following paragraphs provide a discussion of how each table design value is used to select the strength properties of a wooden member:

Compression Stresses

Compression is a load that tends to compress a material. Compression parallel to the grain, Fc, is caused by a force exerted on the end grain of a wooden member, such as the vertical snow and roof loads acting on a post-frame building (figure 27). A different stress in wood, compression perpendicular to the grain, Fc⊥, is caused by a force exerted on the side grain of a wooden member (figure 28). Considering its relatively light weight as a building material, wood has a very efficient compressive strength, with some species surpassing the strength of brick under compressive loading.

Tension Stress

When the force on a wood member tends to pull it apart or stretch it in the longitudinal (long) direction, it is said to be in tension. Therefore, tension is the opposite of compression. Fiber stress in tension, Ft, is caused by the axial (end) force exerted across the full

Table 14. Design values for visually graded posts and timbers (5"x5" and larger) Spruce-Pine-Fir.

Commercial Grade	Design values in pounds per square inch (psi)					
	Bending, Fb [1]	Tension parallel to grain, Ft	Shear parallel to grain, Fv	Compression perpendicular to grain, Fc⊥	Compression parallel to grain, Fc	Modulus of elasticity, E
Select Structural	1050	700	65	425	800	1,300,000
No. 1	850	550	65	425	700	1,300,000
No. 2	500	325	65	425	500	1,000,000

Source: American Forest and Paper Association, *Design Values for Wood Construction, NDS Supplement*, Revised 1991 Edition, p. 35.

Table design values are for normal load duration (ten years) and dry service conditions (< 19% moisture content).

[1] When the depth, d, exceeds 12", the bending design value, F_b, shall be multiplied by the following size factor: $C_F = (12/d)^{1/9}$

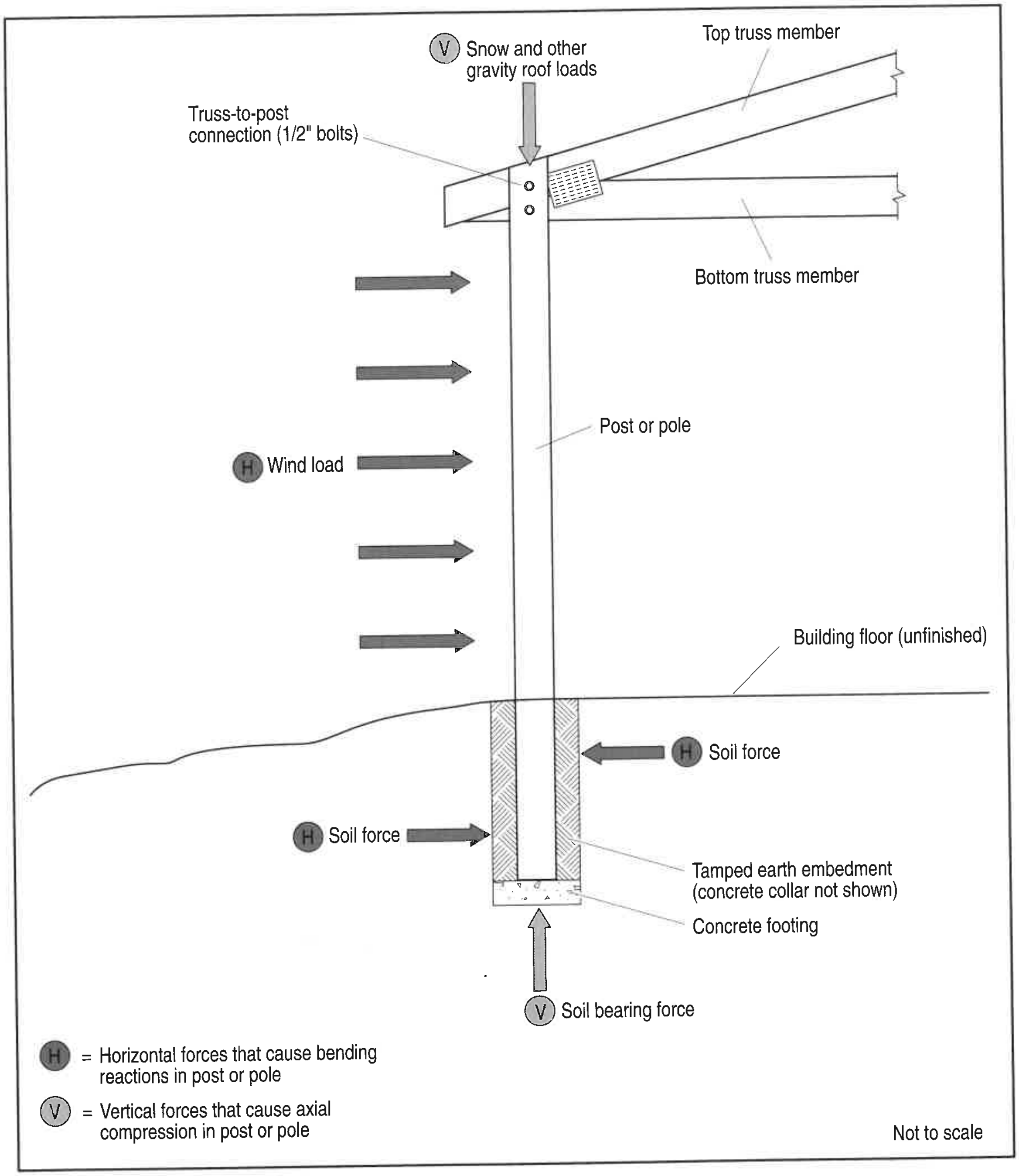


Figure 27. Selected horizontal and vertical forces acting on a post.

cross-section of a member. As an example, the bottom chord of a common triangular truss (see figure 9, page 12), when gravity loaded, is normally in tension. Certain other truss chords simultaneously undergo compressive forces. In order to prevent truss failure, professional design and assembly is critical (see section on Roof Trusses, page 12). When loaded in tension parallel to the grain, wood compares favorably with other building materials, surpassing brick and concrete under tension loads.

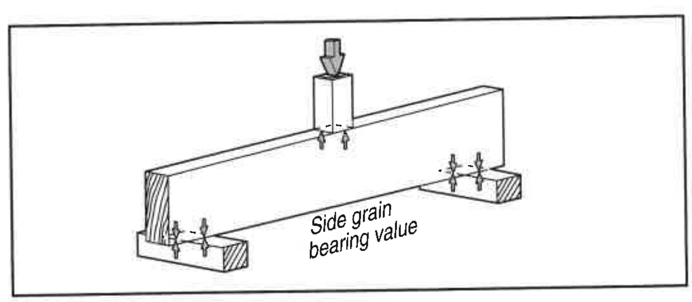


Figure 28. Compression perpendicular to grain. (*Courtesy of Western Wood Products Association*)

Bending Stress

Bending stress, Fb, in a wood member is caused by a force applied perpendicular to its longitudinal axis causing it to bend or sag. The horizontal wind load acting on the post-frame building wall in figure 27, page 33, causes bending stresses that must be resisted by the post. Wood members resist bending best when loaded on edge rather than flat. For example, a beam with dimensions of 3 inches by 12 inches, *placed on edge*, will make a stronger girder than one with 6-inch-by-6-inch dimensions, although both have the same cross-sectional amount of wood (36 square inches). On a numerical basis, the 3-inch-by-12-inch beam would have twice the strength to resist bending as the 6-inch-by-6-inch beam because of its greater depth in the direction of the load.

Shear Stress

Horizontal shear, Fv, also called shear parallel to the grain, occurs when individual wood fibers within a member slide over each other. To illustrate, imagine a beam made up of a stack of boards under a load. If they are not connected, the sagging boards will slide against each other, with the boards sliding most at the end of the beams. *NDS states that it is not necessary to check the strength of wood bending members in shear perpendicular to the grain, as the member will always fail in shear parallel to the grain first.*

Figure 29 shows the stresses in a loaded wood member undergoing both bending and horizontal shear. Note that the beam shown is also undergoing bending-induced compression and tension stresses in its extreme top and bottom fibers, respectively.

While wood members do not have the high strength of steel to resist bending or shear loads, the versatility and relatively low cost of natural wood components make them an excellent choice for structural building components. When properly treated, wood posts and poles provide a useful service life comparable to other building materials (see section on Preservative Treatment, page 9).

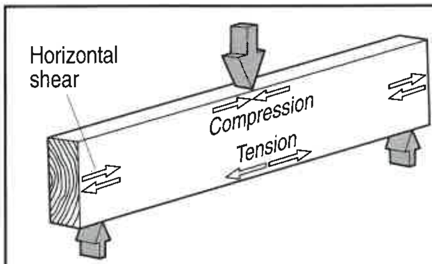


Figure 29. Stresses in a beam in bending and shear. (*Courtesy of Western Wood Products Association*)

Modulus of Elasticity

The modulus of elasticity, E, is used by designers as a measure of the amount a member will deflect in proportion to an applied load. Excessive deflection in building members can cause cracks in ceilings and windows. For a plastered ceiling, building codes often limit the allowable deflection to 1/240 or 1/360 of the total span length. Consequently, a ceiling with a span of 30 feet may have an allowable total deflection of only 1.5 inches (1/240 x 30 feet x 12 inches per foot) at the center of the span. Structural members are designed to limit deflection within allowable limits.

Diaphragm Action

There are at least two ways to design lateral stability into a building. In conventional stud wall construction, the structure above the foundation wall must have sufficient lateral resistance to transmit all horizontal forces (loads) to the concrete foundation wall. In post-frame buildings, all frame components *(including the posts in the ground)* act together to provide adequate lateral resistance. Roofing and siding materials attached to a building frame generally serve to protect building components and contents from wind, rain, snow, and sun. *In a post-frame building, roofing and siding materials can also add stiffness or rigidity to the structure.* This stiffness is called diaphragm action.

Before the mid-1980s, post-frame building designers generally did not allow for the stiffness added to the structure by roofing and wall sheathing. Traditional post-frame building designers determined the various building loads acting on the roof and sidewalls, then transferred those loads directly from the roof trusses and walls to individual posts or poles, and finally to the ground through the foundation. Modern diaphragm designers of post-frame buildings include computerized analysis of the additional stiffness supplied by sheathing to the total stiffness of the building frame. This often allows smaller-sized posts. *The resulting building design can be less costly to construct because of reduced post embedment depth requirements, and because posts can be smaller.*

The stiffness added by diaphragm action can be visualized by considering a rectangular frame of dimension lumber. If a racking or shear load is placed on the frame, it will deform or "rack" out of shape with little resistance (figure 30a). However, if sheathing is fastened to the frame, the racking load will be resisted and the frame and sheathing will act as a unit (figure 30b) due to diaphragm action.

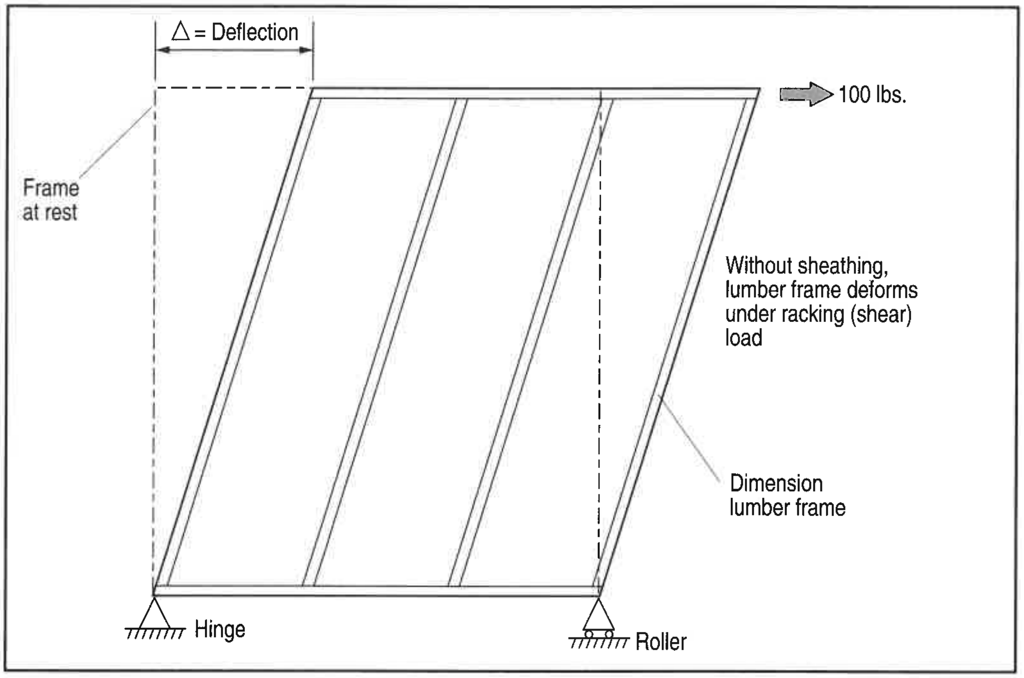


Figure 30a. Lumber frame deflection without sheathing. (*Adapted from ASAE EP484.1 DEC94*)

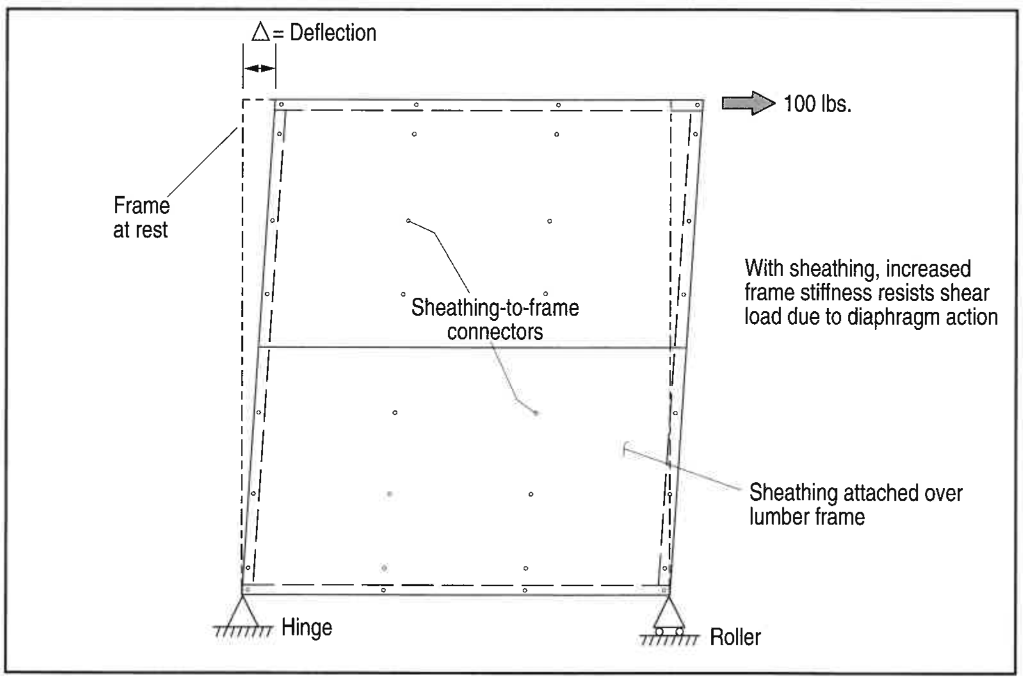


Figure 30b. Lumber frame deflection with sheathing. (*Adapted from ASAE EP484.1 DEC94*)

In a post-frame building, diaphragms are framing members with sheet materials securely fastened to them. The frame or panel designed as a diaphragm has an increased stiffness, which means that more force is required to produce the same amount of deflection at the building eave. Figures 31a and 31b, page 36, illustrate the beneficial effects of diaphragm action on design of a post-frame building. Note that the non-rigid endwall in figure 31a adds little lateral resistance against wind forces, while the rigid endwall of figure 31b decreases eave deflection considerably due to diaphragm shear resistance.

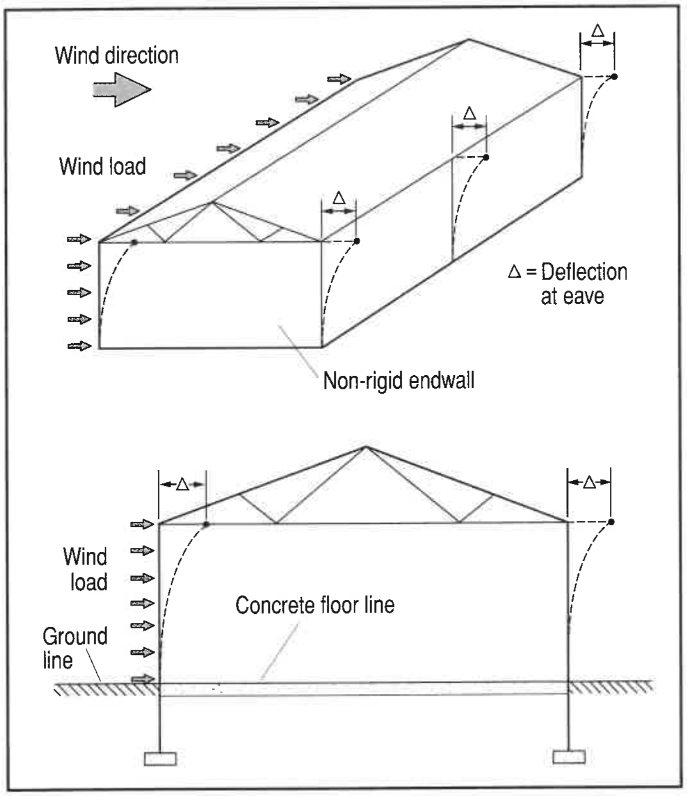


Figure 31a. Post-frame deflection without diaphragm action. (*Adapted from Gebremedhin, Manbeck, and Bahler, 1992)*

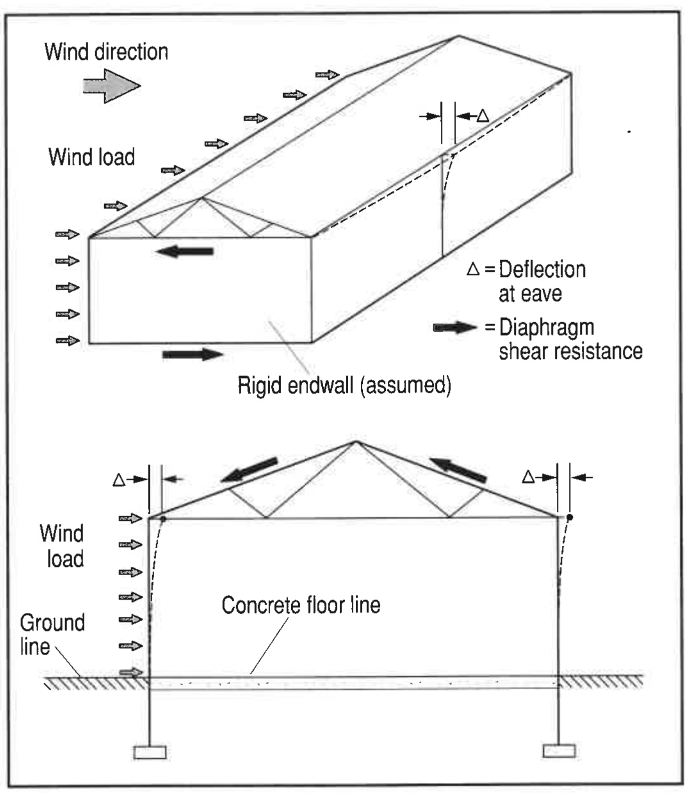


Figure 31b. Post-frame deflection with diaphragm action. (*Adapted from Gebremedhin, Manbeck, and Bahler, 1992)*

Diaphragm panels are strongest at resisting forces in their long direction. For a wind blowing toward the long side of a post-frame building, the largest effective diaphragms would be the end walls and the roof. If the building has a short length (less than approximately 3:1 length-to-width ratio) with no supporting cross walls, then the horizontal wind forces are distributed by the roof diaphragm, first to the end walls, then to the foundation. If the building is long, the roof and ceiling diaphragms may need cross walls, additional bracing, or post foundations specially designed to provide additional lateral resistance.

The racking or shear force in a diaphragm frame or panel is resisted by the sheathing, the fasteners, and the frame. Diaphragm strength is dependent on the strength and stiffness of the sheathing material and the connection between the purlin or girt and the sheathing. The overall stiffness of a post-frame building is enhanced by stitching (fastening) the overlapped sheathing or cladding using the proper number, size, and distribution of fasteners.

Diaphragm action is more effective in one-story post-frame buildings with totally enclosed sidewalls and endwalls. Effective diaphragm action is reduced in longer buildings or in buildings with large doors or openings in the endwalls, unless the remaining endwall bays are braced and fastened to provide additional support for the transfer of loads to the ground. A longer, more open building, such as a dairy freestall barn with open sidewalls, must depend on proper endwall bracing and post embedment to resist racking forces.

Endwalls in post-frame buildings with large openings should be reinforced with plywood sheathing, metal strips, or wooden cross-bracing. For more rigid support, all posts in a post-frame building should continue at equal spacing along both endwalls and around the entire perimeter of the building, from the ground to the roof line, as shown in figure 32.

Further consideration of diaphragm action is beyond the scope of this handbook. *NOTE: None of the tables presented in this handbook include the beneficial effects of diaphragm action from properly designed and installed rigid roof and wall cladding. Consequently, resulting table values for preliminary sizing of structural members may be conservative.* For more detailed information about diaphragm action, readers are referred to ASAE Monograph Number 11, *Post-Frame Building Design* (Walker and Woeste, eds., 1992), listed in the reference section.

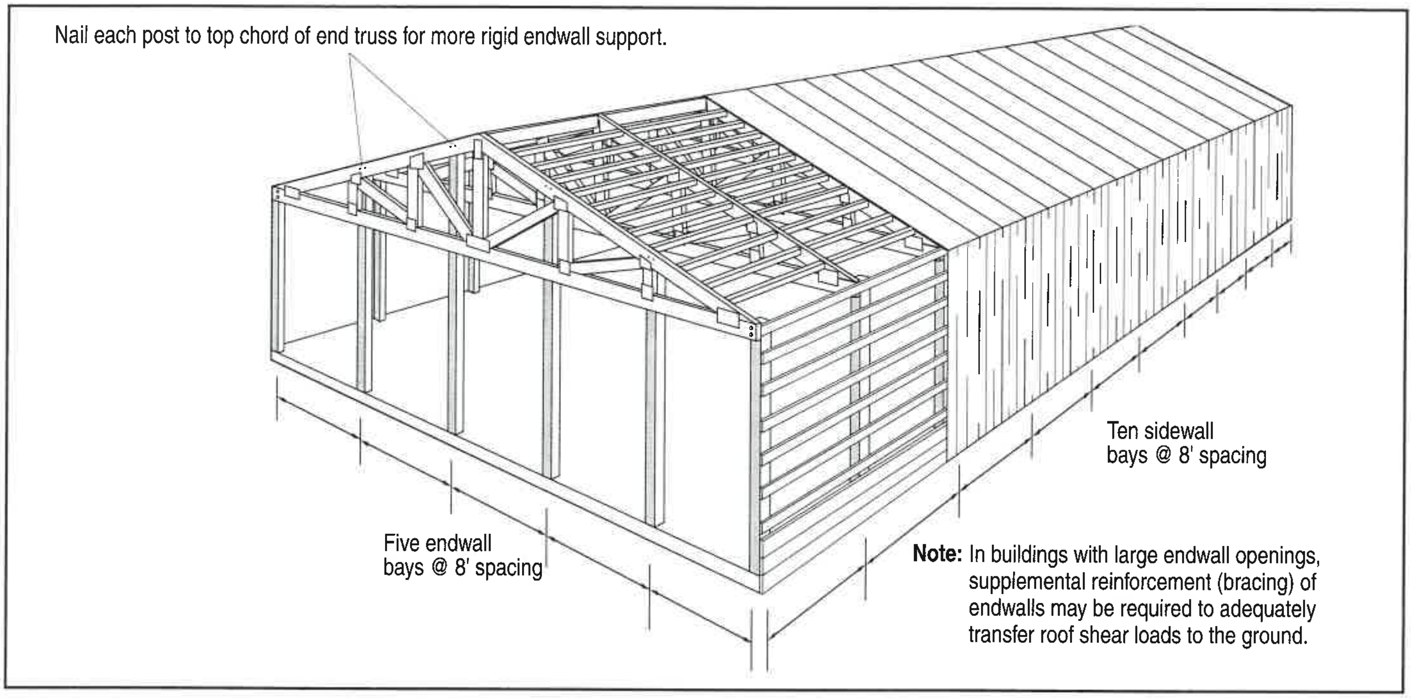


Figure 32. Equal post spacing around the perimeter of a post-frame building. (*Adapted from Walker and Woeste,* Post-Frame Building Design, *1992.*)

Post Size and Spacing

Post size and spacing is dependent on the functional requirements of the building and the loads that the structure must resist. The functional design of the building will determine the height, width, and length of all structural members. Most post-frame buildings are constructed using either a 4-, 6-, or 8-foot post spacing. Common post spacings take advantage of standard lengths of dimension lumber and sheathing. An 8-foot post spacing is most common.

Roof trusses can be designed to any length. However, standard lengths of trusses are normally manufactured in 2-foot increments (for example, 24 feet, 26 feet, 28 feet, 30 feet, 32 feet), corresponding to the width of the building. Standard-width trusses are normally less expensive than special-order trusses.

Generally, it is desirable to have the truss spacing the same as the post spacing. This allows a direct connection between each post and truss. Post-truss connections allow uniform loads (those loads evenly distributed along the length of a member) to be transferred directly to the post-frame assembly through roof purlins and wall girts (figure 33).

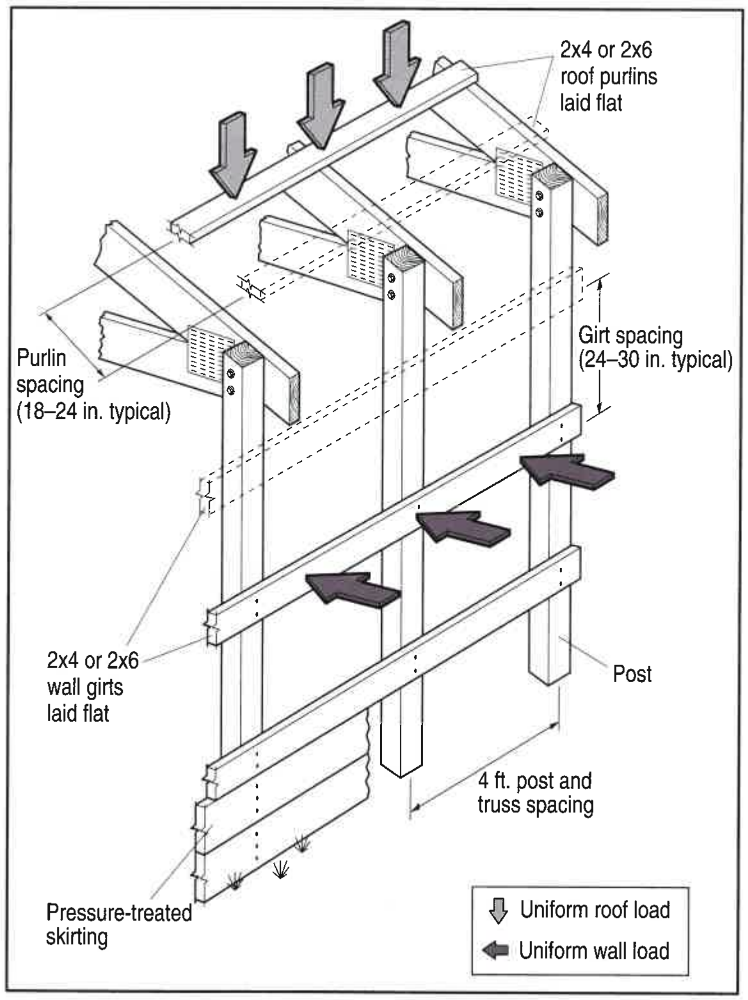


Figure 33. Uniform roof and wall loads on a post-frame building.

Trusses that are placed between the posts must be supported with one or more girders. Figure 34 illustrates how a uniform roof load can be transferred from roof purlins, to intermediate trusses, to girders, before being carried to the ground by the post. Regardless of the post and truss spacing, all trusses require special connections to resist applied loads (see section on Truss Anchorage, page 47). (For sizing of girders, purlins, and girts, see section on Framing Members on page 43.)

Posts require a strong foundation to resist vertical loads such as building dead loads, snow loads, and wind uplift loads. Lateral loads primarily from the wind must also be resisted. Post and foundation design are closely related. For example, both can change significantly with the addition of a suspended floor (see section on Suspended Floors, page 56). Values for soil resistance to vertical and lateral loads are needed to properly design the post foundation. Soil properties for foundation design can be determined either by testing the soil or by using table values based on soil type (see section on Foundations, page 40).

Post spacing is used to determine the magnitude of forces acting on each post. For example, structural posts designed to be placed 8 feet on-center will be required to resist approximately twice the load of posts placed 4 feet on-center, assuming similar building loads. The increased load on posts with wider spacings is a result of the larger surface areas (horizontal and vertical) upon which all distributed loads are acting.

Table 15 presents recommended maximum post spacings for enclosed gable-roofed buildings using Southern Pine No. 2 for the posts. Table values do not consider the added stiffness of building cladding (see section on Diaphragm Action, page 34). As table 15 shows, post spacing is influenced by building post size and eave height, as well as the expected wind speed.

Post spacings greater than 8 feet (shown in bold in table 15) are not recommended, except in the case of specially designed doorways or other building openings. Due to the larger loads on girders, purlins, girts, and foundations, seek professional design assistance for post spacing applications that exceed 8 feet.

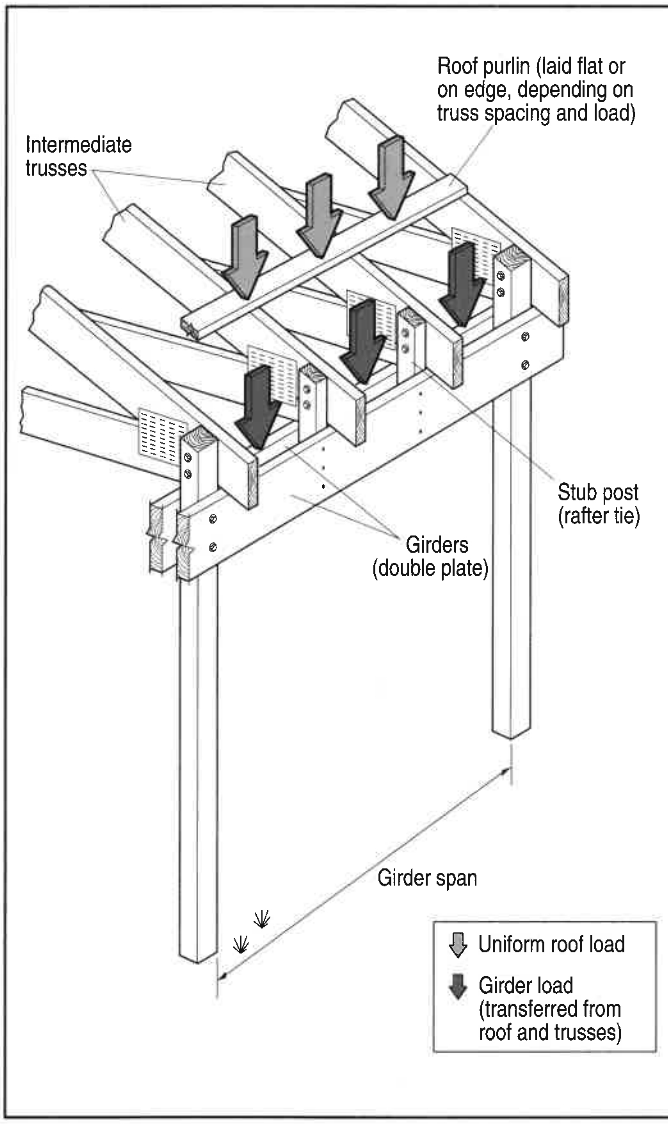


Figure 34. Uniform roof loads transferred to girders.

Table 16 presents the bending strengths for various No. 2-graded wood posts, as well as their bending strength relative to Southern Pine No. 2. To obtain post spacings for wood species other than Southern Pine, multiply table values from table 15 by the relative bending strength value from table 16.

Table 15. Maximum spacing of Southern Pine (No. 2) posts for wind loads on closed gable-roofed buildings.

	90 mph wind (q = 18.6 psf)				100 mph wind (q = 23.0 psf)				110 mph wind (q = 27.8 psf)			
	Eave height, feet											
Post	10	12	14	16	10	12	14	16	10	12	14	16
6x6	5.7	NR	NR	NR	4.6	NR	NR	NR	NR	NR	NR	NR
6x8	**10.5**	7.3	5.4	4.1	**8.5**	5.9	4.3	NR	7.0	4.9	NR	NR
6x10	**16.9**	**11.7**	**8.6**	6.6	**13.7**	**9.5**	7.0	5.3	**11.3**	7.9	5.8	4.4
8x8	**14.4**	**10.0**	7.3	5.6	**11.6**	**8.1**	5.9	4.5	**9.6**	6.7	4.9	NR

Notes to table:

q = wind velocity pressure, in pounds per square foot
NR = not recommended

A closed building is one that has a perimeter of solid walls. These "solid" walls can include protected openings (such as bay doors or large windows).

A gable-roofed building is one with endwalls that extend vertically from the eave to the peak of the roof.

A building is classified as an open building if all walls are at least 80% open.

Wind velocity pressures in table 15 are based on equation (1) (see page 26), using an importance factor (I_w) of 1.0 and an assumed exposure coefficient (K_z) of 0.90.

The resulting velocity pressures (q) shown are 0.0023 times the wind speed, in miles per hour, squared.

Post spacings in table 15 are based on uniform design wind loads acting on windward wall surfaces between unpropped cantilever posts.

The larger post dimension is in the same direction as the wind or parallel to the building width.

To determine design wind loads, velocity pressures (q) shown above are multiplied by a pressure coefficient (Cp) of 0.70 (ASAE EP288.5 DEC92) and a gust effect factor (G) of 0.85 (American Society of Civil Engineers, ASCE 7-95).

The critical section of maximum bending stress is assumed to occur at floor level. Design formulas from American Forest and Paper Association, *National Design Specification for Wood Construction,* Revised 1991 Edition, pp. 5–9:

C_D (load duration factor) = 1.60 (for wind load).

Actual post bending stress = M/S, where M is maximum bending moment = $wL^2/2$ (lb-ft), S is section modulus (in^3) (see appendix B), w is uniform load (lb/ft), and L is the unsupported length of the post from the ground to the eave (ft).

Allowable design values for Southern Pine No. 2 from American Forest and Paper Association, *Design Values for Wood Construction, NDS Supplement,* Revised 1991 Edition, p. 35:

Fb (5"x5" and larger) = 850 psi.

Table values are determined as follows: Post spacing, ft. = section modulus (in^3) x Fb (lb/in^2) x C_D x 2 / [Cp x G x wind pressure (lb/ft^2) x (eave height)^2 (ft^2)] /12 (in/ft).

Table values do not consider diaphragm action of building cladding (see section on Diaphragm Action, page 34).

Table values do not consider deflection criteria as a limiting factor of design.

Post spacings shown in bold should not exceed 8 feet without proper design consideration of the increased load on girders, purlins, girts, and foundations.

For No. 2-grade wood species other than Southern Pine, multiply maximum spacings in table15 by the relative bending strength in table 16.

Resulting post spacings less than 4 feet are not recommended. Use the next larger post size to achieve a minimum 4-foot spacing.

Resulting post spacings less than 4 feet are not recommended. Use the next larger post size to achieve a minimum 4-foot spacing.

For open gable-roofed or open monoslope buildings, divide maximum spacings in table 15 by 1.86.

Table 16. Post bending strength for graded (No. 2) lumber species.

Species	Extreme fiber in bending (Fb, psi)	Relative bending strength to Southern Pine
Birch, Hickory	725	0.85
Douglas Fir-Larch	750	0.88
Hemlock-Fir	575	0.68
Maple-Mixed	500	0.59
Maple - Red	650	0.76
Oak - Mixed, Red	575	0.68
Oak - White	600	0.71
Pine - Ponderosa	475	0.56
Pine - Red	475	0.56
Pine - Western White	450	0.53
Pine - Northern	550	0.65
Pine - Southern	850	1.00
Spruce - Eastern	450	0.53
Spruce - Sitka	550	0.65
Spruce-Pine-Fir	500	0.59

Adapted from: American Forest and Paper Association, *Design Values for Wood Construction, NDS Supplement,* Revised 1991 Edition, pp. 31–37.

Design values are for visually graded timbers (5"x5" and larger) at normal load duration (10 years) and dry service conditions (< 19% moisture content).

Example: Selecting a post spacing

A 6-by-8 Southern Pine No. 2 post has been selected for a closed, gable-roofed post-frame building with a 12-foot eave height. The expected wind speed on the building is 90 mph. What is the recommended post spacing? For a more conservative design, the added stiffness of building cladding (i.e., diaphragm action) is not considered.

From table 15, a value of 7.3 feet is the maximum recommended post spacing. Although the maximum 7.3-foot spacing would be adequate for this building, post spacings are normally set in increments of 2 feet to accommodate standard truss spacings. Therefore, a 6-foot post spacing would be chosen for the Southern Pine No. 2 posts in this building.

If Douglas Fir-Larch No. 2 posts became available for the same building, the maximum recommended post spacing would be:

7.3 feet (from table 15) x 0.88 (from table 16) = 6.4 feet

Use 6-foot post spacings.

Foundations

The foundation of a post-frame building is made up of two components: (1) the post footing and (2) the embedment material used to encase the post. The complete post foundation must create a stable base for the post-frame assembly in order to limit structural settlement or horizontal movement that could cause cracks, leaks, equipment misalignment, or even a sagging roof. Downward loads on the post-frame foundation include all gravity loads associated with the building, including the weight of the building materials, snow, and any fixed equipment.

NOTE: In a diaphragm-designed post-frame structure, distributed shear loads from roof and wall diaphragm panels reduce the size of foundation components (see section on Diaphragm Action, page 34). The foundation size and depth recommendations in this section do not include the beneficial effects of diaphragm design.

Settlement of a post-frame foundation is prevented by using an expanded foundation area called a footing. By utilizing the weight of embedment (soil, gravel, or concrete backfill) along with the footing, post-frame foundations also anchor buildings to the ground during wind storms. In locations where the soil undergoes significant freezing and thawing, properly designed foundations prevent building damage due to excessive post movement below grade (see Frost Action, page 43). In addition, a post-frame foundation may be required to resist internal horizontal forces such as wind or sidewall loads from stored materials (see Sidewall Loading Due to Bulk Storage, page 60). *Because building loads and subsurface soil conditions can vary widely, it is important to obtain professional assistance for post-frame foundation design.*

Table 17. Minimum recommended footing size, diameter (inches) for 30 psf vertical load.

Building width, feet	Post spacing, feet	Soil bearing capacity		
		1000 psf (clay)	1500 psf (sand, silty sand)	2000 psf (sedimentary and layered rock, sandy gravel)
32	4	20	16	**16**
	6	24	20	16
	8	N/R	24	20
36	4	20	16	16
	6	24	20	**20**
	8	N/R	24	20
40	4	**24**	**20**	16
	6	28	**24**	20
	8	N/R	**28**	**24**
44	4	24	20	16
	6	28	24	20
	8	N/R	28	24
48	4	24	20	**20**
	6	N/R	24	**24**
	8	N/R	28	24
52	4	24	20	**20**
	6	N/R	24	**24**
	8	N/R	28	**28**
56	4	N/R	**24**	20
	6	N/R	28	24
	8	N/R	N/R	28
60	4	N/R	**24**	20
	6	N/R	28	24
	8	N/R	N/R	28

Adapted from: ASAE EP486 DEC92
N/R = not recommended.
NOTE: Minimum pad thickness for foundation diameters are:
6" for 16- and 20-inch diameters
8" for 24-inch diameter
12" for 28-inch diameter
Above footing sizes may be used in the absence of recommended codes or soil tests.
Footing sizes shown in bold will support a vertical load of 40 psf.

Footing

The footing of a post-frame building consists of a concrete pad at the bottom of the excavated post hole. The diameter and thickness of the concrete pad is dependent upon the vertical load acting on the post, the ability of the soil to support the load, and the size of the post. Often each post supports 8,000 pounds or more of vertical load. This heavy load bearing on the relatively small post cross-section area will cause a post to settle in most soils. Concrete footing pads prevent settling by increasing the vertical post-to-soil bearing surface. A minimum footing thickness of 6 inches is recommended to provide the necessary strength to resist crushing or cracking of the concrete pad.

Table 17 lists the minimum recommended footing size diameter, in inches, for selected building widths and soil types. Table 17 may be used in the absence of recommended codes or soil tests.

Cast-in-place concrete or butt-encased footings work well for most farm buildings (see figure 35). When compared to a tamped-earth backfill with no footing, a butt-encased footing increases resistance to wind uplift by four times or more and can also reduce post deflection from wind to less than two-thirds that of a tamped-earth backfill. Concrete casings (also called full collars) consist of a concrete collar extending the full length of the embedment.

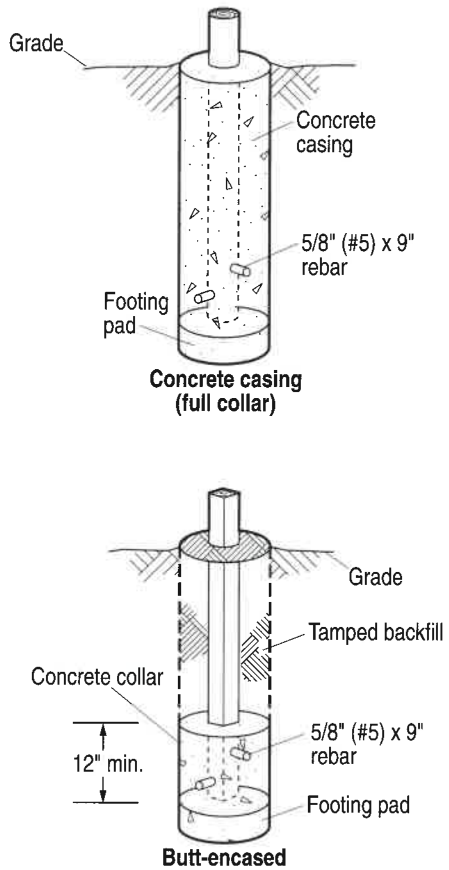


Figure 35. Typical post-frame foundations.

A full encasement of concrete increases the resistance of the post to lateral loads and can reduce the required depth of a post foundation. Full-collar foundations are stronger and can be used where additional resistance is needed. Full concrete casings are beneficial:

- on posts next to large doors,
- in poorly drained soils,
- for posts that cannot be fully embedded because of isolated rock, and
- for posts in open-front buildings with posts spaced 10 feet or more apart.

To properly resist uplift forces, the posts in either a butt-encased or full-collar footing should be positively connected to the concrete collar as follows. Drill two holes through the post and at right angles to each other approximately 3 inches and 5 inches from the end of the post. Insert a 9-inch-long piece of #5 rebar (⅝-inch-diameter steel concrete reinforcement bar) in each hole and place concrete around the post to create the collar.

Example: Sizing a footing pad

A 40-foot clear-span building has posts spaced 4 feet on-center. The expected snow plus dead load is 40 pounds per square foot. Soil is a well-drained silty sand. What size footing pad is needed?

Table 17 shows that, in the absence of building codes or soil tests, this soil should support 1,500 pounds per square foot. Enter the column for sand, silty sand. Values in bold must be used since all other values in table 17 are for 30 pounds per square foot loads. Enter the row for a 40-foot building and 4-foot post spacing. Table 17 shows that a 20-inch-diameter concrete pad (6 inches thick) will support the 40 pounds per square foot vertical load. This size pad would also be sufficient for expected loads less than 40 pounds per square foot.

To verify the table value (or to determine the footing size for other loads and building size configurations) the following procedure can be used:

Each post carries the basic load x total building width ÷ 2 x post spacing = 40 pounds per square foot x 40 feet ÷ 2 x 4 feet = 3,200 pounds vertical load per post.

A 20-inch-diameter pad has a bearing or end area of:

π x (10 inches)^2 ÷ 144 square inches per square foot = 2.18 square feet

In order to avoid settlement, the vertical load per post (pounds) divided by the bearing area of the footing pad (square feet) must be less than the soil-bearing capacity (from table 17). In this example, 3,200 pounds ÷ 2.18 square feet = 1,468 pounds per square foot of vertical pressure acting on the soil through the footing pad. Since footing pad loading (1,468 pounds per square foot) is less than the 1,500 pounds per square foot bearing capacity of the soil, a 20-inch pad is sufficient.

Embedment

Embedment, or backfill, is the material placed between the post and the prebored hole making up the post-frame foundation. Because the embedment material provides the foundation's lateral strength to resist post deflection, it is important to use high-strength, well-packed materials for the entire backfill.

Concrete is the stiffest embedment material but also has the highest cost. A well-graded, granular aggregate is the next stiffest embedment material, followed by gravel, then sand. A well-graded embedment material is one that has a variety of particle sizes, which permits tighter compaction. Gravels and sands provide strength, while clay provides cohesiveness. A well-graded sand and gravel backfill can be compacted by mechanical or hand tamping in layers not more than 8 inches deep to make a stiff embedment. Embedments composed of gravel and sand serve to drain water better than finer-grained clay soils because of the larger pore spaces associated with sand and gravel mixtures.

Although excavated soil is generally the least stiff embedment material, backfilling with soil from the post hole is common. Clay- or silt-based soils, when used for embedment material, must be well graded, moist (not wet), well compacted, and free of individual organic materials, large stones, or clay pieces. Too much clay in an embedment material will make a poor foundation with little stiffness.

Typical post-frame foundations use minimum 4-foot-deep predrilled holes with 20-inch-diameter concrete footings under the post or pole. Poured concrete collars 12 inches thick above the footing pad are recommended, supplemented with concrete backfill to approximately one-third the depth of the hole. Concrete placed in the hole should be positively connected to the post or pole through the use of drilled rebar (see figure 35, page 41) to resist building uplift. *Do not replace topsoil near the surface of a post embedment, because that is where the largest stresses occur in the foundation. Use a firm, inorganic material such as a graded aggregate, gravel, or sand.*

Proper post embedment will increase the ability of the post-frame foundation to resist uplift and deflection from winds and is therefore critical to the structural integrity of the building. *On sites where posts will carry extraordinary loads, soils are soft clay or loam, ground slopes are greater than 1 in 3 (rise/run), or the building is to be used for human occupancy, professional foundation design, including geotechnical (subsurface) investigation, is recommended.*

ASAE Engineering Practice EP486 DEC92, Post and Pole Foundation Design, presents design procedures for structural wooden post and pole building foundations. Table 18 presents recommended embedment depths (based on ASAE EP486 DEC92 and ASCE 7-95) for posts at the spacings shown, and may be used for sandy gravel, sand/silty sand, and clay soils in the absence of building codes or soil tests. If the building site is on an earth fill placed less than two years before construction, extend posts at least 1.5 feet into undisturbed soil *beneath* the fill. If substantial fill has been brought in, it may be advisable to dig a continuous trench and pour a full-length footing to set the posts on.

If the collar height above the footing is increased, shallower embedment depths may be appropriate (as in cases of shallow bedrock). Maximum foundation strength is developed with a full-collar encasement. *Professional foundation design assistance should be obtained when considering the use of shallower post embedment depths than those shown in table 18.*

Drainage

It is important to provide surface and subsurface drainage from around the post-frame building foundation. Good drainage around the building site and perimeter will help prevent outside posts from settling. Roof rain gutters with extended downspouts and site grading prevent saturation of the soil around the post-frame building (see Site Drainage, page 22). Interior posts in dry soil seldom settle, even when supporting heavy building loads. In addition to prevention of settlement, good drainage can prevent the alternating heaving and settling of a foundation or floor slab caused by frost action.

Table 18. Minimum recommended post embedment depth (inches) for building widths up to 60 feet.

Wind Speed (mph)		90											
Post Spacing (ft)	Eave Height (ft)	10			12			14			16		
	Soil	SG	SS	CL	SG	SS	CL	SG	SS	CL	SG	SS	CL
4		42	54	60	42	60	66f	54	66f	60	60	66f	66f
6		42	60	66f	54	66f	NR	60	66f	66f	66	66f	NR
8		48	66f	NR	60	66f	66f	66	66f	NR	66f	NR	NR
10		60	66f	NR	66f	66f	NR	66f	66f	NR	66f	NR	NR

Wind Speed (mph)		100											
Post Spacing (ft)	Eave Height (ft)	10			12			14			16		
	Soil	SG	SS	CL	SG	SS	CL	SG	SS	CL	SG	SS	CL
4		42	60	66	48	66	66f	54	66f	66f	66	66f	66f
6		48	66	66f	60	66f	66f	66	66f	NR	66f	66f	NR
8		54	66f	66f	66	66f	NR	66f	66f	NR	66f	NR	NR
10		66	NR	NR	66f	66f	NR	66f	NR	NR	66f	NR	NR

Wind Speed (mph)		110											
Post Spacing (ft)	Eave Height (ft)	10			12			14			16		
	Soil	SG	SS	CL	SG	SS	CL	SG	SS	CL	SG	SS	CL
4		48	60	66f	54	66f	66f	60	66f	66f	66f	66f	NR
6		54	66f	NR	66	66f	66f	66f	66f	NR	66f	NR	NR
8		60	66f	66f	66f	66f	NR	66f	NR	NR	66f	NR	NR
10		66f	66f	NR	66f	NR	NR	66f	NR	NR	66f	NR	NR

Adapted from: ASAE EP486 DEC92, Section 4.3.3.2 and American Society of Civil Engineers, ASCE 7-95.

SG = Sandy gravel soils with an allowable vertical bearing pressure of 2000 psf
SS = Sandy silt soils with an allowable vertical bearing pressure of 1500 psf
CL = Clay soils with an allowable vertical bearing pressure of 1000 psf

Foundation design is for enclosed or partially enclosed low-rise buildings with no internal floors or internal equipment loads supported by the posts.
Trusses are attached to the posts.
Depths are from grade to the bottom of the post.
66f indicates a full collar foundation (see figure 35, page 41).
NR indicates that a post foundation up to 66 inches deep and 28 inches in diameter is not adequate.
All depths use a minimum pad thickness of 8 inches.
All depths, except 66f, use a connected pad and 12-inch collar. Concrete collars are mechanically connected with the footing pad.
Rebar in post-collar connection is covered with at least 1 1/2" of concrete.
Foundation design does NOT consider diaphragm action of the building.

If the building site is on an earth fill placed less than two years before construction, extend posts a minimum of 1.5 feet into undisturbed soil below fill.
If substantial fill has been brought into a site, it may be necessary to dig a continuous trench, and pour a full-length footing that the posts are set on.
For soils susceptible to frost heaving, extend footings to below maximum frost penetration depth (see figure 36, page 44).

This table is to be used in the absence of building codes and soil tests, and is advisory only.

Frost Action

Foundation damage can result from layers of ice that form directly under a post foundation (or a building slab). Under wet soil conditions above the frost layer, naturally expanding ice layers force footings upward. Expanding ice layers can generate an enormous amount of upward force (called frost heave), which can cause serious damage to a post-frame building. Foundations in wet soils using concrete backfill with rough sides that taper outward at the top are also susceptible to frost heave. Subsequent settlement during thaw undermines the structural integrity of the building. Because of the large forces at work, it is not practical to resist frost action by increasing the foundation strength. Rather, steps should be taken to reduce the risk of ice layers forming directly under a foundation.

For post foundations in soils susceptible to frost heaving (i.e., those with saturated, fine-grained soils above the frost line), the following construction procedures are recommended:

1. Extend footings to below maximum frost penetration depth (figure 36 on page 44).
2. Provide smooth-sided concrete collars that don't taper upward.
3. Backfill with a well-draining embedment material such as sand, gravel, or crushed rock.

Framing Members

Wooden framing members (including rafters, girders, purlins, girts, joists, and braces) are designed based on specific shear, bending, and deflection limitations (see Stresses in Wood, page 32). Member deflection is determined using "E" (the modulus of elasticity) and design properties of the member. Design properties of standard-dressed (S4S), sawn lumber are presented in appendix B. Building codes normally specify the allowable deflection of a wooden member. Shear and bending limitations in members are determined from allowable stress values and design formulas. Design formulas and allowable stress values used for sizing wood framing members are found in the *National Design Specification for Wood Construction* and the *NDS Supplement* (American Forest and Paper Association, revised 1991 editions).

Table 19 on page 45 presents the maximum allowable uniform loads that selected sizes and spans of Southern Pine No. 2 wood can support, in pounds per linear foot. Building designers use tables like this, called load or span tables, to determine the span, spacing, and number of wood members required to support a known load over a specified area. Note in table 19 that the load-carrying capacity of shorter spans or deeper beams is generally limited by shear stress (shear parallel to the grain). For intermediate spans, bending stress limits the load-carrying capacity.

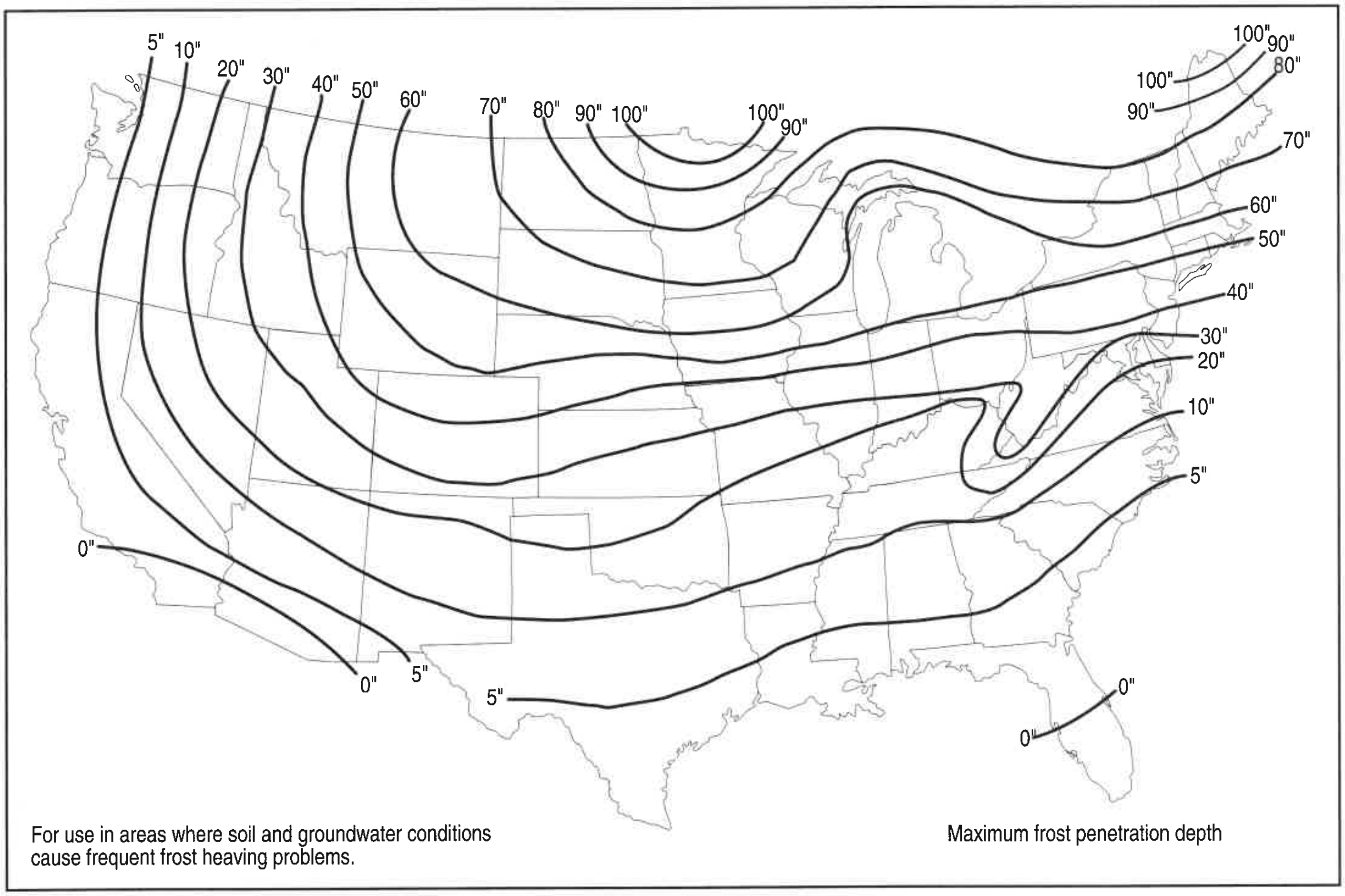


Figure 36. Extreme frost depth. (*Source: MidWest Plan Service*)

For longer spans or beams laid flat (such as roof purlins or wall girts), deflection normally controls the amount of acceptable load.

Girders, joists, and rafters are laid on edge for maximum strength (see section on Stresses in Wood, page 32). For increased carrying capacity, members may be doubled, tripled, or connected as multiple members. Figure 34, page 38, shows two girders being used to support a uniform load consisting of a roof load (snow or wind load) plus dead load (roofing and truss materials). Roof purlins can be laid flat or on edge, depending on the spacing and load. Roof purlins and wall girts are made of 2-by-4's or 2-by-6's. Wall girts are normally laid flat. Figure 33, page 37, shows typical spacings for roof purlins and wall girts.

Table 19 can be used to select girders, joists, rafters, girts, and purlins made of Southern Pine No. 2 which are braced (or sheathed) to prevent twisting or buckling. In table 19, design values for allowable bending stress, F_b, and allowable shear stress, F_v, can be increased by a factor of 1.15 for members supporting snow and by 1.60 for members supporting wind loads (due to the relatively short duration of these two types of loads).

Example girder sizing

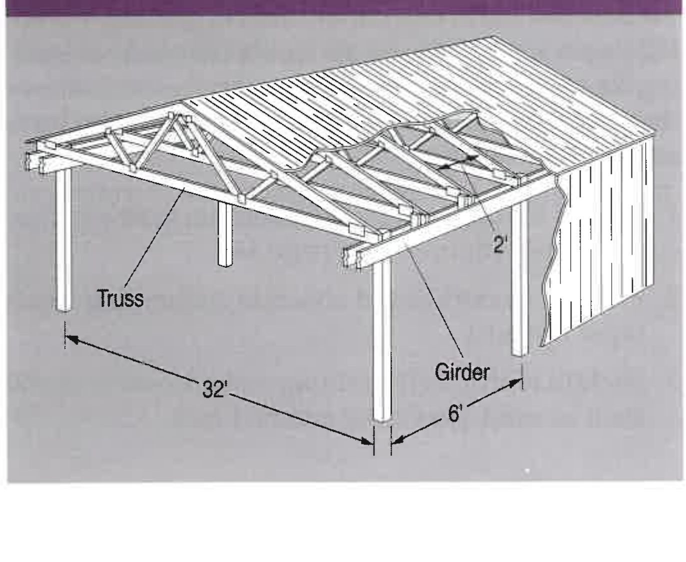


Table 19. Uniform load-carrying capacity for Southern Pine No. 2 wood beams.

	Size (Nominal) (base x depth)	Span, feet								
		4	6	8	10	12	14	16	18	20
	on edge	Uniform Load, pounds per linear foot								
Depth / Base	2x4	142_s	77_b	37_d	19_d	11_d	7_d	5_d	3_d	2_d
	2x6	223_s	149_s	89_b	57_b	39_b	27_d	18_d	13_d	9_d
	2x8	294_s	196_s	147_s	95_b	66_b	48_b	37_b	29_d	21_d
	2x10	375_s	250_s	187_s	135_b	94_b	69_b	53_b	42_b	34_b
	2x12	456_s	304_s	228_s	182_s	129_b	94_b	72_b	57_b	46_b
	laid flat									
Depth / Base	4x2	55_d	16_d	7_d	4_d	uniform beam loading				
	6x2	86_d	25_d	11_d	6_d					
	8x2	113_d	34_d	14_d	7_d					

Notes:

- All spans checked for allowable shear stress, bending stress, and deflection using a uniform load on a simply supported beam.
  - s = beam limited by shear stress (shown in dark shading)
  - b = beam limited by bending stress (shown in light shading)
  - d = beam limited by deflection (shown with no shading)
- Table values assume dry service conditions (< 19% moisture content) and beams braced (or sheathed) along compression edge to prevent twisting or buckling. Consequently, C_M (wet service factor) and C_L (lateral stability factor) adjustments are not included.
- Design formulas from American Forest and Paper Association, *National Design Specification for Wood Construction,* Revised 1991 Edition, pp. 5–13:
  - -C_D (load duration factor) = 0.90 (for permanent dead load)
  - -Actual beam shear stress = 3V/2bd, where V is shear force = wL/2, w is uniform load (lb/ft), and L is span of beam (ft).
  - -Actual beam bending stress = M/S, where M is maximum moment = $wL^2/8$ (lb-ft) and S is section modulus (in^3) (see appendix B).
  - -Actual beam deflection = $5wL^4/384EI$, where E is modulus of elasticity (psi) and I is moment of inertia (in^4) (see appendix B).
- Allowable deflection = 1/240 x span
- Allowable design values for Southern Pine No.2 from American Forest and Paper Association, *Design Values for Wood Construction, NDS Supplement,* Revised 1991 Edition, p. 26:
  - Fv = 90 psi
  - Fb (2–4" wide) = 1500 psi
  - Fb (5–6" wide) = 1250 psi
  - Fb (8" wide) = 1200 psi
  - Fb (10" wide) = 1050 psi
  - Fb (12" wide) = 975 psi
  - Modulus of elasticity (E) = 1.6×10^6 psi
- Allowable design values for F_V and F_b can be increased by a load duration factor of C_D = 1.15 for members supporting snow loads, and by a load duration factor of C_D = 1.60 for members supporting wind loads.

Example: Use of table 19 for preliminary girder design.

A 32-foot-wide clear-span building uses trusses spaced 2 feet apart and posts spaced 6 feet apart, as shown at left. Snow load on the roof is determined to be 30 pounds per square foot. Dead load is 5 pounds per square foot. Southern Pine No. 2 lumber is available. What size girder(s) will support this load? Assume that all roof loads between posts are supported by the girder span. Assume uniform beam loading on the girder(s).

Step 1. The snow load is of short duration, so capacity values in girder selection table 19 can be increased by 1.15. For simplicity, divide the snow load by 1.15 instead. Snow load = 30 ÷ 1.15 = 26 pounds per square foot.

Step 2. Compute the uniform load on the girder (that is, the roof load supported per foot of girder span).

load per foot = truss span ÷ 2 x (snow + dead load) = 32 ÷ 2 x (26 + 5)
= 500 pounds per linear foot of girder

Note: *The assumption of uniform beam loading in this example is used to simplify the analysis. Actual girder loading is more complex and consists of two concentrated loads in the center of the girder (the two intermediate trusses). The two post-connected trusses are supported directly by the posts (see figure). All preliminary designs should be checked by a professional.*

Step 3. The girder will span 6 feet, so enter table 19 under the 6-foot-span column. None of the lumber listed will support 500 pounds per linear foot on a 6-foot span, so more than one girder must be used.

If two girders are used, the load supported by each girder is 500 ÷ 2 = 250 pounds. Table 19 shows that two 2-by-10's will support the load. Also, three 2-by-8's or four 2-by-6's will support the load (see figures 37 and 47 on pages 46 and 57 for girder fastening details).

Bracing

Bracing strengthens and adds rigidity to the building frame. The type and prevalence of bracing depends on the building design and function, including requirements for building size, building shape, interior partitions, and wall sheathing. Types of bracing used in post-frame structures include: post-to-girder bracing, truss anchorage (including post-to-truss or knee bracing), permanent roof bracing, and construction bracing. If rigid roof or wall panels are designed to take advantage of diaphragm action, the added stiffness will allow the post-frame building to better withstand deflection (see figures 31a and 31b on page 36). A properly constructed diaphragm-designed building will reduce the need for knee bracing (see section on Truss Anchorage on the following page).

Permanent roof bracing is required for the long-term structural integrity of a building, especially those that are open on one or more sides and over 14 feet high at the eave. Temporary bracing, often called construction bracing, is required to hold posts and trusses in place during erection. *Proper construction bracing techniques are essential to protect workers and wood components of the structure from unexpected wind, impact, or other loads during assembly (see chapter 3, Construction Procedures, page 64).*

Post-to-Girder Bracing

Post-to-girder braces attached at 45° angles allow a girder to carry a heavier load, tie the girder down in heavy winds, and strengthen the building longitudinally. Figure 1, page 1, shows an example of pole-to-girder bracing on a "pole barn." A girder properly braced at one-third its span can carry 80% more load than one without braces. Generally, post-to-girder bracing is not required in buildings less than 30 to 40 feet wide and with posts spaced 8 feet or less apart. A ½-inch bolt or four or five 30d to 40d pole barn nails spaced 2 inches apart are typical brace fasteners. Selected post-to-girder bracing details are shown in figure 37. Table 20 shows the required length of square (45°) braces for various support dimensions.

Braces must be stiff enough not to bow or deflect under load. Limit the unsupported length of a brace to fifty times its actual thickness (6 feet for a dressed 2-by-4). Braces with lengths between 6 feet and 12 feet should be made up of a doubled 2-by-4 well nailed or a 2-by-6. Usually a 2-by-4 is used for post-to-girder bracing and a 2-by-6 for truss-to-post bracing.

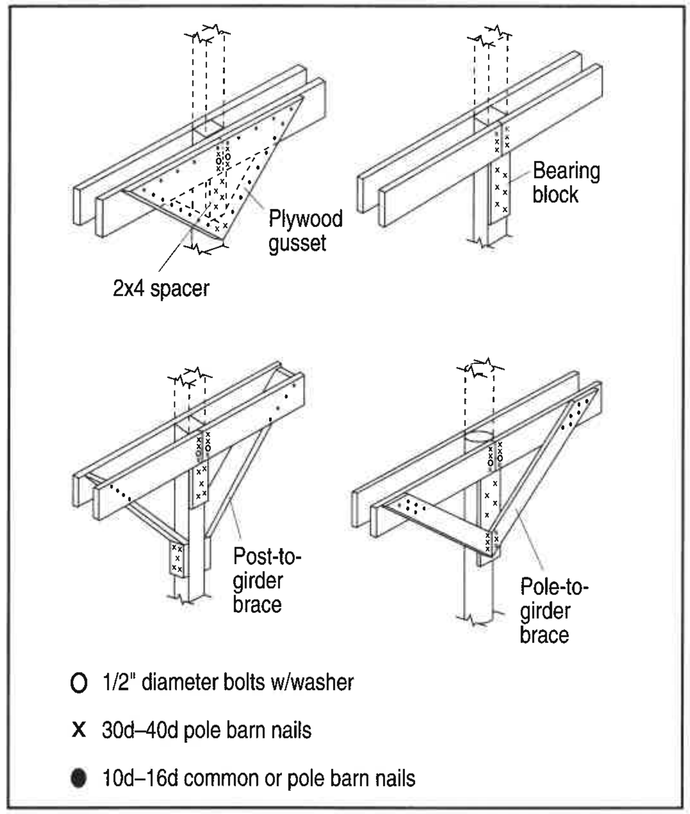
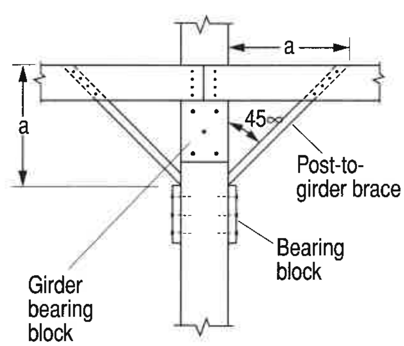


Figure 37. Post-to-girder braces and supports.

Table 20. Square (45°) brace table.

a, in.	Brace length, in.
24	33 15/16
27	38 3/16
30	42 7/16
33	46 5/8
39	55 1/8
42	59 3/8
45	63 5/8
48	67 7/8
51	72 1/8
54	76 3/8
57	80 5/8
60	84 7/8



Truss Anchorage

Trusses must be fastened to the posts or sidewalls to resist uplifting forces caused by the wind. Bolts, stub posts (rafter ties), or framing anchors can be used to fasten the truss to the post or girder. In post-frame buildings, it is desirable for truss and post spacing to be equal (see Post Size and Spacing, page 37). Therefore, trusses should be anchored directly to the posts. In post-frame buildings with truss spacing less than the post spacing, the truss between the posts (the intermediate truss) is anchored directly to the girder using a stub post or rafter tie (figure 34, page 38).

Trusses up to 30 feet wide usually require at least one ½-inch bolt or framing anchor on each end of the truss. When trusses are spaced over 8 feet apart, or whenever conservative post-to-truss design is desired, use two bolts or two anchors per end. Selected fastening details for trusses are shown in figure 38.

Knee braces, shown in figure 2, page 2, are used from post to truss if the truss manufacturer has considered it in the truss design. The use of knee bracing is questioned if diaphragm action is presumed, since most of the in-plane load is effectively transferred to the endwalls. In fact, knee bracing has been shown to add little stiffness to a properly constructed diaphragm-designed post-frame building (see section on Diaphragm Action, page 34).

Permanent Roof Bracing

Roof bracing is used to align trusses during installation and to prevent buckling of members under load. Permanent roof bracing remains part of the building's long-term structure. Temporary bracing is removed after construction. *The truss designer should specify the permanent truss bracing as part of the trussed roof design. Truss design should be reviewed and approved by the building designer. It should be made the responsibility of the*

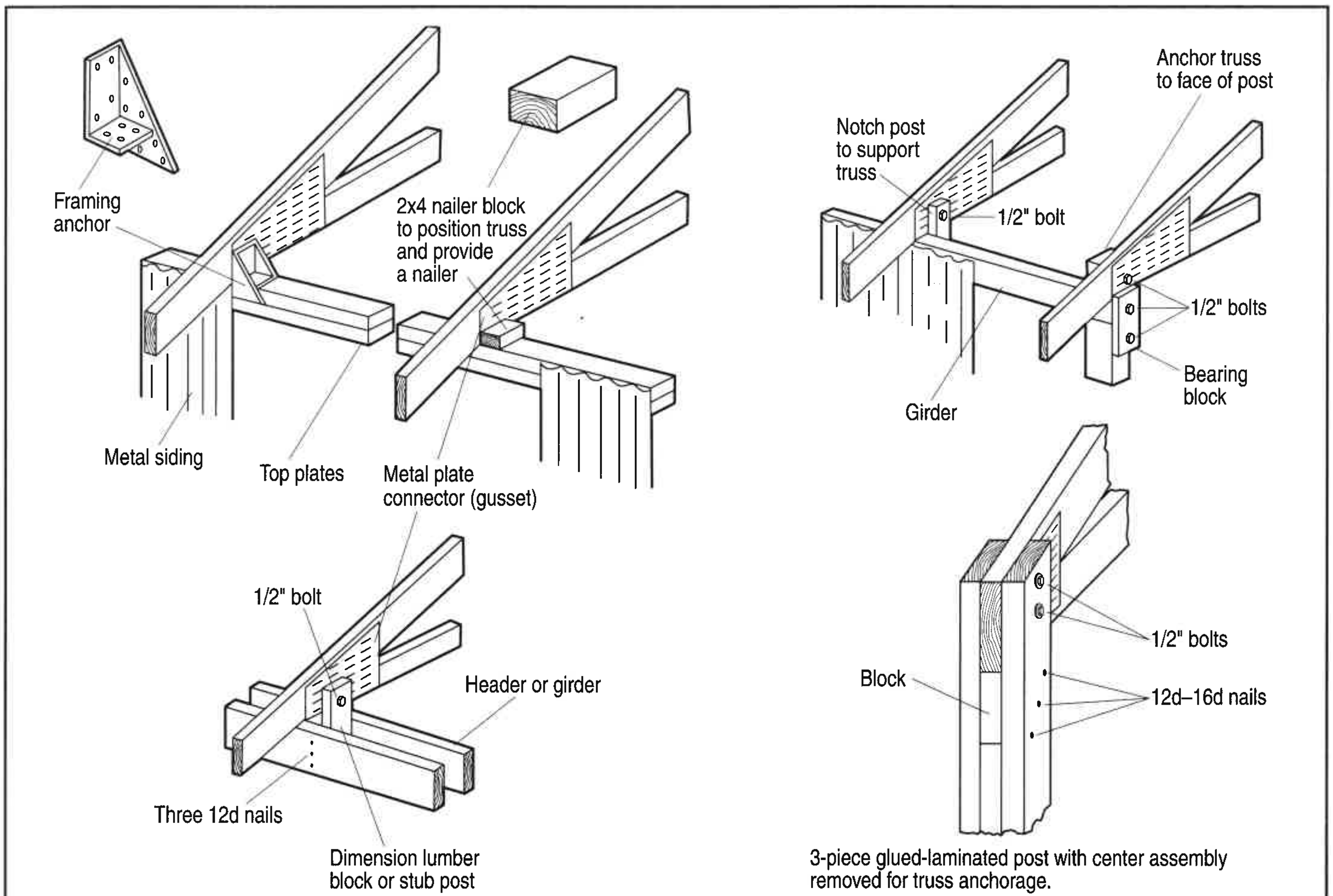


Figure 38. Selected truss fastening details.

building designer to specify how the permanent lateral bracing (described below) is to be anchored or restrained to prevent lateral movement if all truss members buckle together.

Three types of permanent roof bracing are needed in most post-frame buildings:

1. *Web bracing*, also called cross or "X" bracing, keeps trusses vertical and prevents the trusses from buckling due to wind loading. As a minimum, install web bracing at each end of the building and at 20-foot intervals of building length (figure 39), *or as specified by the building designer.*
2. *Top chord bracing* is made up of diagonal and lateral braces. Diagonal bracing is usually installed at a 45° angle to the eave line, as shown in figure 40. Lateral braces are overlapped to span at least two trusses (figure 40), *or as specified by the building designer.*
3. *Bottom chord bracing*, or horizontal bracing, maintains lateral support in truss bottom chords. Install 2-by-4 laterals continuously the entire building length close to each bottom chord joint unless a rigid ceiling is installed, *or as specified by the building designer.* Diagonals at 45° to the building length are usually added to the bottom chord for further bracing (figure 39).

Fasteners

Several types of fasteners are commonly used in wood frame and post-frame construction (figure 41), including: the common steel nail or spike (6d to 60d), double-headed construction nails (scaffold nails), deformed shank nails (several types), bolts with washers (½- to 1-inch-diameter), lag screws with washers (¼- to 1¼-inch-diameter), wood screws (6-gauge to 24-gauge), threaded hardened-steel nails (6d to 90d), and heavy wire steel staples. Wood fasteners can be used separately or in conjunction with manufactured connectors such as truss plates (gussets), shear plates, joist hangers, or tie-down anchors, among others.

Load Capacity

The load-carrying capacity of a wood fastener is strongly influenced by several factors, including: the type of connection, type and size of fastener, wood density, moisture use condition, and type of design loading (snow, wind, etc.). Load capacity values for wood fasteners are defined in terms of the type of connection used. Common wood fasteners such as nails are usually loaded in several ways:

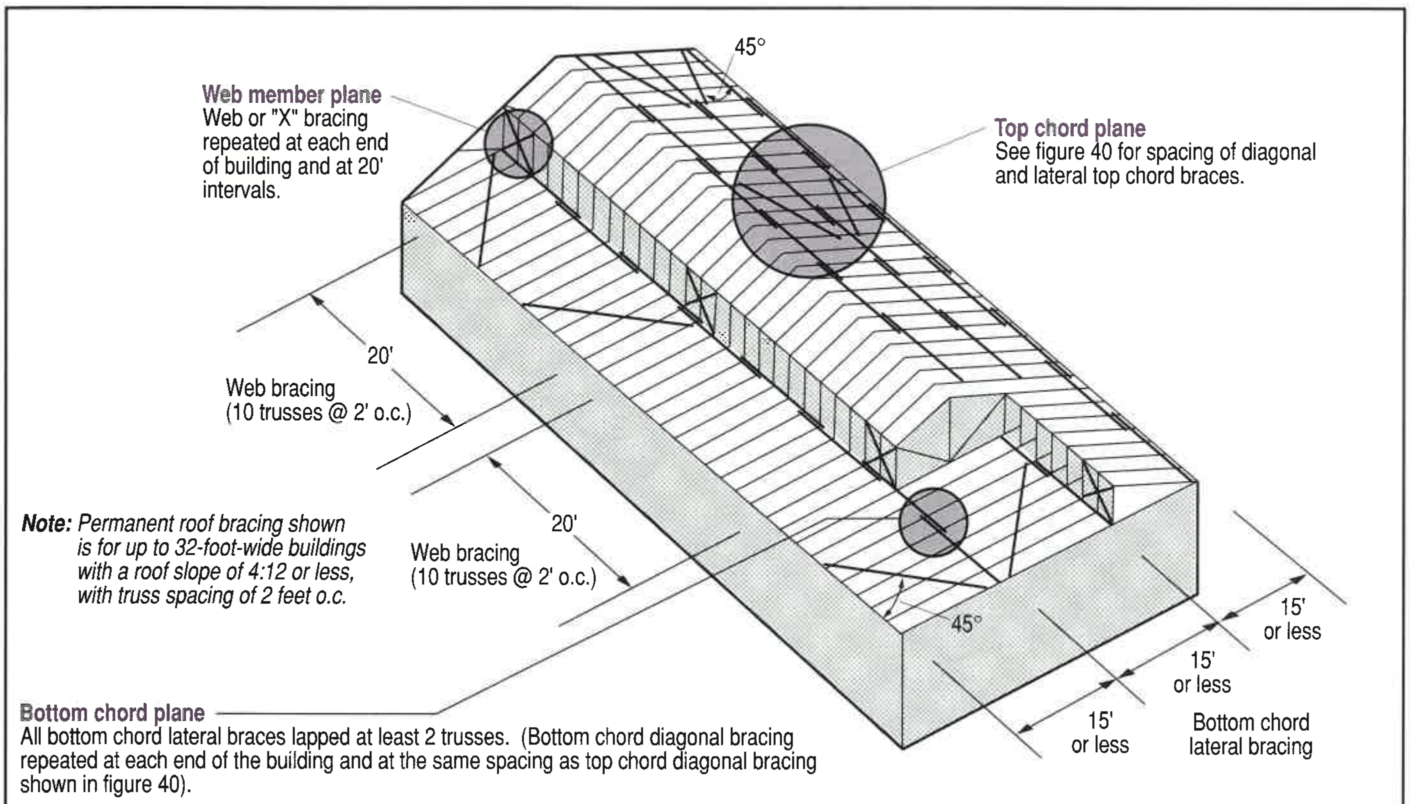


Figure 39. Permanent roof bracing with truss. (*Adapted from* Commentary and Recommendations for Handling, Installing, and Bracing Metal-Plate-Connected Wood Trusses, *HIB-91 Summary Sheet, Truss Plate Institute*)

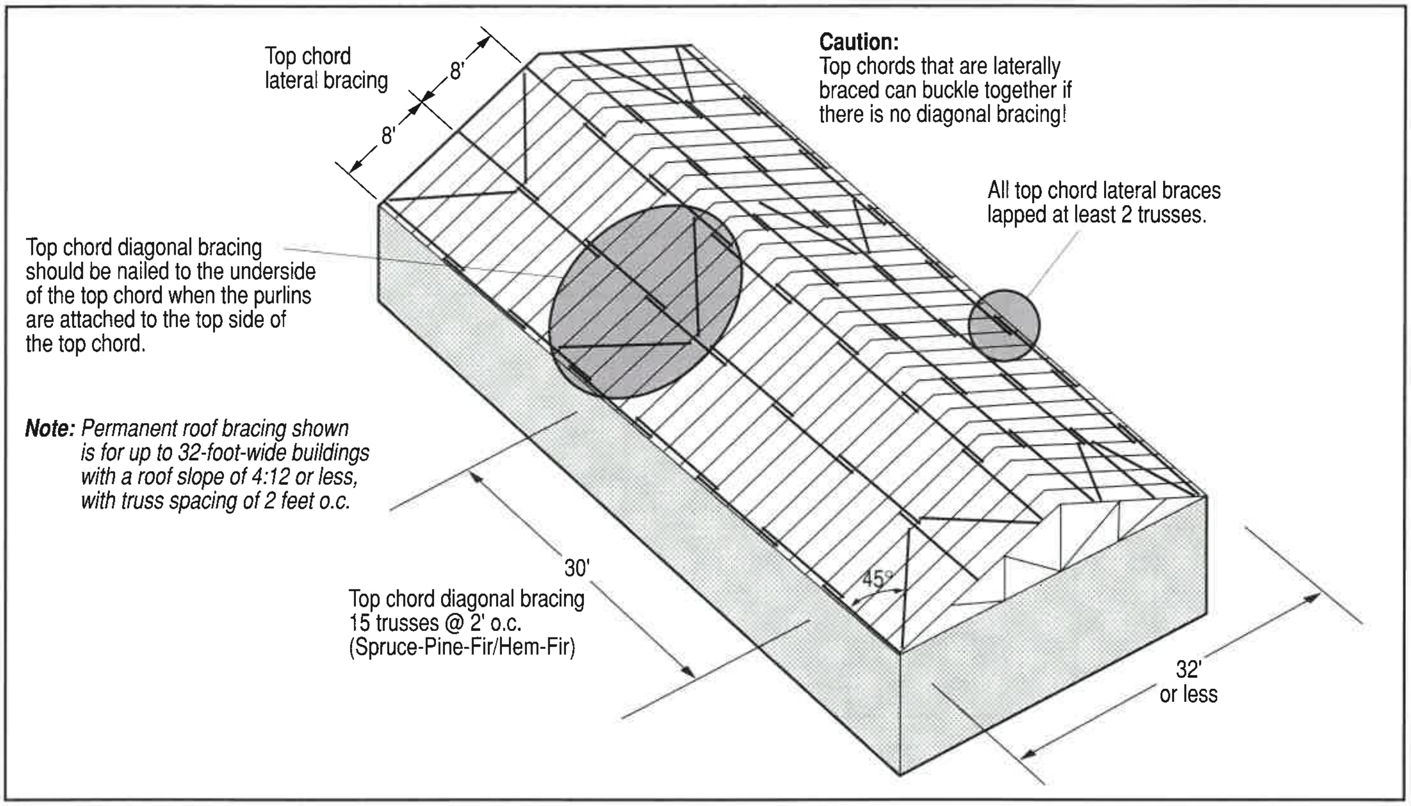


Figure 40. Permanent top chord bracing. (*Adapted from* Commentary and Recommendations for Handling, Installing, and Bracing Metal-Plate-Connected Wood Trusses, *HIB-91 Summary Sheet, Truss Plate Institute*)

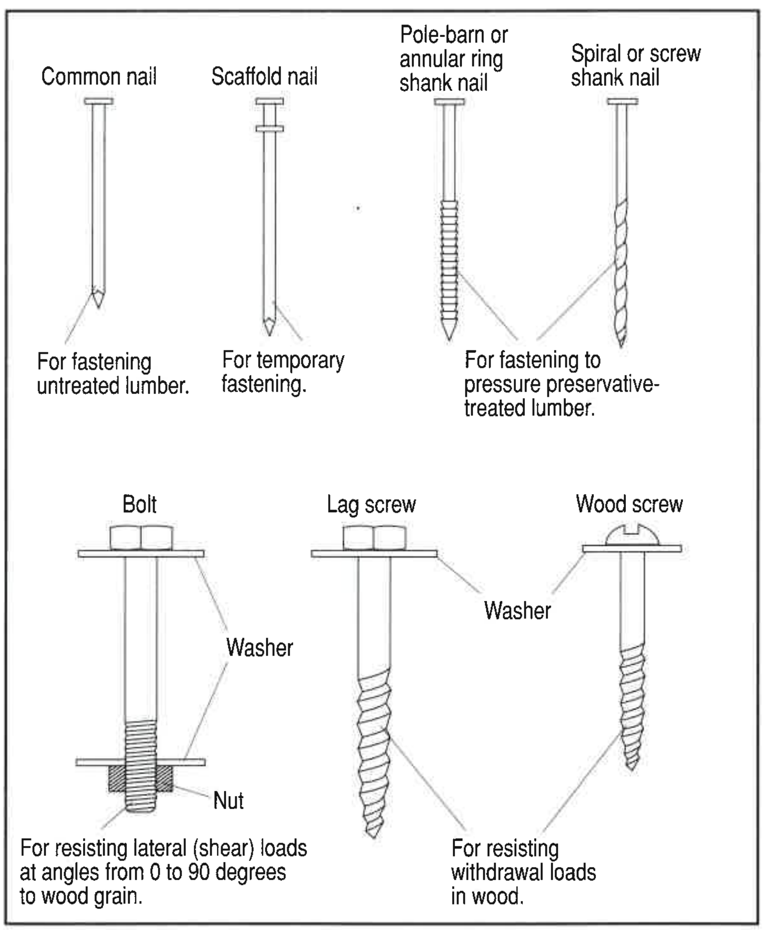


Figure 41. Typical wood fasteners.

- laterally, using a single-shear connection (figure 42a),
- laterally, in double shear (figure 42b),
- in withdrawal, as with a toe nail (figure 42c), or
- laterally, using a toe nail (figure 42d).

Table 21 shows the load capacities of selected wood fasteners and species groups in single shear. Design values for lateral loads in table 21 are dependent upon the specific gravity (or density) of the wood species, as well as the loading direction. Design values for wood species not shown can be estimated using specific gravities (G) from table 22 on page 52.

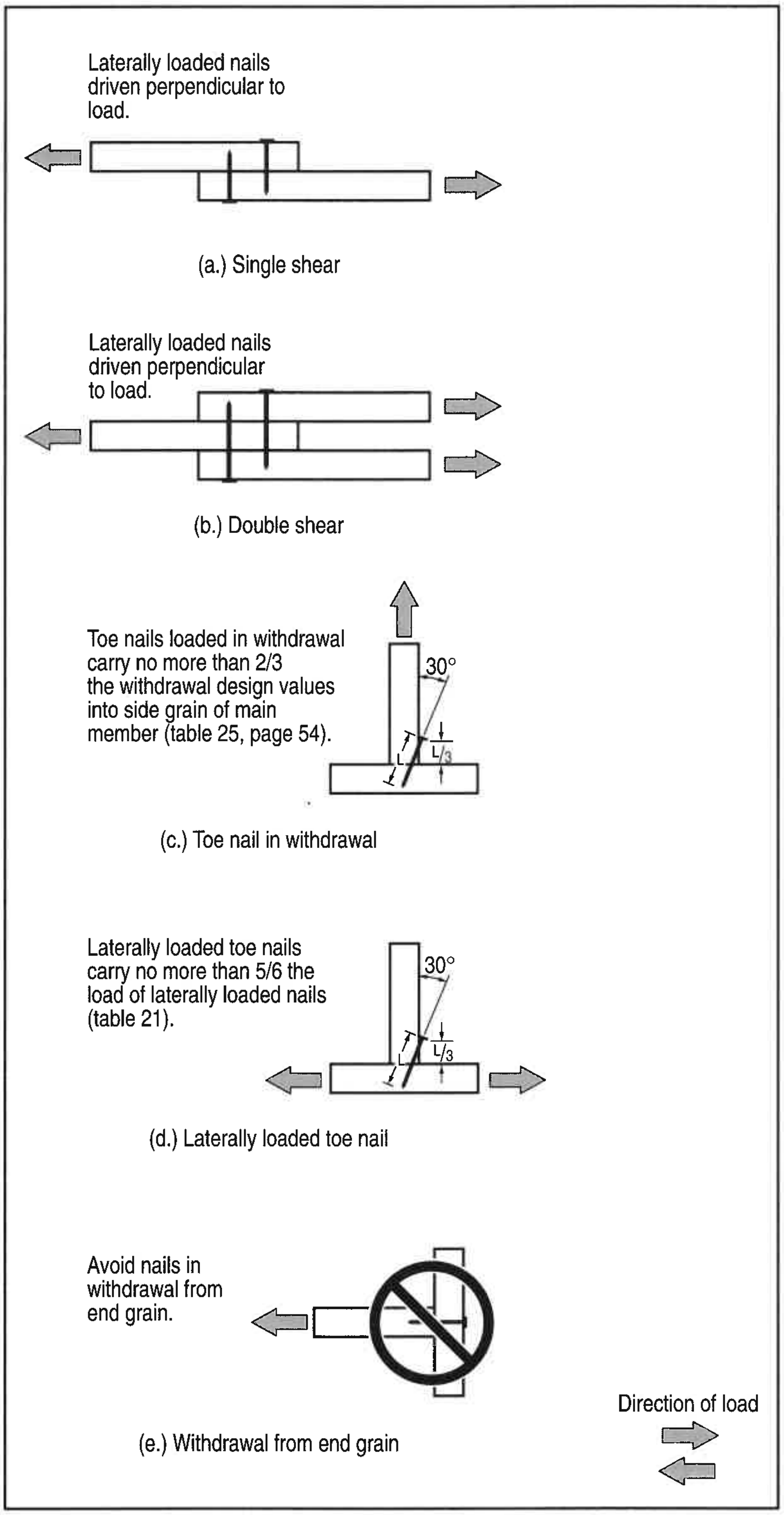


Figure 42. Fastener loading.

Table 21. Design values for lateral loads of wood fasteners in single shear (pounds).

Fastener	Diameter D inches	Red Oak (G=0.67)		Southern Pine, Mixed Maple (G=0.55)		Spruce-Pine-Fir (G=0.42)		Eastern Softwoods (G=0.36)	
		Parallel to grain	Perpendicular to grain	Parallel to grain	Perpendicular to grain	Parallel to grain	Perpendicular to grain	Parallel to grain	Perpendicular to grain
20d common nail	0.192	222	222	185	185	144	144	126	126
40d common nail	0.225	268	268	224	224	172	172	138	138
40d threaded/ hardened nail	0.177	241	241	201	201	156	156	129	129
80d threaded/ hardened nail	0.207	271	271	227	227	171	171	138	138
1/2-inch bolt (2 1/2-inch main member)	0.500	770	480	660	400	540	320	490	280
3/4-inch bolt (3-inch main member)	0.750	1450	890	1270	660	1000	450	860	360
1/4-inch lag screw	0.250	260	200	230	180	200	150	190	130
1/2-inch lag screw	0.500	830	510	710	420	570	320	510	290
3/4-inch lag screw	0.750	1510	890	1320	660	1100	450	1010	360
10g wood screw	0.190	205	205	171	171	133	133	116	116
16g wood screw	0.268	305	305	255	255	185	185	149	149

Adapted from American Forest and Paper Association, *National Design Specification for Wood Construction (NDS),* Revised 1991 Edition, pp. 42,58,76,86,88.

Notes to table values:

- Load values are for fasteners used in two-member connections (single shear).
- Load values are for members of identical species and 1 1/2-inch side and main members, except as otherwise noted.
- G = specific gravity.
- Multiply all load values for connections by 1.15 for designs based on snow loads.
- Multiply all load values for connections by not greater than 1.6 for designs based on impact or other loads.
- Multiply all load values for connections by appropriate wet service factors shown in table 23, page 53.
- Fastener load values for wood species not shown can be estimated using the species groupings from table 22, page 52
- The following steel bending yield strengths (F_yb) for wood fasteners were used to determine values for table 21:
  1. F_yb = 80,000 psi for common nails.
  2. F_yb = 115,000 psi for 40d threaded/hardened nails.
  3. F_yb = 100,000 psi for 80d threaded/hardened nails.
  4. F_yb = 45,000 psi for bolts.
  5. F_yb = 70,000 psi for 1/4-inch lag screws.
  6. F_yb = 45,000 psi for 1/2-inch and 3/4-inch lag screws.
  7. F_yb = 80,000 psi for 10g wood screws.
  8. F_yb = 70,000 psi for 16g wood screws.
- Nominal nail lateral design values are based on nail penetration into the main member of twelve times the nail diameter (D), p = 12D (*NDS,* p. 83).
- Nominal lag screw lateral design values are based on lag screw penetration (not including the length of the tapered tip) into the main member of approximately eight times the shank diameter, p = 8D (*NDS,* p. 57).
- Nominal wood screw lateral design values are based on wood screw penetration into the main member of approximately seven times the shank diameter, p = 7D (*NDS,* p. 75).

Table 22. Specific gravity of wood species for design of lag screw, bolt, nail, spike, and wood screw fasteners.

Species combination	Specific gravity (G)[1]
Aspen	0.39
Balsam Fir	0.36
Beech-Birch-Hickory	0.71
Coast Sitka Spruce	0.39
Cottonwood	0.41
Douglas Fir-Larch	0.50
Douglas Fir-Larch (North)	0.49
Douglas Fir-South	0.46
Eastern Hemlock	0.41
Eastern Hemlock-Tamarack	0.41
Eastern Hemlock-Tamarack (North)	0.47
Eastern Softwoods	0.36
Eastern Spruce	0.41
Eastern White Pine	0.36
Engelmann Spruce-Lodgepole Pine[2] (MSR 1650f and higher grades)	0.46
Engelmann Spruce-Lodgepole Pine[2] (MSR 1500f and lower grades)	0.38
Hem-Fir	0.43
Hem-Fir (North)	0.46
Mixed Maple	0.55
Mixed Oak	0.68
Mixed Southern Pine	0.51
Mountain Hemlock	0.47
Northern Pine	0.42
Northern Red Oak	0.68
Northern Species	0.35
Northern White Cedar	0.31
Ponderosa Pine	0.43
Red Maple	0.58
Red Oak	0.67
Red Pine	0.44
Redwood, close grain	0.44
Redwood, open grain	0.37
Sitka Spruce	0.43
Southern Pine	0.55
Spruce-Pine-Fir	0.42
Spruce-Pine-Fir (South)	0.36
Western Cedars	0.36
Western Cedars (North)	0.35
Western Hemlock	0.47
Western Hemlock (North)	0.46
Western White Pine	0.40
Western Woods	0.36
White Oak	0.73
Yellow Poplar	0.43

Source: American Forest and Paper Association, *National Design Specification for Wood Construction,* Revised 1991 Edition, p. 73.

[1] Specific gravity based on weight and volume when oven-dry.

[2] Applies only to Engelmann Spruce-Lodgepole Pine machine stress-rated (MSR) structural lumber.

Figure 43 shows bolted wood members loaded parallel to the grain and perpendicular to the grain.

Design values for nails and wood screws are not affected by load direction. The load capacities of bolt and lag screw connections, however, are strongly influenced by the direction of the load relative to wood grain. As table 21 on page 51 shows, design values for bolt and lag screw fasteners in softer woods (Eastern Softwoods and Spruce-Pine-Fir) loaded parallel to the grain can be more than twice those of identical fasteners loaded perpendicular to the grain.

Note that table 21 (page 51) design values must be modified for snow- or wind-loaded connections. Design values from table 21 must also be modified for wet service conditions, using factors in table 23. With the exception of wood screws, all fasteners shown in table 21 are commonly used to connect the framing members in a post-frame building.

Nails

Figure 44 on page 54 presents selected common wire nails. Table 24, page 54 shows nail lengths and the recommended penetration distance of common wire nails into laterally loaded members. Wood density affects the loading capacity of both laterally loaded nails and nails in withdrawal. When loaded laterally or in withdrawal, nails in wood species of higher specific gravity can support higher design loads.

Table 21 (page 51) presents lateral loads for selected common and threaded/hardened nails based on nail size, specific gravity, and load direction. Note that while load direction has no effect on laterally loaded nails (or wood screws), specific gravity directly affects design load values. Table 25, page 54 presents withdrawal design values for common wire nails and threaded nails based on nail size and wood specific gravity. Note that design values in withdrawal for threaded nails are higher than those for similarly sized common wire nails. Table 25 highlights the critical importance of wood specific gravity on the design of nails in withdrawal.

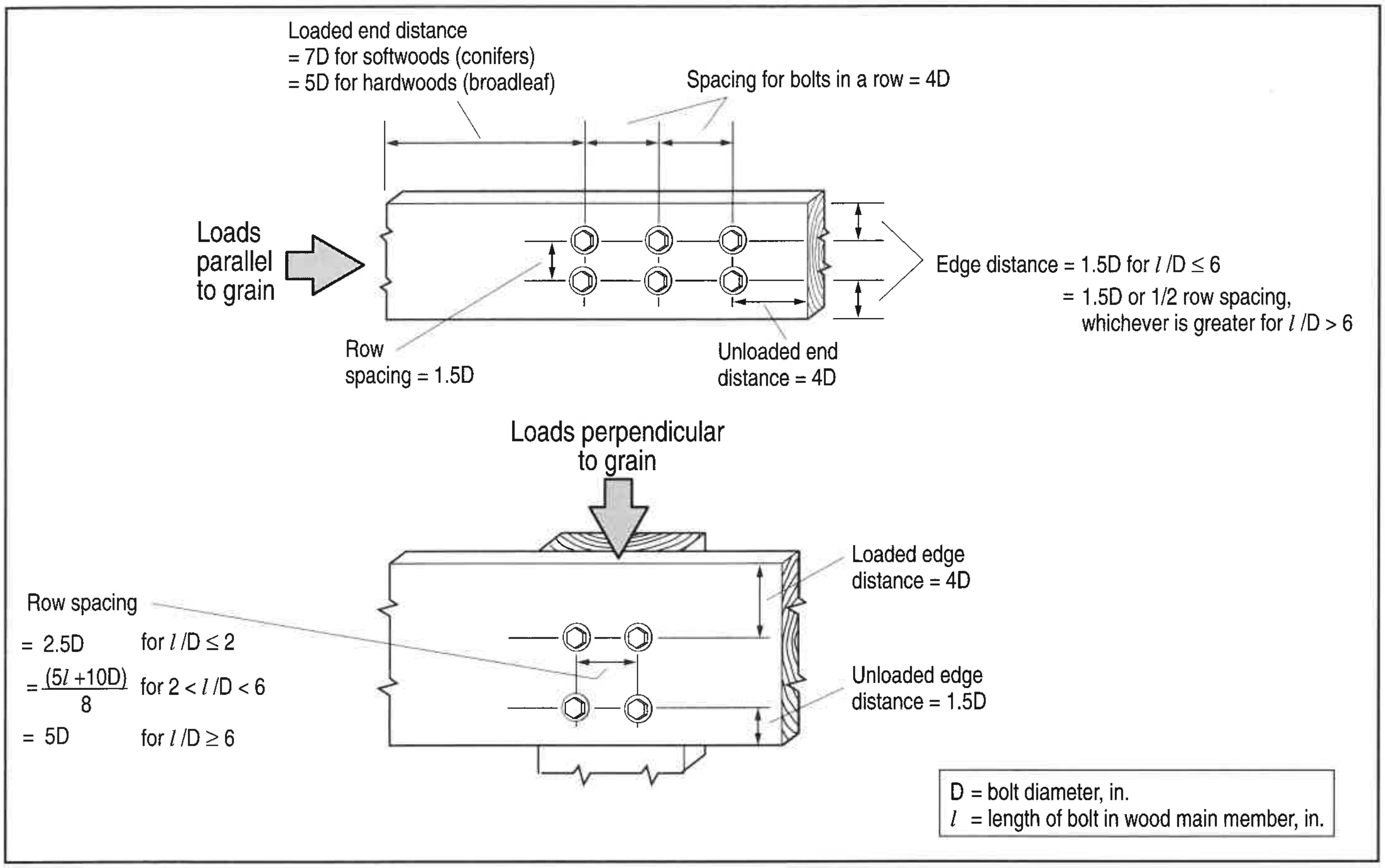


Figure 43. Loading direction and minimum bolt spacing. (*Adapted from American Forest and Paper Association,* National Design Specification for Wood Construction, *Revised 1991 Edition.)*

Table 23. Wet service factors for connections (to be used with design values in tables 21 and 25).

Fastener type	Condition of wood[1]		
	At time of assembly	In service	Wet service factor
Bolts, lag screws, or wood screws	Dry Dry or wet Dry or wet	Dry Exposed to weather Wet	1.0 0.75 0.67
Common wire nails, box nails, or common wire spikes:			
-Withdrawal loads[2]	Dry Partially seasoned or wet Partially seasoned or wet Dry	Dry Wet Dry Subject to wetting and drying	1.0 1.0 0.25 0.25
-Lateral loads	Dry Partially seasoned or wet Dry	Dry Dry or wet Partially seasoned or wet	1.0 0.75 0.75
Threaded, hardened steel nails	Dry or wet	Dry or wet	1.0

Source: American Forest and Paper Association, *National Design Specification for Wood Construction,* Revised 1991 Edition, p. 29.

[1] Conditions of wood are defined as follows for determining wet service factors for connections:

"Dry" wood has a moisture content of ≤ 19%.

"Wet" wood has a moisture content ≥ 30% (the approximate saturation point of the wood fibers).

"Partially seasoned" wood has a moisture content between 19% and 30%.

"Exposed to weather" means that the wood will vary in moisture content from dry to partially seasoned or wet, or vice versa, with consequent effects on the tightness of the connection.

[2] Wet service factor shall not apply to toe nails in withdrawal.

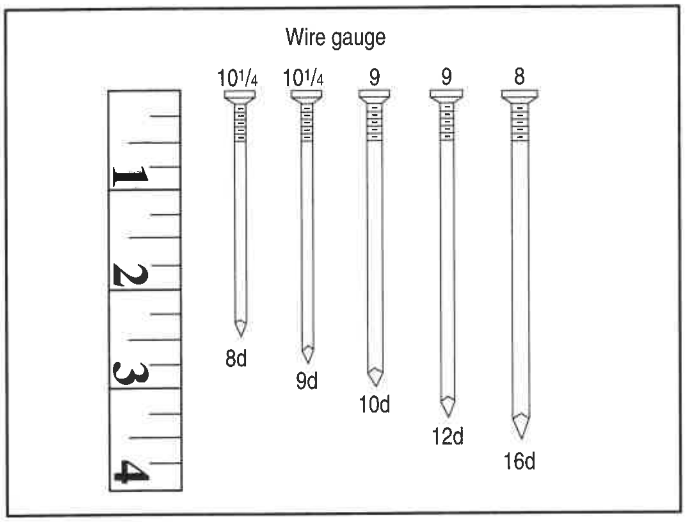


Figure 44. Selected common wire nails. *(Source:* Wood-Frame House Construction, *USDA Forest Service)*

Table 24. Size and design penetration of common wire nails into laterally loaded members.

Penny weight	Approximate No. per pound[1]	Length, inches	Required penetration, p, into main member,[2] inches
6d	165	2	1.4
8d	100	$2^1/2$	1.6
10d	65	3	1.8
12d	60	$3^1/4$	1.8
16d	48	$3^1/2$	1.9
20d	30	4	2.3
30d	23	$4^1/2$	2.5
40d	19	5	2.7
50d	17	$5^1/2$	2.9
60d	15	6	3.2

[1] Source: Harold R. Foster.

[2] p = 12D, where D = nail diameter, inches (see table 25 for values of D)

Source: American Forest and Paper Association, *National Design Specification for Wood Construction,* Revised 1991 Edition, p. 83.

Table 25. Nails – Withdrawal design values, pounds per inch of penetration into side grain of main member.

Specific gravity G*	Common wire nails[1] Penny weight and Diameter, D									Threaded nails Penny weight and Diameter, D				
	6d	8d	10d/12d	16d	20d	30d	40d	50d	60d	8d	10d/12d	16d	20d	80d
	0.113"	0.131"	0.148"	0.162"	0.192"	0.207"	0.225"	0.244"	0.263"	0.120"	0.135"	0.148"	0.177"	0.207"
0.73	71	82	93	102	121	130	141	153	165	82	93	102	121	141
0.71	66	77	87	95	113	121	132	143	154	77	87	95	113	132
0.68	59	69	78	85	101	109	118	128	138	69	78	85	101	118
0.67	57	66	75	82	97	105	114	124	133	66	75	82	97	114
0.58	40	46	52	57	68	73	80	86	93	46	52	57	68	80
0.55	35	41	46	50	59	64	70	76	81	41	46	50	59	70
0.51	29	34	38	42	49	53	58	63	67	34	38	42	49	58
0.50	28	32	36	40	47	50	55	60	64	32	36	40	47	55
0.49	26	30	34	38	45	48	52	57	61	30	34	38	45	52
0.47	24	27	31	34	40	43	47	51	55	27	31	34	40	47
0.46	22	26	29	32	38	41	45	48	52	26	29	32	38	45
0.44	20	23	26	29	34	37	40	43	47	23	26	29	34	40
0.43	19	22	25	27	32	35	38	41	44	22	25	27	32	38
0.42	18	21	23	26	30	33	35	38	41	21	23	26	30	35
0.41	17	19	22	24	29	31	33	36	39	19	22	24	29	33
0.40	16	18	21	23	27	29	31	34	37	18	21	23	27	31
0.39	15	17	19	21	25	27	29	32	34	17	19	21	25	29
0.38	14	16	18	20	24	25	28	30	32	16	18	20	24	28
0.37	13	15	17	19	22	24	26	28	30	15	17	19	22	26
0.36	12	14	16	17	21	22	24	26	28	14	16	17	21	24
0.35	11	13	15	16	19	21	23	24	26	13	15	16	19	23
0.31	8	10	11	12	14	15	17	18	19	10	11	12	14	17

Source: American Forest and Paper Association, *National Design Specification for Wood Construction,* Revised 1991 Edition, p. 82.

[1] Design values in withdrawal for box nails and common wire spikes must be based on actual diameter, in inches.

* Specific gravity of the wood, based on weight and volume when oven-dry.

Notes:

- Multiply all load values for connections by 1.15 for designs based on snow loads.
- Multiply all load values for connections by not greater than 1.6 for designs based on impact or other loads.
- Multiply all loads values for connections by appropriate wet service factors shown in table 23, page 53.

Toe nails are often used in wood construction to connect perpendicular framing members. Toe nails should be driven at approximately 30° from the vertical starting at ⅓ the length of the nail from the end of the piece (see figure 42c, page 50). Design values in withdrawal for toe-nailed joints, for all conditions of wood moisture content, shall not exceed ⅔ of the withdrawal design values shown in table 25. Design values for laterally loaded toe-nailed joints (figure 42d) carry no more than ⅚ the load of the laterally loaded design values in table 21, page 51. *As figure 42e shows, nailed connections should never be designed in withdrawal from the end grain.*

Four- to five-inch (20d to 40d) nails are often used to fasten rafters, girders, cleats, or braces to pressure-treated posts or poles. Pressure-treated lumber does not hold nails as well as untreated lumber because the preservative acts as a lubricant. Subsequently, threaded (spiral or annular ring shank) galvanized nails are used because they have a higher withdrawal resistance (figure 41, page 49). Untreated framing members are often fastened to each other with 10d to 12d nails. Examples include roof purlins to rafters, and tie-down cleats or braces to rafters or girders. Six-inch (60d) nails are used to fasten 2-by-4 roof purlins on edge.

Splitting

A nail that splits wood has no load-carrying strength. Nails should be located at a sufficient end distance, edge distance, and spacing to avoid splitting of wood members. Lead holes not more than ¾ the diameter of the nail can be predrilled to prevent splitting without reducing the nail's safe carrying strength.

Clinching Nails

Driving nails completely through both members and clinching the protruding end will increase the lateral resistance of the nail. However, no additional strength value is given for design because the nail is often driven back slightly as it is clinched.

Bolts

Bolted joints are commonly used in timber construction to resist lateral loads at angles from 0 to 90° to the grain. Although bolts require more time to install than nails, they have greater lateral load capacities than nails (see table 21, page 51) due principally to their larger diameters. Bolts do not have withdrawal load ratings. Do not forcibly drive bolts, as the wood may split. Predrill holes 1⁄32 to 1⁄16 inch larger than the bolt diameter. Locate bolts at the proper end distance, edge distance, and spacing, as shown in figure 43, page 53. Using standard cut washers, metal plates, or straps, tighten bolts snugly but not enough to crush wood fibers.

In the past, an assembly called a split ring timber connector was used to increase the effective shear area of a bolt. However, because special grooving tools and additional labor are required, split ring connectors are seldom used in modern wood frame construction.

Common bolts of ASTM (American Society of Testing Materials) A307 steel are often used as important fasteners for wood construction. Bolts are readily available in a wide range of sizes and are relatively easy to install. The strength properties of bolted joints, such as those in table 21, page 51, have been obtained through many years of research experience and industry testing.

Lag Screws and Wood Screws

Lag screws are produced in the same diameter as machine bolts, with the main difference being that lag screws have a screw thread tapering to a point (figure 41, page 49). Commonly called lag bolts, lag screws function well as bolts in joints where the main member is too thick to be penetrated by standard machine bolts. Lag screws are also used where a member face is not accessible for the installation of a nut and washer. Lateral loads for selected lag screws are shown in table 21, page 51.

Wood screws are generally smaller than lag screws and are found in a variety of head shapes. Wood screws are rarely used to fasten main structural members. However, they are often used to fasten doors and partitions and are of considerable importance in furniture and fixture design and manufacture. Lateral loads for selected wood screws have been included in table 21, page 51.

Both lag screws and wood screws are unique in their particular resistance to withdrawal loads, compared to nails of equal diameter. For example, a No. 9 wood screw, which has the same diameter as a 20d nail, has a withdrawal resistance in Douglas Fir of 131 pounds per inch of penetration, versus 49 pounds per inch for the nail. A ¼-inch lag screw with roughly the same diameter as a 50d nail has a corresponding withdrawal resistance of 232 pounds per inch, versus 63 pounds per inch for the nail.

Because screw fasteners are difficult to dislodge, they are recommended in structural applications where vibrations are common. Screw fasteners are also used to bring members into alignment, and are often used for field repairs, with or without adhesives. Design values in withdrawal for lag screws and wood screws can be found in the American Forest and Paper Association's *National Design Specification for Wood Construction*, revised 1991 edition.

Other Fasteners

A variety of manufactured metal framing anchors and supports are available to simplify construction and save time and materials. Metal fasteners are relatively expensive however, and properly designed wood braces and ties can often be used effectively at less cost (figure 38, page 47). Design loads for proprietary metal fasteners should be obtained from the manufacturer.

Structural members fastened using manufactured glued joints can result in joints that are stronger than the original members joined. *Gluing of structural members such as glued-laminated posts or beams should not be attempted in the field, since proper application of glue requires clean, dry, and warm conditions.* Manufactured glued joints are made with dry, smooth wood that is free of dirt, oil, and other coatings. The moisture content of the wood must be below 15% before gluing. During gluing, joints are kept under pressure for at least four to eight hours to allow the glue to set. Design loads are not applied to fabricated joints for at least twenty-four hours after gluing.

Waterproof (resorcinol resin) glues are recommended for construction applications where moisture is present (such as livestock confinement buildings or outdoor equipment storages). Water-resistant (casein) glues may be used in buildings used for dry storage where the moisture content of the wood in service is consistently low.

Suspended Floors

Post-frame farm buildings are usually designed as single-story structures with concrete slab, earthen, or gravel floors. There are times, however, when it is desirable to frame a suspended floor in a post-frame building. A building with 14- or 16-foot sidewalls has room for a ground floor office or workshop framed with an 8-foot ceiling and storage area above. With experienced professional design, suspended floors can be used in post-frame buildings constructed on both level and sloping sites (figure 45).

NOTE: If you are considering the use of a suspended floor in a post-frame building, structural design must be completed by a professional with experience in your type of building. All distributed and concentrated floor loads (both live and dead) ***must*** *be accurately accounted for in order to assure proper floor, frame, and foundation design. The safety of those using buildings with suspended floors requires the utmost care during design and construction. The serious consequences of a suspended floor failure cannot be ignored. Potential loss of life and property in any structure, including post-frame buildings, demands the use of competent design and building professionals.*

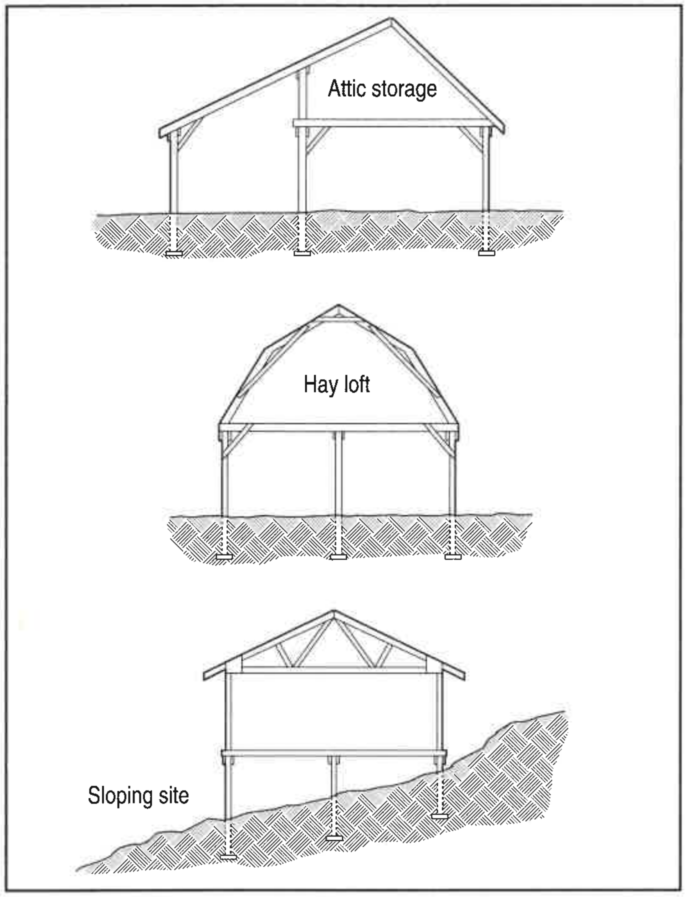


Figure 45. Suspended floor construction in post-frame buildings.

Figure 46 identifies the major components of a suspended floor. Figure 47 shows some commonly used construction techniques for attaching multiple-member girders to posts. Posts can be notched to accept one or more girders for better anchoring, as in the three-member girder shown. Alternately, girders can be designed to rest on top of the support post, as shown in the four-member girder. Figure 48 on page 58 illustrates the use of metal joist hangers to attach floor-supporting joists to a girder.

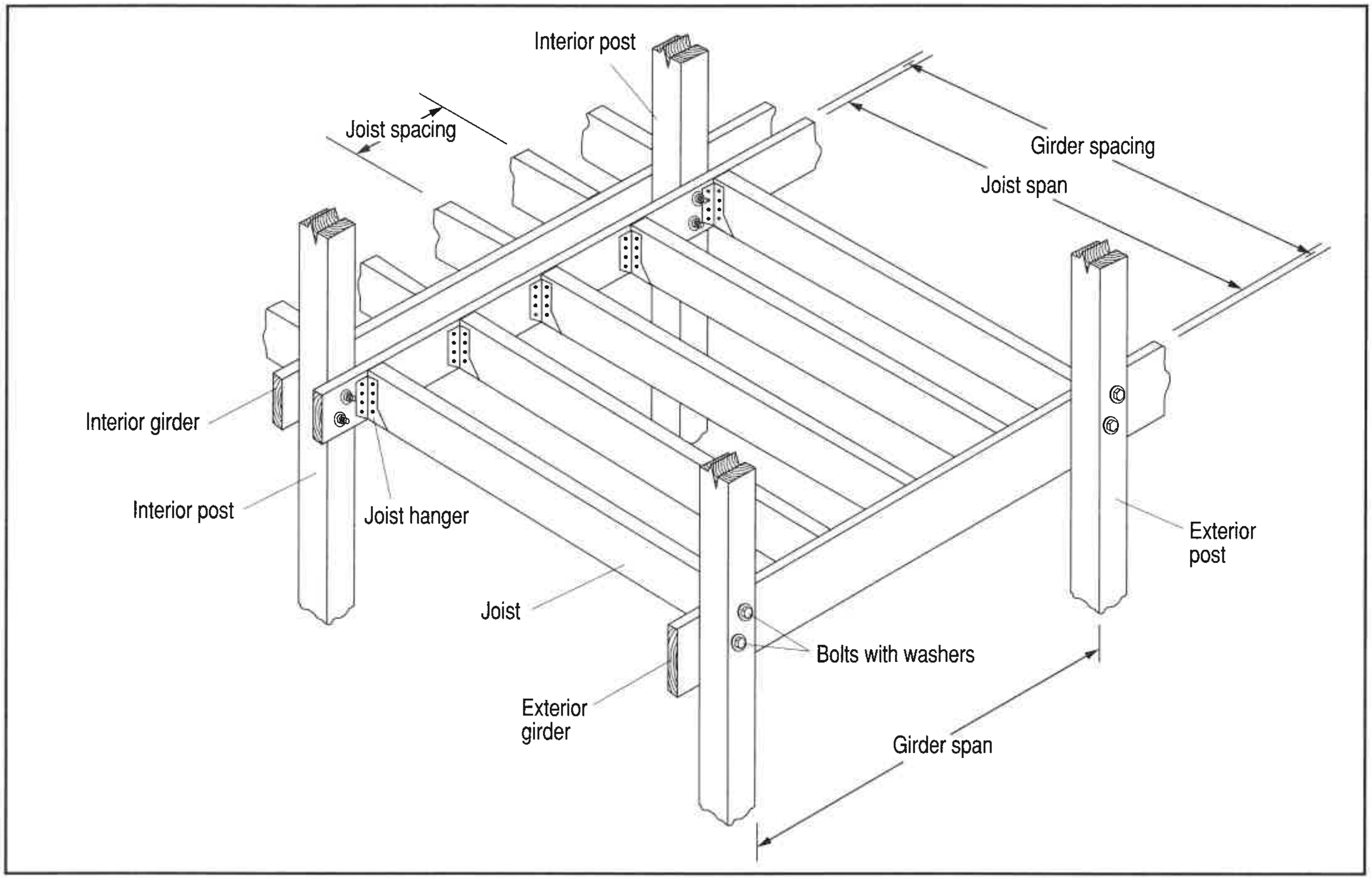


Figure 46. Components of a suspended floor.

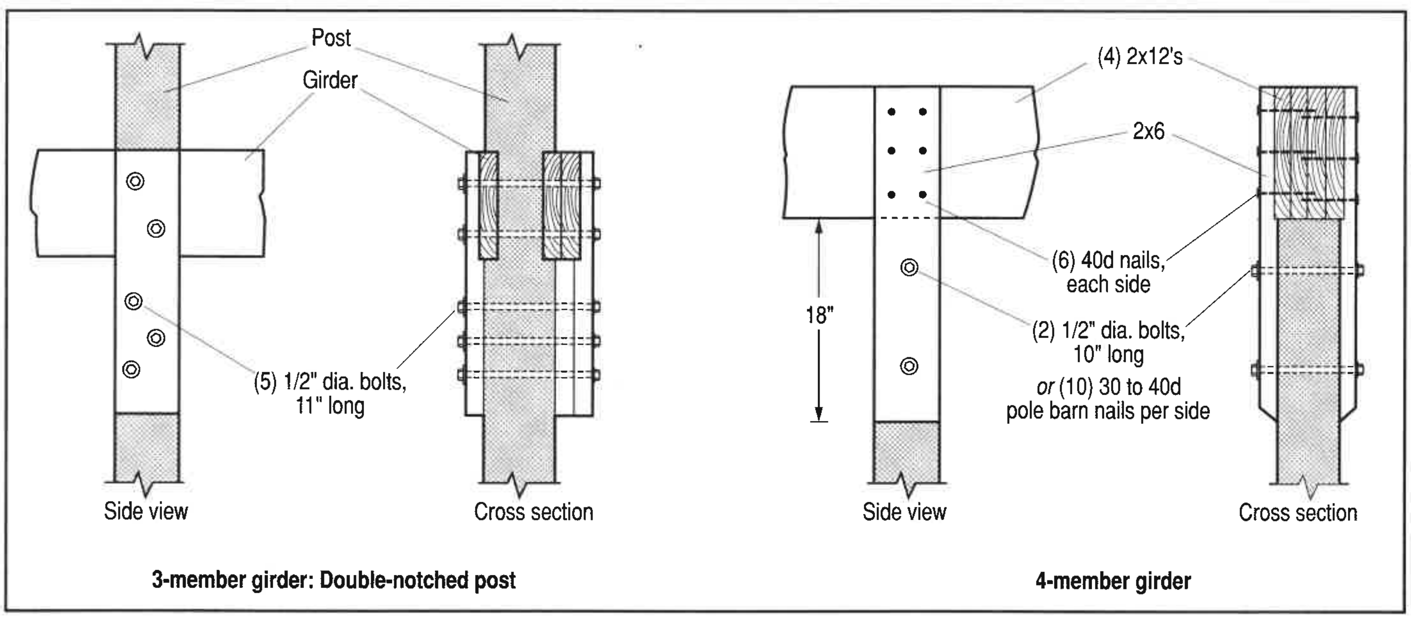


Figure 47. Multiple girder fastening.

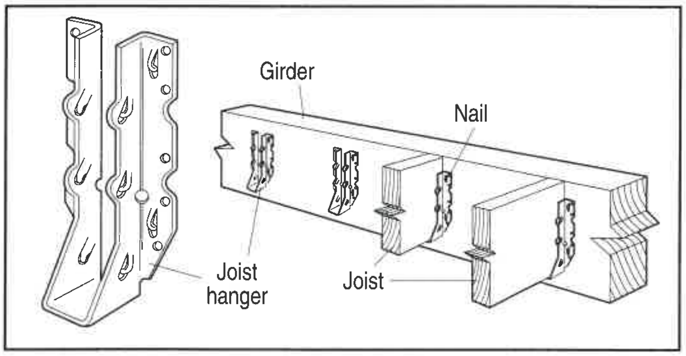


Figure 48. Floor joist hanger detail. (*Courtesy of Simpson Strong-Tie Company, Inc.*)

Selected distributed loads on floors have been listed previously in table 7, page 26. Table 26 lists the bulk densities for a variety of products and materials, in pounds per cubic foot. These values can be used to calculate the load that a proposed floor system must support.

For example, table 26 lists the bulk density of baled hay as 10 pounds per cubic foot. This means that every square foot of floor area must support 10 pounds per foot of depth. If you stack baled hay 16 feet deep, then each square foot of floor must support 160 pounds (10 pounds per cubic foot x 16 feet = 160 pounds per square foot).

With suspended floor design, all floor gravity loads (including the dead weight of the suspended floor itself) must be considered. Suspended floors attached to posts in a post-frame structure add loads that must be carried to the foundation. In many cases, the cumulative suspended floor load is greater than projected snow loads. Initial post and embedment design can change significantly with the addition of a suspended floor. It may be necessary to increase the depth and diameter of the post foundation, or the initial post size may not be sufficient to support the additional suspended floor loads. *Suspended floors should not be planned in a post-frame building without careful consideration of the anticipated loads by a professional designer.*

Table 27 lists maximum recommended spans for selected floor joists and spacings with a uniform distributed load of 50 pounds per square foot. This 50 pounds per square foot suspended floor load is assumed to consist of 40 pounds per square foot live load plus 10 pounds per square foot dead load from the framing and flooring materials. Table 28 on page 60 lists maximum recommended spans for girders consisting of multiple members at selected spacings.

Table 26. Bulk density of selected products and materials.

Product or Material	Bulk Density (pounds per cubic foot)
Baled straw or hay	5 to 10
Bran	16
Shelled corn, wheat	45, 48
Oats, ear corn (husked)	26, 28
Concentrates, typical	45
Corn meal	38
Linseed meal	23
Mixed mill feed (bran & middlings)	15
Molasses	78
Pellets, mixed feed & ground hay	35 to 45
Rye meal	38
Salt, fine	50
Soybean meal	42
Tankage	32
Water	62
Fruits and vegetables	30 to 40
Concrete	150
Plywood	36
Wood, seasoned	28 to 47

Adapted from:

American Society of Civil Engineers, *Minimum Design Loads for Buildings and Other Structures,* ASCE 7-93, 1994.

Building Officials and Code Administrators (BOCA), *The BOCA National Building Code/1987.*

MidWest Plan Service, *Structures and Environment Handbook,* MWPS–1, 1983.

Table 27 on the following page and table 28 on page 60 for suspended floor components in post-frame buildings should not be used in place of professional design expertise.

Post-to-girder bracing and post embedment are especially important in buildings with suspended floor loads to prevent failure by buckling and sway. Braces also strengthen the floor. Whenever possible, suspended floor designs should include bracing in both directions on all load-bearing posts and poles (figure 37, page 46).

Bulk Storage of Commodities

Post-frame buildings are often used for bulk storage of various commodities (figure 49 and figure 50, page 60). On many livestock operations, bulk commodities are delivered ready to feed but require covered storage. When properly designed and constructed, post-frame commodity barns provide good resistance to the substantial sidewall loads associated with bulk storage. Buildings that do not utilize a post-type foundation must rely on either strong joints where the supporting sidewall meets the foundation, or a continuous above-ground foundation (see Design Recommendations for Commodity Barns, page 63).

Table 27. Maximum floor joist spans for 50 psf.

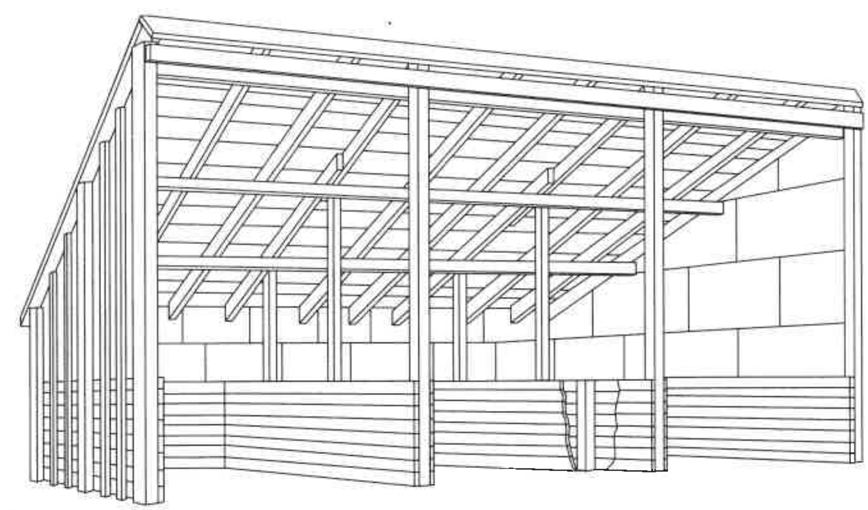
	Nominal Size	Joist Spacing, inches: 8	10	12	14	16	20	24
		Maximum Joist Span, feet-inches						
Depth / Base	2x4	8-0	7-6	7-0	6-6	6-6	6-0	5-6
	2x6	13-0	12-0	11-6	10-0	9-6	8-6	7-6
	2x8	17-0	15-6	14-6	13-0	12-6	11-0	10-0
	2x10	21-0	18-6	17-0	16-0	15-0	13-0	12-0
	2x12	24-6	22-0	20-0	18-6	17-6	15-6	14-0

Notes:

- All joist spans checked for allowable shear stress, bending stress, and deflection using a distributed floor load of 50 psf (40 live + 10 dead) on a simply supported beam at spacings shown.
- Design formulas from American Forest and Paper Association, *National Design Specification for Wood Construction,* Revised 1991 Edition, pp. 5–13:
  - C_D (load duration factor) = 1.0 (for occupancy live load)
  - C_L (lateral stability factor) adjustment is not included. Lateral instability is prevented by floor sheathing or other continuous lateral bracing of compression edge.
  - Actual joist shear stress = 3V/2bd, where V is shear force = wL/2, w is uniform load (lb/ft), L is span of beam (ft), and b and d represent the actual base and depth of the cross-section (see appendix B).
  - Actual bending stress = M/S, where M is maximum moment = $wL^2/8$ (lb-ft) and S is section modulus (in^3) (see appendix B).
  - Actual joist deflection = $5wL^4/384EI$, where E is modulus of elasticity (psi) and I is moment of inertia (in^4) (see appendix B).
- Allowable deflection = $^1/_{240}$ x span.
- Allowable design values are for Southern Pine No. 2 from American Forest and Paper Association, *Design Values for Wood Construction, NDS Supplement,* Revised 1991 Edition, p. 26:

Fv	=	90 psi
Fb (2–4" wide)	=	1500 psi
Fb (5–6" wide)	=	1250 psi
Fb (8" wide)	=	1200 psi
Fb (10" wide)	=	1050 psi
Fb (12" wide)	=	975 psi
Modulus of elasticity (E)	=	1.6×10^6 psi

Caution: Table 27 should not be used in place of professional design expertise for suspended floors in post-frame buildings.



Notes:
1. Design roof load 30 psf.
2. Lumber bending stress F_b = 1200 psi.
3. Bulk material capacity 4000 cubic feet.
4. All columns in earth to be pressure preservative-treated.
5. All planking to be rough-sawn hardwood.
6. Check dumping height before construction.

Figure 49. Open commodity storage shed. (*USDA Cooperative Extension, Plan No. 6364*)

Table 28. Maximum spans for 2-, 3-, and 4-member floor girders for 50 psf.

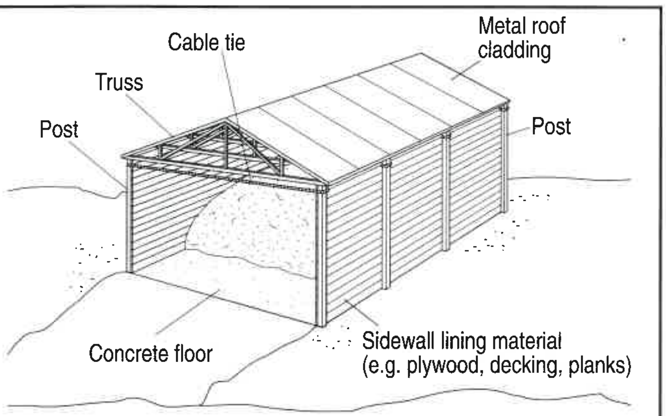
Girder Size	Girder spacing, feet					
	8	10	12	14	16	20
	Maximum girder span, feet-inches					
2 - 2x8's	10-0	9-0	8-0	7-6	7-0	6-6
3 - 2x8's	12-6	11-0	10-0	9-6	8-6	8-0
4 - 2x8's	14-6	13-0	11-6	11-0	10-0	9-0
2 - 2x10's	12-0	11-0	10-0	9-0	8-6	7-6
3 - 2x10's	15-0	13-0	12-0	11-0	10-6	9-6
4 - 2x10's	17-0	15-6	14-0	13-0	12-0	11-0
2 - 2x12's	14-0	12-6	11-6	10-6	10-0	9-0
3 - 2x12's	17-6	15-6	14-0	13-0	12-0	11-0
4 - 2x12's	20-0	18-0	16-6	15-0	14-0	12-6

Notes:

- Table 28 presents maximum spans for girders supporting single spans of floor joists, as shown in figure 46, page 57. Maximum spans for a girder supporting two spans of floor joists will be considerably less.
- All girder spans checked for allowable shear stress, bending stress, and deflection using a distributed floor load of 50 psf (40 live + 10 dead) on a simply supported beam at girder spacings shown.
- Design formulas from American Forest and Paper Association, *National Design Specification for Wood Construction,* Revised 1991 Edition, pp. 5–13:
  - C_D (load duration factor) = 1.0 (for occupancy live load)
  - C_M (wet service factor) and C_L (lateral stability factor) adjustments are not considered.
  - Actual joist shear stress = 3V/2bd, where V is shear force = wL/2, w is uniform load (lb/ft), L is span of beam (ft), and b and d represent the actual base and depth of the cross-section (see appendix B).
  - Actual bending stress = M/S, where M is maximum moment = $wL^2/8$ (lb-ft) and S is section modulus (in^3) (see appendix B).
  - Actual joist deflection = $5wL^4/384EI$, where E is modulus of elasticity (psi) and I is moment of inertia (in^4) (see appendix B)
- Allowable deflection = $^1/_{240}$ x span.
- Allowable design values are for Southern Pine No. 2 from American Forest and Paper Association, *Design Values for Wood Construction, NDS Supplement,* Revised 1991 Edition, p. 26:

Fv	= 90 psi
Fb (8" wide)	= 1200 psi
Fb (10" wide)	= 1050 psi
Fb (12" wide)	= 975 psi
Modulus of elasticity (E)	= 1.6×10^6 psi

Caution: Table 28 should not be used in place of professional design expertise for suspended floors in post-frame buildings.



Note: A professional engineer experienced in commodity storages should be consulted for structural design.

Figure 50. Large capacity bulk storage barn.

Post-frame buildings are well adapted to resisting sidewall loads. However, proper post size and foundation design is critical to obtain a safe and cost-effective structure. *Because of the high sidewall loads associated with bulk storage, professional design of commodity barns or sheds is recommended.*

Sidewall Loading Due to Bulk Storage

As figure 51 shows, posts in a bulk storage building may be required to withstand several combinations of loads, in addition to the conventional wind, snow, and dead loads acting on the structure. Forces (A), (B), and (C) in figure 51 illustrate the horizontal forces caused by the stored product in the commodity storage building shown in figure 50, including:

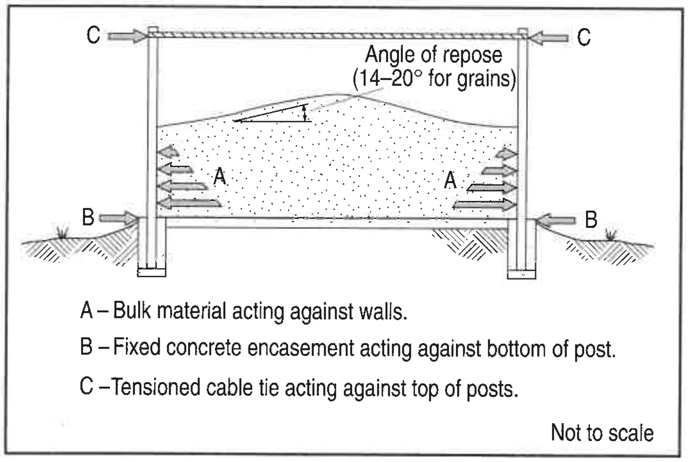


Figure 51. Forces acting on load bearing posts in figure 50.

(A) The outward force of the piled bulk material acting against the sidewall and pushing against the supporting post. These product sidewall loads are complex, but for approximations in shallow bins they may be treated as semi-fluids, with wall pressures increasing linearly per foot of depth.

(B) The reaction force of the concrete-encased foundation acting to "anchor" or fix the bottom of the post to the ground. In a post-frame bulk storage facility, the foundation prevents horizontal wall movement or collapse.

(C) The reaction force of the tensioned cable acting against the top of the tied posts. In this type of design, the cable tie is used to prevent the top of the walls from collapsing outward, since trusses are not generally designed to withstand such high external tensile forces.

Design loads due to storage of bulk materials such as potatoes, grain, or mixed ration components are estimated using the concept of equivalent fluid density (EFD). Bulk materials in shallow bins press outward against the sidewall much like a fluid. Fluids apply a horizontal force on the supporting wall that is dependent on the fluid density (pounds per cubic foot) and the depth of the fluid (feet). The pressure at any depth on the wall is calculated by multiplying the depth (from the fluid surface) times the equivalent fluid density of the fluid.

For example, the fluid density of water is 62.4 pounds per cubic foot. In a 10-foot-deep swimming pool, 624 pounds per square foot (62.4 pounds per cubic foot x 10 feet) of horizontal pressure is exerted outward against the bottom of the pool wall.

Table 29 presents the equivalent fluid densities of selected agricultural commodities at level fill and piled at their normal filling angle, called the angle of repose (figure 51). To estimate the maximum sidewall pressure of a bulk product, multiply the product EFD (from table 29) by the total depth of product, as follows:

maximum sidewall pressure (pounds per square foot) = EFD (pounds per cubic foot) x total product depth (feet)

Horizontal pressure at the bottom of a storage building filled with corn that is heaped 10 feet deep may reach 225 pounds per square foot (22.5 pounds per cubic foot x 10 feet). This sidewall grain pressure subjects the supporting posts (at an assumed 4-foot spacing) to approximately three times the bending moment (or torque) caused by a 90-mph wind on a similarly supported 10-foot post-frame wall. Note that in table 29 the equivalent fluid density (and resulting sidewall pressure) of a piled product is greater than the same product at level fill. Generally, leveled grain exerts 20 to 25% less sidewall pressure than grain piled to its filling angle.

Table 29. Equivalent fluid density (EFD) of various agricultural bulk products, pounds per cubic foot.

Products	Level Fill	Piled to Filling Angle
Corn, shelled	18	22.5
Rough rice, American Pearl	10.8	13.6
Rye	18.1	23.3
Soybeans	16.7	20.5
Barley		
Eastern	14.5	18
Western	15.6	19.4
Oats		
Central U.S.	10.3	12.9
Pacific NW & Canada	10.8	13.5
Wheat		
Soft red winter	18.3	22.9
Hard red spring	18.8	23.8
Hard red winter	19.2	24
Durum	20.3	26.1
Potatoes		
Dry	11	N/A
Wet	12	N/A

Source: MidWest Plan Service, 1987

Notes:

EFD = pounds horizontal force per square foot per foot of depth.

Table values assume smooth, vertical storage walls (i.e., no wall friction).

N/A = not available.

Horizontal loads from bulk materials are directly resisted by sidewall planking or sheathing materials that are in turn supported by the posts in a post-frame structure. Sufficiently strong sheathing between posts is required to resist sidewall loads. Factors involved in the selection of plywood sheathing include: the spacing of supports, the direction of plywood face grain, and the moisture content of the plywood.

In most storage bins, Exterior grade, Structural I (S-I) plywood of at least ¾-inch thickness will be installed on the inside of the supporting posts. Plywood should be nailed 6 inches on-center at all edges and 12 inches on-center at intermediate supports. Use 6d nails for plywood ½-inch-thick or less and 8d nails for thicker panels. Plywood that is installed on the outside of supporting posts will require fasteners specially designed for withdrawal loading. All fasteners should be corrosion-resistant. In addition, it is recommended to "overdesign" fasteners in withdrawal to allow for losses due to corrosion.

Nominal 2-inch (1.5-inch) tongue-and-groove decking or center-matched planks are often used to withstand the high lateral pressures at the bottom of bulk storage walls. Combinations of wood and metal lining materials (or additional rigid supports) may be needed for larger post spacings. *Install plywood sheets or planks long enough to cover at least two spans (three posts). Pieces that span between two posts only may deflect excessively under load.*

Table 30 lists the maximum uniform load for plywood and plank lining with supports spaced at 2, 4, 6, and 8 feet apart. To determine the maximum product depth that the sheathing or lining material can withstand, divide the maximum uniform load from table 30 by the equivalent fluid density in table 29, page 61. For example, ¾-inch unsanded Structural I (S-I) plywood supported by rigid supports spaced 4 feet apart will safely hold shelled corn at a level depth of 2.5 feet (46 pounds per square foot ÷ 18 pounds per cubic foot = 2.5 feet). Spruce-Pine-Fir planks (2-by-10's) laid horizontally between rigid supports spaced 4 feet apart will allow corn to be piled to a depth of 5.6 feet (126 pounds per square foot ÷ 22.5 pounds per cubic foot = 5.6 feet).

Note that allowable product depths determined from table 29 (page 61) and table 30 account only for sidewall loads from bulk product acting on the sheathing. Table 31 on page 64 is to be used in conjunction with these two tables as a guide to sizing and spacing the posts that support the sheathing material and bulk product. *Where the estimated product depth based on sheathing strength (from table 29, page 61 and table 30) is greater than the maximum product depth based on post size (from table 31, page 64), product depth based on post size must control.*

Table 30. Load-span for selected wood sheathing materials.

Sheathing Material	Maximum uniform load in psf with supports spaced at:			
	2 ft.	4 ft.	6 ft.	8 ft.
¾-inch APA Structural I (unsanded, dry) Fb = 2000 psi	183	46	20	11
1⅛-inch APA Structural I (unsanded, dry) Fb = 2000 psi	388	97	43	24
2x10 Maple planks (No. 2) Fb = 700 psi	405	101	45	25
2x10 Spruce-Pine-Fir planks (No. 2) Fb = 875 psi	506	126	56	32
2x10 Mixed Oak planks (No. 2) Fb = 800 psi	462	116	51	29
2x10 Southern Pine planks (No. 2) Fb = 1051 psi	607	152	67	38

Notes:

Uniform load values in table 30 are based on a distributed load acting on simply supported sheathing material between rigid supports.

Critical bending stress in the horizontally laid plywood and plank sheathing is assumed to occur at midspan between vertical supports.

Table values assume one-way "beam" action, rather than two-way "slab" action in the sheathing material.

All table values determined as follows: Uniform load (psf) = 96 x Fb (psi) x KS or section modulus (in^3/ft) / post spacing^2 (in^2).

To determine maximum product depth in feet based on sheathing material: Divide allowable uniform loads from table 30 (psf) by EFD from table 29, page 61 (lb/ft^3).

Design formula for computing structural plywood loads from APA–The Engineered Wood Association, *Plywood Design Specification,* August 1986, p. 23:

Uniform load based on bending stress (psf), w = 96 x Fb x KS / l^2, where
Fb is the allowable bending stress (psi),
KS is the effective section modulus of the plywood (in^3/ft), and
l is the span center-to-center of supports (in).

Design formulas for computing 2x10 plank loads from American Forest and Paper Association, *National Design Specification for Wood Construction,* Revised 1991 Edition, pp. 5–9:

C_D (load duration factor) = 1.00 (for normal duration).
Actual bending stress in planking = M/S, where M is maximum bending moment = $wL^2/8$ (lb-ft), w is the calculated uniform load (psf), L is the support or post spacing (ft), S is section modulus = $bd^2/6$ (in^3/ft), and b and d represent the actual base and depth of the plank cross-section (see appendix B).

Allowable design values for plywood from APA–The Engineered Wood Association, *Plywood Design Specification,* August 1986, pp.16–17.

KS = 0.549 in^3/ft (23/32 & ¾ - U)
KS = 1.164 in^3/ft (1⅛ - U)

Allowable design values for 2x10's from American Forest and Paper Association, *Design Values for Wood Construction, NDS Supplement,* Revised 1991 Edition, pp. 21,22,26:

Caution: Loads shown in table 30 are for sheathing only and in no way account for design size of framing supports. When selecting bulk storage component sizes, compare product depths derived from table 29, page 61 and table 30 with maximum product depths from table 31, page 64. In cases where maximum product depth based on sheathing strength is greater than maximum product depth based on post size, depth based on post size must control.

Example: Use of tables 30 and 31 to determine commodity depth.

Determine the maximum depth (level fill) of wet potatoes in a post-frame storage facility utilizing 2-by-10 Southern Pine No. 2 planks as sheathing and 4-by-6 or 6-by-6 Southern Pine No. 2 posts spaced at 4 feet on-center. Assume that the foundation design is adequate. Exclude external building loads such as snow, wind, or impact loads.

Step 1. Determine the maximum uniform load of the horizontally laid 2-by-10 planks at a 4-foot support spacing. Using table 30, Southern Pine No. 2 planks can resist a maximum uniform load capacity of approximately 152 pounds per square foot.

Step 2. Determine the equivalent fluid density (EFD) of the bulk product. From table 29, page 61, the EFD for wet potatoes is 12 pounds per cubic foot.

Step 3. Determine the recommended depth of product *based on sheathing strength*. Divide the maximum uniform sheathing load (from table 30) by the product EFD (from table 29, page 61). For wet potatoes stored against Southern Pine No. 2 planks, a maximum depth of 12.7 feet (152 pounds per square foot ÷ 12 pounds per cubic foot = 12.7 feet) is recommended for the potatoes.

Step 4. Determine the maximum depth of product *based on post size*. From table 31, page 64, for wet potatoes at a 4-foot post spacing, a 4-by-6 post can support a maximum level potato depth of 5.4 feet. (If a 6-by-6 post is selected, wet potatoes can be stored up to 6.3 feet deep.)

Step 5. Compare the maximum depth of product based on post size with the recommended depth of product based on sheathing strength. In this example, recommended product depth based on sheathing strength (12.7 feet) is substantially greater than the maximum product depth based on post size (5.4 feet). Therefore, product depth must be based on post size. If 4-by-6 posts are used at a 4-foot spacing, the potatoes should not be stored above 5.4 feet.

If 6-by-6 posts are used at the same spacing, wet potatoes should not be stored above 6.3 feet. In both of these cases, post size controls maximum product depth only because the sheathing has more horizontal loading capacity than the supporting posts. (Conversely, where product depths based on post size exceed those based on sheathing, sheathing strength must control.)

CAUTION: Maximum product depths presented in table 31, page 64, are for guidance only and should not be used in place of professional structural design.

Table 31, page 64, which lists the maximum product depths for various post sizes and spacings, assumes that the stored product pushes on one wall only and does not include any combined external building loads (such as snow, wind, impact, etc.). Safety factors are not included. *Because of the high sidewall pressures found in bulk storage facilities, professional structural and foundation design is recommended.*

Design Recommendations for Commodity Barns

Commodity barns generally provide storage of bulk feeds or other commodities in floor bins. Bays in commodity barns or sheds should be at least 12 feet wide (preferably 14 feet). Lighter commodities (such as chopped hay) will require more storage space. Bin floors can be of concrete or asphalt (both work equally well). Steel angles or concrete-filled pipe (ballard posts) should be used to protect the front or open edge of each bin divider. The front eave of the building should be from 14 to 26 feet high to allow dump bed delivery into the bins (figure 49, page 59). Back walls may be from 10 to 14 feet high. To shed rainfall, include a 14-foot concrete or asphalt apron in front of bins, sloped away from the storage (1 inch per 10 feet).

Table 31. Maximum level depth of bulk products for selected post sizes and spacings (Southern Pine No. 2).

Post Size	Corn, Wheat, Rye 18 lb/ft^3 = EFD				Oats 10.3 lb/ft^3 = EFD				Potatoes (wet) 12 lb/ft^3 = EFD			
	Post Spacing, feet											
	2	4	6	8	2	4	6	8	2	4	6	8
4x6	5.9	4.7	4.1	3.7	7.1	5.7	4.9	4.5	6.8	5.4	4.7	4.3
6x6	6.9	5.5	4.8	4.3	8.3	6.6	5.7	5.2	7.9	6.3	5.5	5.0
6x8	8.5	6.7	5.9	5.3	10.2	8.1	7.1	6.4	9.7	7.7	6.7	6.1
6x10	9.9	7.9	6.9	6.2	11.9	9.5	8.3	7.5	11.3	9.0	7.9	7.1
8x8	9.4	7.4	6.5	5.9	11.3	9.0	7.8	7.1	10.7	8.5	7.4	6.8
8x10	11.0	8.7	7.6	6.9	13.2	10.5	9.2	8.3	12.6	10.0	8.7	7.9

Notes:

Depths of product in table 31 are based on linearly increasing product loads acting on adequate wall liner surfaces between unpropped cantilever posts.

EFD = Equivalent fluid density

Table values are for guidance only and do not include external structural loads such as snow, wind, or impact loads. Safety factors are not included.

Professional design assistance is recommended for appropriate combination and application of external structural loads and safety factors.

Critical bending stress in vertical posts are assumed to occur at $^2/_3$ depth of product.

Table values determined as follows: Maximum product depth, ft. = [Fb (lb/in^2) x section modulus (in^3) x 6 / (EFD (lb/ft^3) x post spacing (ft) x 12 (in/ft))] $^{0.333}$.

Design formulas from American Forest and Paper Association, *National Design Specification for Wood Construction*, Revised 1991 Edition, pp. 5–9:

C_D (load duration factor) = 1.00 (for normal duration).

Actual post bending stress = M/S, where M is maximum bending moment = $wL^2/6$ (lb-ft), w is linear load acting on the post (lb/ft) = EFD (lb/ft^3) x product depth (ft) x post spacing (ft), L is unsupported length of post from ground to eave (ft), S is section modulus = $bd^2/6$ (in^3), and b and d represent the actual base and depth of the plank cross-section (see appendix B).

The larger post dimension is in the same direction as wind or parallel to building width.

Allowable design values for Southern Pine No. 2 from American Forest and Paper Association, *Design Values for Wood Construction, NDS Supplement*, Revised 1991 Edition, p. 35:

Fb (5" x 5" and larger) = 850 psi.

Use embedment depths listed in table 18, page 43.

Reduce grain depths on the wall 8% if grain is piled at filling angle of repose.

[An alternative to a post foundation is a continuous aboveground foundation, with 4-foot-high concrete walls (6 to 8 inches thick). The concrete walls serve as a perimeter foundation, and also as outside bin walls. Either a post- or frame-type structure can be constructed up from the concrete walls. The outside of the frame is covered with metal sheathing. Posts or studs are covered on the interior with plywood or similar material at least 8 feet above the top of the concrete walls.]

The location of a commodity barn is critical. Be sure to put the barn in a place where the least experienced truck driver can back in, dump, and get out without damage. Also, consider site drainage and disruptions to animal and equipment flow (see Site Selection and Site Drainage, pages 21 and 22).

Consider adding lights to allow for night deliveries. If finances permit, consider extra bins for premixes (dry ingredients to a total mixed ration). Extra bins can also be used for unanticipated bargain purchases of bulk feed or other commodities. In addition to feed storage, consider construction of a smaller bay with a gravel base for palletized storage of sacked minerals or feed additives.

Chapter 3. Construction Procedures

The success of any building project depends upon planning, efficient use of labor and machinery, convenient location of materials and components, good site drainage, and conducive weather. A builder's responsibility is to assure that the building is erected according to the plans, using the materials and designs specified. Often the builder-owner of a modest post-frame structure becomes the general contractor when he or she calls on specialists to complete various phases of the building construction (such as electrical wiring or plumbing).

A post-frame building can be constructed several ways. The following construction procedure will be helpful for a first job. It can also be used to review procedures after several jobs. With careful organization of the construction crew, and depending on weather, some steps can either be interchanged or proceed simultaneously.

Building Layout

1. Tools and Materials

Two 100-foot steel tapes, pry bar, hatchet, sledge hammer, level, plumb bob, at least twenty 2-by-4 stakes (35 inches long), eight 2-by-4 batter boards 8 feet long, building line or cord (length = building perimeter + 100 feet), 12d nails, and builder's level and rod.

2. Procedure

a. Stake out a base line at the front edge or side of the building.

b. Locate and set front stake A on base line. Drive a nail in the top of the stake as a reference point (figure 52).

c. Measure the building length along the base line from stake A and set corner stake B. Use a construction level and drive stake B level with stake A. Drive a nail in the top of the stake at the exact length of the building (outside to outside).

d. Make the endwall perpendicular to the front wall as follows. Measure 18 feet along the base line from stake B and set a temporary stake. The point 30 feet from this temporary stake and 24 feet from stake B is perpendicular to the base line. Set a temporary stake at this point.

e. Measure the outside width of the building along this line and set the third corner stake C. Drive stake C level with stakes A and B. Drive a nail in top of the stake at the exact outside width of building.

f. From stake C measure the outside building length. From the nail in stake A measure the outside building width. Where these two measurements meet, drive a fourth corner stake D. Drive nail at exact outside corner point.

g. Check tops of all stakes; all should be level. Then measure: (1) baseline length AB, (2) triangulation at second corner (ABC), (3) widths BC & AD, and (4) length CD. Adjust nails or stakes B, C, or D as necessary.

h. Check that diagonals AC and BD are equal for a rectangular building. Make diagonals equal by shifting C and D along rear wall line. Keep width BC and AD equal. Recheck level of any shifted stakes.

i. Drive batter board stakes 8 to 12 feet from all corners. Batter boards provide a level reference plane for the building layout. They should not interfere with excavation or construction and should remain undisturbed until the building frame is complete.

j. Level and fasten batter boards to stakes at same height as tops of corner stakes.

k. Stretch building cord between batter boards to just touch nails on top of stakes. Drive nail or make saw kerf in top of batter boards to line up string lines. Corner marking stakes can then be removed and corners located where lines cross.

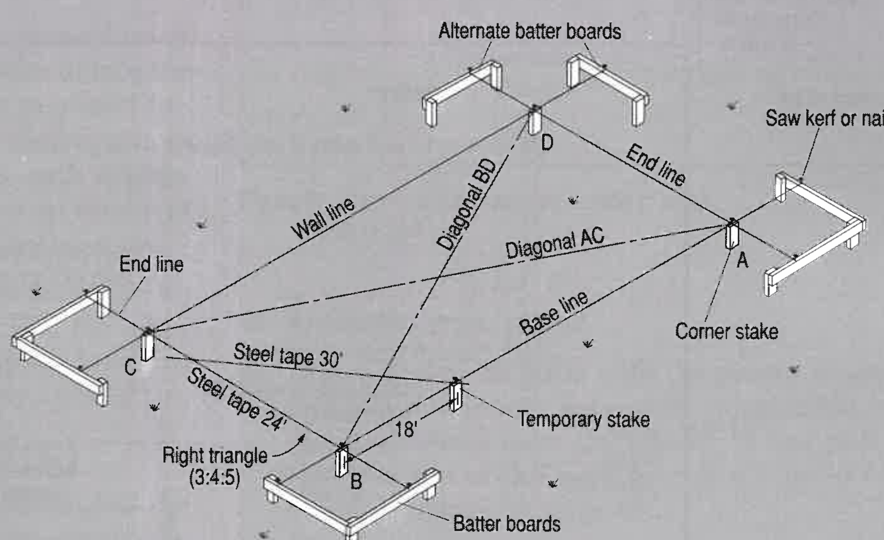


Figure 52. Building layout with batter boards.

Layout and Excavation

1. Select the site. Use guidelines as described earlier in this handbook. (Refer to Site Selection, page 21.)
2. Remove all sod and vegetation. Fill, compact, and grade the site to the desired elevation. Grade to level an area approximately 24 feet longer and 24 feet wider than the building, to provide 12 feet of clear space on all sides. This space allows room for construction equipment as well as for future maintenance. If the building site is in a heavily wooded or obstructed area, special site planning may be necessary.
3. Lay out the building. The layout of the building establishes exact reference lines and elevations. Care in layout makes construction easier and helps keep the building square.
4. Mark post or pole locations with ground limestone or a small stake. Temporarily remove stretched string lines. Figure 53 indicates the location of posts and poles with respect to the outside building line. It is preferred to leave string lines offset (usually about 1½ inches or the width of the wall girt) from post faces, measuring from the line to each post as it is set. Alternately, the outside edge of posts can be aligned by moving string lines inward the thickness of the wall girts. However, string lines may become deflected by posts leaning against the string.
5. Bore holes with a truck- or tractor-powered 14- or 24-inch-diameter auger the depth required by the plans or design notes. Dig holes wide and deep enough to install the specified pad or casing or at least 8 inches larger than the post or pole butt. If the earth is stony, use a backhoe. *NOTE: Holes dug to receive concrete casings must not be dug wider at the top than at the bottom or frost action may "heave" the entire post/casing assembly.*

Concrete Footing Pads

6. Remove water or loose material from the bottoms of holes so they are smooth and level. Check that the foundation depth extends below the frost line (see figure 36, page 44) to avoid possible "heaving."
7. Pour the concrete footings at the design thickness in the bottoms of the holes on undisturbed earth. Let them cure for twenty-four hours. All concrete should be made up with at least six 94-pound sacks of Portland cement per cubic yard, with a maximum water/cement ratio of 6 gallons per sack. *NOTE: For proper curing, concrete and ambient temperatures should be above 50°. Concrete should generally be covered with plastic to prevent evaporation of moisture. Do not allow concrete to freeze until it has adequately cured. Use only air-entrained concrete (a special mixture of concrete with 3 to 6% air) in places where the concrete will be subjected to cycles of freezing and thawing.* Alternately, precast concrete pads may be used if they meet foundation design specifications for strength.

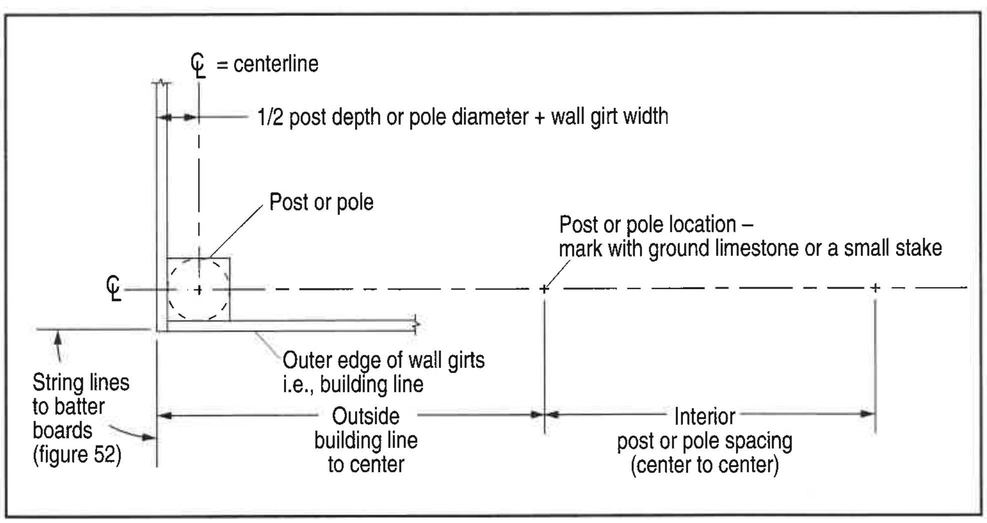


Figure 53. Location of posts or poles and string lines (plan view).

Posts and Poles

8. Select four straight corner posts or poles.
9. Place posts in the holes. Raise posts with a tractor hydraulic loader and timber hitch or nonslip sling attached above the mid-height of the post (figure 54). Let the posts lean toward the inside of the building.
10. Replace string lines and plumb the two outside edges of corner posts with a carpenter's level and straight edge. Keep posts at the preset distance from the string lines.
11. Drive 2-by-4 stakes inside building lines. Brace corner posts with 2-by-4's (figure 55). Place concrete for a minimum 12-inch-thick concrete collar above the footing pad. *NOTE: Assure a positive connection between the post and concrete collar with rebar (see figure 35, page 41). Be aware that some building codes may require a sand, soil/cement, or concrete embedment above the collar.* Tamp soil or aggregate backfill materials with a 2-by-4, tamping bar, or power tamper in 4- to 6-inch layers (lifts) according to foundation design. Do not backfill to more than one-half the hole depth until girders are secured in place (to allow readjustment of posts).
12. Nail 2-by-4 spacers to the tops of the corner posts and tie a building line around the tops of the corner posts. Remeasure building line around the tops of the corner posts.
13. Determine the spacing between posts (from design drawings). Then, either on a center-to-center or clear-distance basis, mark 2-by-4 supports to locate posts.
14. Locate and plumb the outside edges of all posts using plumb lines as a guide. Be sure to face the straightest side out. Use previously marked 2-by-4's to space posts. Brace posts with 2-by-4's to driven stakes. Fasten the braces with duplex (double-headed) nails. Place braces so they will not interfere with girder and truss installation.
15. For reference, the grade or datum level can be marked with a nail driven partly into the outer edge of each post (figure 55). The grade level can be set with a builder's level and rod.

Girders (Truss Supports)

16. Measure and mark with a partly driven nail the desired height to the top of the girder (figure 55). Cut a straight board or 2-by-4 to this dimension for fast and consistent marking from the nails driven at the grade level in step 15.

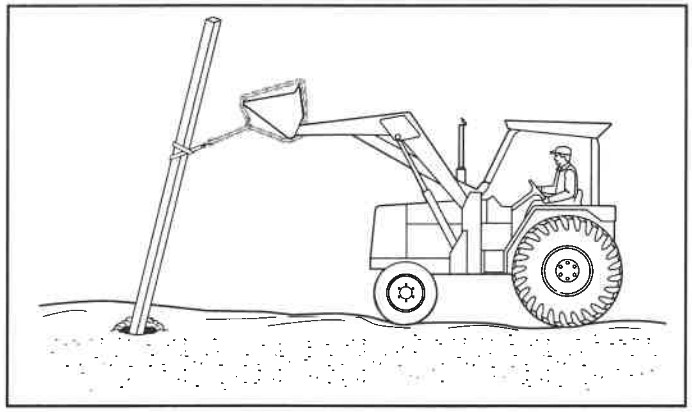


Figure 54. Placement of posts.

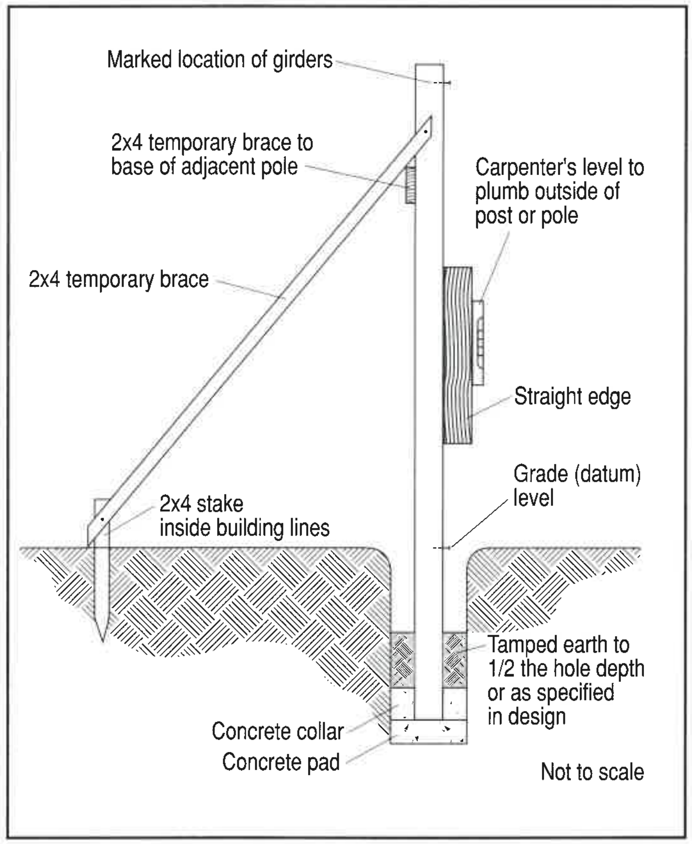


Figure 55. Alignment and temporary bracing of posts.

17. Replumb corner posts.
18. Attach girders to posts with the proper number and size of fasteners. To keep the posts stable, run diagonal braces from the bottom of one post to near the top of the next post at 40- to 50-foot intervals (figure 56, page 68).
19. Trim post tops as specified on the plan.
20. Recheck that corners are plumb and walls are straight.

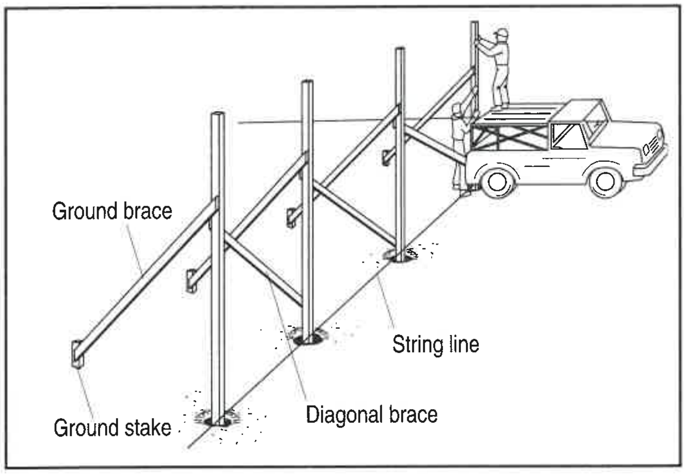


Figure 56. Marking height to top of girders.

Trusses and Construction Braces

NOTE: Construction bracing design is not usually furnished as part of a truss package and must be made the responsibility of the builder or contractor in charge of erection. The recommendations of the Truss Plate Institute's (TPI) Recommended Design Specification for Temporary Bracing of Metal-Plate-Connected Wood Trusses, DSB-89, *and* Commentary and Recommendations for Handling, Installing & Bracing Metal-Plate-Connected Wood Trusses, HIB-91 Summary Sheet, *should be followed to assure adequate and safe installation of roof trusses. TPI is currently working with the post-frame industry on a set of recommendations specifically for post-frame construction.*

21. Check the building width (outside to outside of girders) before placing trusses.
22. Lift a gable-end truss in place with a crane, boom truck, or front end loader. Lift devices should be connected to the truss top chords with a closed loop attachment of sufficient length to carry the truss (figure 57). *Do not lift single trusses of greater than 30 feet by the peak (see figure 58).* Use the erection equipment to hold the truss in alignment while attaching it at one end. For attachment to the other end, the corner post brace may need to be loosened to align the width mark on the truss with the post. Take care to fasten trusses properly and brace them promptly. (Brisk winds come with little warning and have damaged many unbraced or poorly fastened trusses. Timely installation of roofing material also prevents wind damage.)

CAUTION: Many construction injuries occur as a result of improper handling, placement, and bracing of trusses. Install truss ground bracing in all applications (figure 59), as well as all other required construction bracing. The builder must assure that wood trusses are not structurally damaged during erection, and that they are maintained in proper alignment before, during, and after installation.

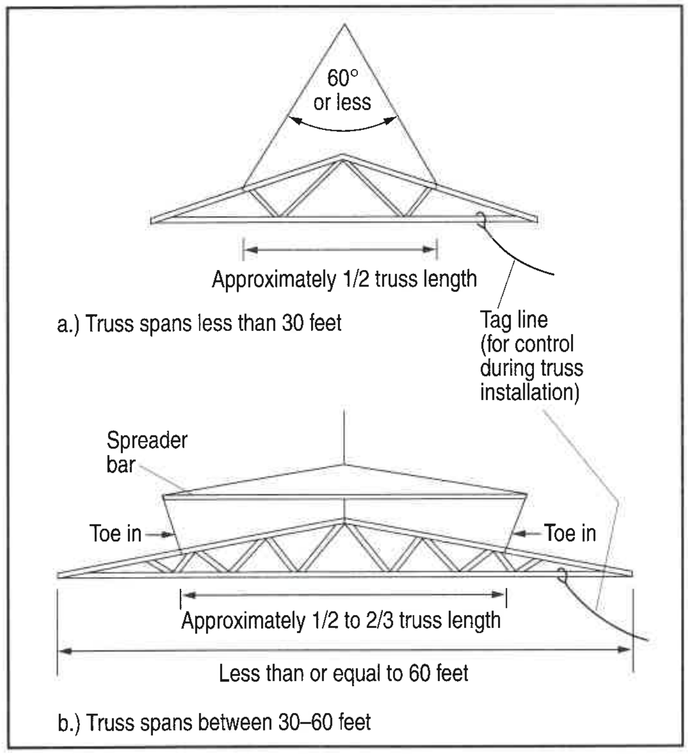


Figure 57. Mechanical installation of trusses. (*Reprinted from* Commentary and Recommendations for Handling, Installing, and Bracing Metal-Plate-Connected Wood Trusses, *HIB-91 Summary Sheet, Truss Plate Institute*)

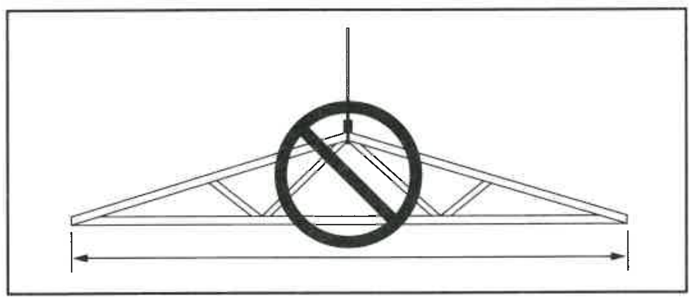


Figure 58. Improper lifting. (*Reprinted from* Commentary and Recommendations for Handling, Installing, and Bracing Metal-Plate-Connected Wood Trusses, *HIB-91 Summary Sheet, Truss Plate Institute*)

23. Mark 2-by-4 purlins with the exact spacing between trusses.
24. Set the second truss in place and attach it at one end. Fasten purlin at peaks of end truss and second truss with duplex-head nails. On 40-foot or longer trusses, fasten a temporary spacing member half way between the eaves and the peak. *NOTE: Truss spacing members should not take the place of an adequately designed, temporary truss-bracing system.*

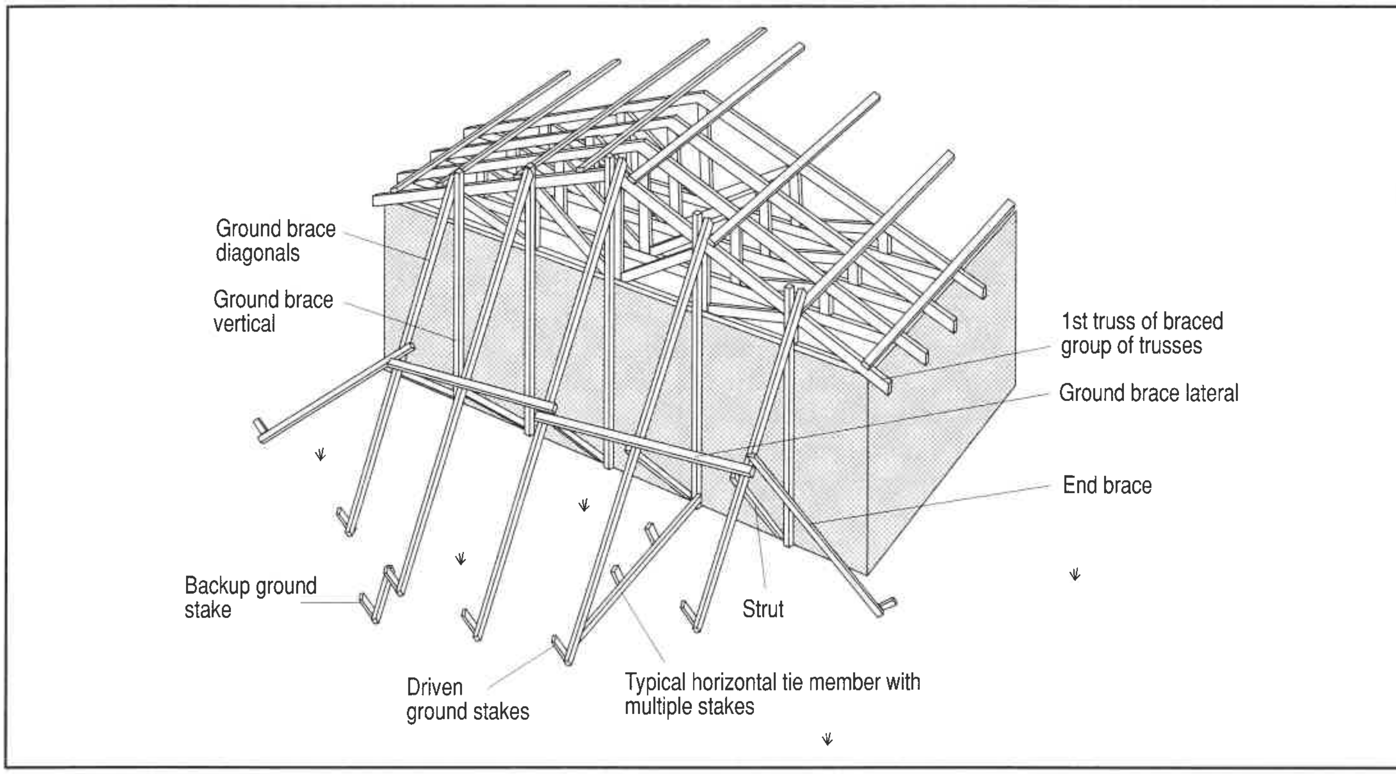


Figure 59. Construction ground bracing (required for all installations). (*Adapted from* Commentary and Recommendations for Handling, Installing, and Bracing Metal-Plate-Connected Wood Trusses, *HIB-91 Summary Sheet, Truss Plate Institute*)

25. Extend 2-by-4 temporary bracing from the corner post at a 45° angle to the next truss, or according to building contractor's specifications.
26. Continue setting trusses. Secure at each end. Space with 2-by-4 spacers as required. Brace with temporary diagonal, lateral, or web bracing, as specified by the building contractor. After one set of diagonal bracing reaches the peak, the next set can be run at a 45° angle, from the peak down, with this pattern continuing along the length of the roof.
27. Backfill posts as time and labor become available, according to foundation design specifications.
28. Recheck the gable-end truss and replumb if necessary.
29. Sight along top chords of each truss and straighten by readjusting bracing as required.

Purlins and Permanent Braces

30. Fasten purlins working from the eaves toward the peak. Use wood gauges to obtain proper spacing.
31. Install permanent bracing as required by the truss designer and approved by the building designer.
32. As purlins are attached, remove temporary top chord bracing and reinstall to the bottom side of the top chord according to design specifications.
33. Extend permanent top chord diagonal bracing at a 45° angle from each corner, and at 30-foot intervals (figure 40, page 49). *NOTE: Internal web or cross bracing (sometimes called wind bracing) may be installed according to design specifications as the trusses are set in step 26 (figure 39, page 48).* Knee braces (figure 2, page 2), if required, may also be installed during step 26.

Roofing

34. Determine roofing overhang at the eaves line, fasten spacer blocks every 30 to 50 feet along eaves, and stretch a building line between corners to mark roofing overhang.
35. Mark purlins at 20-foot intervals to check alignment of roofing sheets.
36. Install roofing starting at lower corner of downwind end so side laps are away from the prevailing winds. Follow manufacturer's fastening instructions. *To reduce leaks, use only nails or screws with neoprene sealing washers designed to*

fasten metal roofing and siding. To avoid corrosion, use galvanized nails or screws with galvanized steel sheets, or use aluminum fasteners with aluminum sheets.

Lap each side of corrugated sheets one and one-half corrugations (see figure 15, page 16), and lap ends 6 to 9 inches. For roofing, nail *through the tops* of the corrugations using fasteners with neoprene washers. Fasteners should penetrate at least 1 inch into the purlin. On a roof with roof purlins spaced at 2 feet on-center, 1 pound of 2-inch nails with neoprene washers will fasten approximately 100 square feet of metal roofing. Use fiberglass panels in roofing (or in sidewalls) as desired for natural light (see section on Skylights and Windows, page 20).

37. Finish installing all permanent truss stiffeners, internal vertical cross bracing (at minimum 20-foot intervals), and lateral bracing (at minimum 20-foot intervals) across the building, as specified by the building designer.

Siding and Finishing

38. Nail pressure-treated base planks (skirt boards) at a uniform distance from the previously established datum line. *NOTE: Skirt boards should extend far enough above the ground to protect the exterior lining from splashing rain water and to protect the interior lining from water, chemical, or manure contact and from physical damage due to equipment or animals. Skirt boards should extend below ground far enough to prevent rodents or other animals from burrowing under the wall.*
39. Remove temporary post bracing and use as wall girts (figure 60).
40. Install siding starting from the downwind end. A temporary 2-by-4 ledger tacked down the distance the siding overlaps the base plank assures proper alignment. Follow manufacturers' application and handling instructions. As with roofing (step 36), use galvanized nails or screws with galvanized steel sheets and aluminum fasteners with aluminum sheets. Use only nails or screws with neoprene sealing washers designed to fasten metal roofing and siding. Place sidewall fasteners *in the valley* of corrugated metal sheets (see figure 15, page 16). Self-drilling screws with flat sealing washers may be power-driven into the flat or valley of the corrugation.
41. Install trim, doors, and other accessories. It is important to install flashing in roof valleys, at roof and wall intersections, or wherever the roof slope changes. The cross-sectional profile of metal sheeting makes it difficult to seal the edges of wall corners and around doors, windows, or other openings. Flashing and trim should be fastened carefully to these areas following manufacturer's recommendations, since wind uplift forces are greater at the corners and edges of a building.

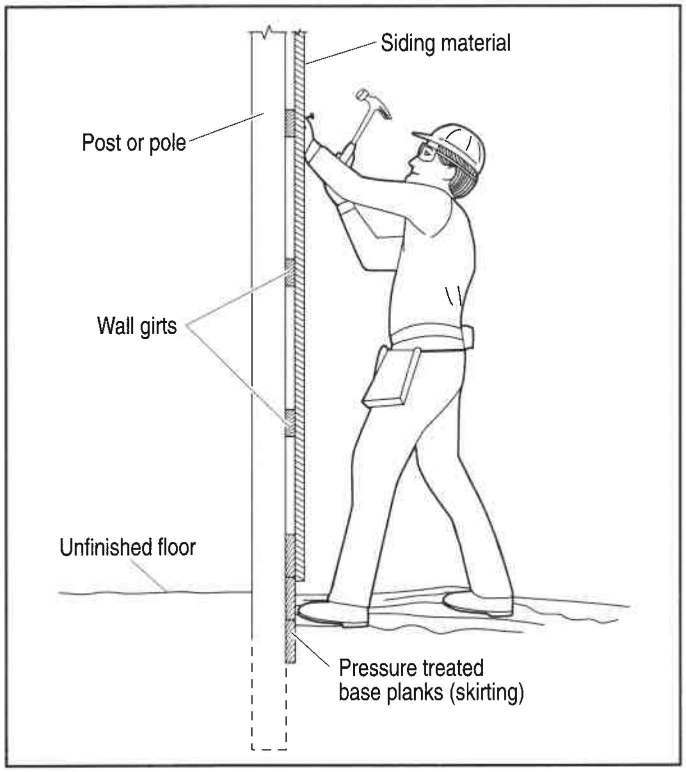


Figure 60. Installation of siding.

42. Install concrete floor and approach apron, if required.
43. Clean all debris from building site and complete final grading and seeding.

Construction Checklist

Appendix C includes a construction checklist (not necessarily all inclusive) that can be used to plan and schedule the various stages of construction in most types of post-frame buildings. Not all items in the checklist will be used in all projects. If desired, itemized computer spreadsheets can be created from this construction checklist to estimate material quantities. The construction checklist can also be used to estimate construction costs. However, a cost estimate will only be as accurate as the numbers used to generate it. *When estimating the cost of any construction project, actual material costs should be used.*

Appendix A

Conversion Factors

Quantity	Application	To convert from	To	Multiply by
Area, A	cross-section area of structural shapes	square inch (in^2)	square foot (ft^2)	6.944 x 10^{-3}
			square millimeter (mm^2)	645.16
			square centimeter (cm^2)	6.452
	roof and floor areas	square foot (ft^2)	square inch (in^2)	144
			square yard (yd^2)	0.1111
			square mile (mi^2)	3.587 x 10^{-8}
			acre	2.296 x 10^{-5}
			square centimeter (cm^2)	929.0
			square meter (m^2)	0.0929
Bending moment, M	beam and column design, materials testing	pound force·foot (lbf·ft)	Newton·meter (N·m)	1.3558
Density	agricultural products, building materials, preservative retention	pounds per cubic foot (lb/ft^3)	kilograms per cubic meter (kg/m^3)	16.0185
	earthwork (soil)	pounds per cubic yard (lb/yd^3)	kilograms per cubic meter (kg/m^3)	0.5933
	liquid	pounds per gallon (lb/gal)	kilograms per liter (kg/L)	0.1198
Force*	structural design analysis	pound force (lbf)	Newton (N)	4.448
		ounce force (ozf)	Newton (N)	0.2780
Force per length	beam loading	pound force per foot (lbf/ft)	Newton per meter (N/m)	14.5939
Length, L	engineering drawings, cross-sectional lumber dimensions	inch (in)	foot (ft)	0.08333
			yard (yd)	0.0278
			millimeter (mm)	25.4
			centimeter (cm)	2.54
	engineering drawings, lumber dimensions, land distances and land leveling	foot (ft)	inch (in)	12
			yard (yd)	0.3333
			mile (mi)	1.894 x 10^{-4}
			meter (m)	0.3048
			kilometer (km)	3.048 x 10^{-4}
Mass	building materials	ounce (oz)	gram (g)	28.3495
	load, structural capacity	pound (lb)	kilogram (kg)	0.4536
	not widely used	slug (32.2 lb)	kilogram (kg)	14.59
Mass per area	floor, roof, and wall loading, fabric and surface coatings	pounds per square foot (lb/ft^2 or psf)	kilograms per square meter (kg/m^2)	4.8824
Mass per length	general, structural members	pounds per foot (lb/ft)	kilograms per meter (kg/m)	1.4882
Modulus of elasticity, E	rigidity in structural members, design values for graded lumber, materials testing	pound force per square inch (lbf/in^2 or psi)	MegaPascal (MPa)	6.895 x 10^{-3}
Moment of inertia, I	design property of structural cross-sections	inch to the fourth power (in^4)	centimeter to the fourth power (cm^4)	41.6231

Notes:

* In the U.S. Customary or English system, engineers define a pound of force as the force required to accelerate one slug of mass (approximately 32.2 pounds) on the earth's surface at the rate one foot per second per second. The mass of any object is independent of gravitational acceleration. The term weight, which may mean either mass or force, should be avoided in engineering applications.

In metric or SI units, engineers define a Newton of force as the force required to accelerate one kilogram of mass at the rate of one meter per second per second. The SI (Système Internationale d' Unités) is an absolute system where mass (kilogram) is a basic unit and force (Newton) is a derived unit. The analogous units in the English system are for mass (slugs) and for force (pound).

Conversion Factors

Quantity	Application	To convert from	To	Multiply by
Power	engine, electrical power	horsepower (hp)	foot·pound per second (ft·lbf/sec)	550
			foot·pound per minute (ft·lbf/min)	9.167
			kiloWatt (kW)	0.7457
Pressure	all pressures except very small	pound force per square inch (lbf/in^2 or psi)	pound force per square foot (lbf/ft^2)	144
			kiloPascal (kPa)	6.8948
			foot of water (ft H_2O)	2.309
		pound force per square foot (lbf/ft^2)	kiloPascal (kPa)	0.0479
Section modulus, S	design property of structural cross-sections	cubic inches (in^3)	cubic centimeters (cm^3)	16.3871
Stress	design values for graded lumber, materials testing	pound force per square inch (lbf/in^2 or psi)	MegaPascal (MPa)	6.895×10^{-3}
Temperature	environmental control, kiln drying	degrees Fahrenheit (°F)	degrees Celsius (Centigrade) (°C)	°C = (°F - 32) ÷ 1.8
Velocity	wind speed	feet per minute (ft/min or fpm)	meters per minute (m/min)	0.3048
		feet per second (ft/s or fps)	meters per second (m/s)	0.3048
		miles per hour (mph)	kilometers per hour (km/h)	1.6093
Volume	agricultural products	bushel (U.S.)	liter (L)	35.2391
	grain bins	bushel (U.S.)	cubic meter (m^3)	0.0352
	lumber, building, general	cubic foot (ft^3)	cubic meter (m^3)	0.0283
	earthwork	cubic yard (yd^3)	cubic meter (m^3)	0.7646
	liquid	gallon (gal)	liter (L)	3.7854
	liquid	ounce (oz)	milliliter (mL)	29.5735
Weight (see Mass)				

Appendix B

Section Properties of Standard Dressed (S4S) Sawn Lumber

Nominal base x nominal depth	Actual base x actual depth	Cross-sectional area	Loaded on X-X axis (Depth X-X, Base)		Loaded on Y-Y axis (Depth Y-Y, Base)	
			Section modulus[1]	Moment of inertia[2]	Section modulus[1]	Moment of inertia[2]
b_n x d_n (in)	b x d (in)	A = b x d (in^2)	$S_{xx} = bd^2/6$ (in^3)	$I_{xx} = bd^3/12$ (in^4)	$S_{yy} = bd^2/6$ (in^3)	$I_{yy} = bd^3/12$ (in^4)
1 x 3	3/4 x 2-1/2	1.875	0.781	0.977	0.234	0.088
1 x 4	3/4 x 3-1/2	2.625	1.531	2.680	0.328	0.123
1 x 6	3/4 x 5-1/2	4.125	3.781	10.40	0.516	0.193
1 x 8	3/4 x 7-1/4	5.438	6.570	23.82	0.680	0.255
1 x 10	3/4 x 9-1/4	6.938	10.70	49.47	0.867	0.325
1 x 12	3/4 x 11-1/4	8.438	15.82	88.99	1.055	0.396
2 x 3	1-1/2 x 2-1/2	3.750	1.563	1.953	0.938	0.703
2 x 4	1-1/2 x 3-1/2	5.250	3.063	5.359	1.313	0.984
2 x 5	1-1/2 x 4-1/2	6.750	5.063	11.39	1.688	1.266
2 x 6	1-1/2 x 5-1/2	8.250	7.563	20.80	2.063	1.547
2 x 8	1-1/2 x 7-1/4	10.88	13.14	47.63	2.719	2.039
2 x 10	1-1/2 x 9-1/4	13.88	21.39	98.93	3.469	2.602
2 x 12	1-1/2 x 11-1/4	16.88	31.64	178.0	4.219	3.164
2 x 14	1-1/2 x 13-1/4	19.88	43.89	290.8	4.969	3.727
3 x 4	2-1/2 x 3-1/2	8.750	5.104	8.932	3.646	4.557
3 x 5	2-1/2 x 4-1/2	11.25	8.438	18.98	4.688	5.859
3 x 6	2-1/2 x 5-1/2	13.75	12.60	34.66	5.729	7.161
3 x 8	2-1/2 x 7-1/4	18.13	21.90	79.39	7.552	9.440
3 x 10	2-1/2 x 9-1/4	23.13	35.65	164.9	9.635	12.04
3 x 12	2-1/2 x 11-1/4	28.13	52.73	296.6	11.72	14.65
3 x 14	2-1/2 x 13-1/4	33.13	73.15	484.6	13.80	17.25
3 x 16	2-1/2 x 15-1/4	38.13	96.90	738.9	15.89	19.86
4 x 4	3-1/2 x 3-1/2	12.25	7.146	12.51	7.146	12.51
4 x 5	3-1/2 x 4-1/2	15.75	11.81	26.58	9.188	16.08
4 x 6	3-1/2 x 5-1/2	19.25	17.65	48.53	11.23	19.65
4 x 8	3-1/2 x 7-1/4	25.38	30.66	111.1	14.80	25.90
4 x 10	3-1/2 x 9-1/4	32.38	49.91	230.8	18.89	33.05
4 x 12	3-1/2 x 11-1/4	39.38	73.83	415.3	22.97	40.20
4 x 14	3-1/2 x 13-1/2	47.25	106.3	717.6	27.56	48.23
4 x 16	3-1/2 x 15-1/2	54.25	140.1	1086.1	31.64	55.38

Adapted from American Forest and Paper Association, *Design Values for Wood Construction, NDS Supplement,* Revised 1991 Edition, page 10.

[1] Section modulus, S, is a mathematical value used to determine the actual bending stress in a cross-sectional member. Section modulus is based on the shape and size of the cross-section, as well as the direction of load.

[2] Moment of inertia, I, is a mathematical value used to determine the actual deflection in a cross-sectional member. Moment of inertia is based on the shape and size of the cross-section, as well as the direction of load.

Section Properties of Standard Dressed (S4S) Sawn Lumber (cont'd)

Nominal base x nominal depth	Actual base x actual depth	Cross-sectional area	Loaded on X-X axis: Depth X–X, Base		Loaded on Y-Y axis: Depth Y–Y, Base	
			Section modulus[1]	Moment of inertia[2]	Section modulus[1]	Moment of inertia[2]
$b_n \times d_n$ (in)	b x d (in)	A = b x d (in^2)	$S_{xx} = bd^2/6$ (in^3)	$I_{xx} = bd^3/12$ (in^4)	$S_{yy} = bd^2/6$ (in^3)	$I_{yy} = bd^3/12$ (in^4)
5 x 5	4-1/2 x 4-1/2	20.25	15.19	34.17	15.19	34.17
6 x 6	5-1/2 x 5-1/2	30.25	27.73	76.26	27.73	76.26
6 x 8	5-1/2 x 7-1/2	41.25	51.56	193.4	37.81	104.0
6 x 10	5-1/2 x 9-1/2	52.25	82.73	393.0	47.90	131.7
6 x 12	5-1/2 x 11-1/2	63.25	121.2	697.1	57.98	159.4
6 x 14	5-1/2 x 13-1/2	74.25	167.1	1128	68.06	187.2
6 x 16	5-1/2 x 15-1/2	85.25	220.2	1707	78.15	214.9
6 x 18	5-1/2 x 17-1/2	96.25	280.7	2456	88.23	242.6
6 x 20	5-1/2 x 19-1/2	107.3	348.6	3398	98.31	270.4
6 x 22	5-1/2 x 21-1/2	118.3	423.7	4555	108.4	298.1
6 x 24	5-1/2 x 23-1/2	129.3	506.2	5948	118.5	325.8
8 x 8	7-1/2 x 7-1/2	56.25	70.31	263.7	70.31	263.7
8 x 10	7-1/2 x 9-1/2	71.25	112.8	535.9	89.06	334.0
8 x 12	7-1/2 x 11-1/2	86.25	165.3	950.5	107.8	404.3
8 x 14	7-1/2 x 13-1/2	101.3	227.8	1538	126.6	474.6
8 x 16	7-1/2 x 15-1/2	116.3	300.3	2327	145.3	544.9
8 x 18	7-1/2 x 17-1/2	131.3	382.8	3350	164.1	615.2
8 x 20	7-1/2 x 19-1/2	146.3	475.3	4634	182.8	685.5
8 x 22	7-1/2 x 21-1/2	161.3	577.8	6211	201.6	755.9
8 x 24	7-1/2 x 23-1/2	176.3	690.3	8111	220.3	826.2
10 x 10	9-1/2 x 9-1/2	90.25	142.9	678.8	142.9	678.8
10 x 12	9-1/2 x 11-1/2	109.3	209.4	1204	173.0	821.7
10 x 14	9-1/2 x 13-1/2	128.3	288.6	1948	203.1	964.5
10 x 16	9-1/2 x 15-1/2	147.3	380.4	2948	233.1	1107
10 x 18	9-1/2 x 17-1/2	166.3	484.9	4243	263.2	1250
10 x 20	9-1/2 x 19-1/2	185.3	602.1	5870	293.3	1393
10 x 22	9-1/2 x 21-1/2	204.3	731.9	7868	323.4	1536
10 x 24	9-1/2 x 23-1/2	223.3	874.4	10270	353.5	1679

Adapted from American Forest and Paper Association, *Design Values for Wood Construction, NDS Supplement*, Revised 1991 Edition, page 10.

[1] Section modulus, S, is a mathematical value used to determine the actual bending stress in a cross-sectional member. Section modulus is based on the shape and size of the cross-section, as well as the direction of load.

[2] Moment of inertia, I, is a mathematical value used to determine the actual deflection in a cross-sectional member. Moment of inertia is based on the shape and size of the cross-section, as well as the direction of load.

Appendix C

Construction Checklist

	Responsible Person	Completion Date		Cost	
		Projected	Actual	Projected	Actual
CONSTRUCTION					
1. Excavation					
2. Drainage					
3. Fill					
4. Grading					
5. Setting posts (foundation)					
6. Retaining walls					
7. Loading docks					
8. Concrete floors					
9. Paving					
10. Framing					
11. Trusses					
12. Roofing					
13. Siding					
14. Windows					
15. Doors					
16. Inlets & vents					
17. Other openings					
18. Finish & trim					
19. Eaves & troughs					
20. Lightning rods					
21. Insulation					
22. Ceilings					
23. Partitions					
24. Interior skin					
25. Finish floors					
UTILITIES					
1. Plumbing					
2. Waste disposal					
3. Wiring					
4. Inspections					
5. Install equipment					
6. Heating					
7. Ventilating					
8. Cooling					
9. Other					
MISCELLANEOUS					
1. Painting					
2. Cleanup					
3. Landscaping					
4. Supervise construction					
5. Check materials					
6. Check time					
7. Approve changes					
8. Final acceptance					

TOTAL

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Before ordering, contact NRAES (Natural Resource, Agriculture, and Engineering Service) for current prices and shipping and handling charges. See contact information on inside back cover.

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150 pages • 2005 • This publication provides livestock/poultry housing designers, greenhouse designers, and extension engineers unbiased performance data for over 200 commercially available ventilation fans. Fans range in size from 8 to 54 inches in diameter and are grouped according to size, so readers can easily compare models and manufacturers.

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Farm Shop Plans Book

31 pages • MWPS–26 • 1994 • This book contains useful information for planning a farm shop. Topics addressed include site choice, layout, construction, environment and utilities, and accident prevention. Fourteen full-page construction plans show designs for different size shops. Tables reflect the 1991 National Design Specification design codes.

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Phone: (607) 255-7654
Fax: (607) 254-8770
E-mail: NRAES@CORNELL.EDU
Web site: WWW.NRAES.ORG

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