11 Wood Construction

11-1 INTRODUCTION

Wood is one of humankind's oldest construction materials. Today it is still widely used to construct residential, commercial, and industrial buildings, as well as such varied structures as piers, bridges, retaining walls, and power transmission towers. In the United States, for example, 90% of all houses are constructed of wood. In this chapter, we will consider the properties of wood that influence its use in construction, together with the principles and practices of both frame and timber construction.

11-2 WOOD MATERIALS AND PROPERTIES

Types

Wood is divided into two major classes, hardwood and softwood, according to its origin. *Hardwood* is produced from deciduous (leaf-shedding) trees. *Softwood* comes from conifers (trees having needlelike or scalelike leaves), which are primarily evergreens. The terms "hardwood" and "softwood" indicate only the wood species and may be misleading, because some softwoods are actually harder than some hardwoods. In the United States, lumber is grouped into several grading types, which have similar properties. Most of the lumber used in the United States for structural purposes is softwood.

Moisture Content

The moisture content of lumber (which is defined as the weight of moisture in the wood divided by the oven-dry weight of the wood and then expressed as a percentage) has a great influence on its strength properties. At moisture contents above 30%, wood is essentially in its natural state, and no changes in size or strength properties occur. At moisture contents below 30%, wood shrinks and its strength properties increase. For example, the bending strength of common softwood at moisture contents below 19% is approximately 2½ times its bending strength at moisture contents above 30%. Warping of lumber often occurs as it shrinks.

Structural Wood

Lumber is any wood that is cut into a size and shape suitable for use as a building material. *Timber* is broadly classified as lumber having a smallest dimension of at least 5 in. (12.7 cm). Structural lumber is further divided into *board, dimension, beam and stringer,* and *post and timber* classifications. The board classification applies to lumber less than 2 in. (5 cm) thick and at least 2 in. (5 cm) wide. Dimension applies to lumber at least 2 in. (5 cm) but less than 5 in. (12.7 cm) thick and 2 in. (5 cm) or more wide. The beam and stringer classification applies to lumber at least 5 in. (12.7 cm) thick and 8 in. (20 cm) wide, graded for its strength in bending with the load applied to the narrow face (thickness). The post and beam classification applies to lumber that is approximately square in cross section, at least 5 in. (12.7 cm) in thickness and width, and intended for use where bending strength is not important. Lumber may be either rough or dressed. *Rough lumber* has been sawn on all four sides but not surfaced (planed smooth or dressed). *Dressed lumber* has been surfaced on one or more sides. Possible classifications include surfaced one side (S1S), surfaced two sides (S2S), surfaced one edge (S1E), surfaced two edges (S2E), and combinations of sides and edges (S1S1E, S1S2E, and S4S).

Structural lumber is usually available in lengths from 10 ft (3 m) to 20 ft (6 m) in 2-ft (0.6-m) increments. Studs are available in 8-ft (2.4-m) lengths. Longer lengths may be available on special order. Section dimensions and properties for common sizes of dimension lumber are given in Table 13–7. Warping can be minimized by shaping lumber after it has been dried to within a few percent of the moisture content at which it will be used. Grading rules define *green lumber* as having a moisture content greater than 19%, *dry lumber* as having a moisture content of 19% or less, and *kiln-dried lumber* as having a moisture content of 15% or less.

Strength

In the United States, lumber grading rules are set by a national Grading Rule Committee established by the U.S. Department of Commerce. The allowable stresses for dimensioned lumber are determined by the wood species, moisture content, and grade. Allowable stresses for common species are set forth in reference 8. Allowable stresses should be adjusted for duration of load and wet conditions as explained in the notes to that table. Some typical values of allowable stress are shown in Table 13–8 of this text.

Wood Preservation

Wood is subject to damage by decay and by wood-boring insects. Mechanical shields of solid metal or stainless steel mesh may be used to reduce exposure to insect damage. However, wood preservation by chemical treatment is the principal method used today to provide protection against decay and insect damage. Surface treatment of wood has largely been replaced by pressure treatment, which forces the preservatives deep into wood cells. The principal wood preservatives now used include creosote, pentachlorophenol, copper azole (CA), alkaline copper quaternary (ACQ), and sodium borates (SBX). Creosote is often used to protect railroad ties and utility poles, whereas poles and posts are often treated with pentachlorophenol. Alkaline copper quaternary, copper azole, and sodium borates are now the principal preservatives used for the framing components of residential and commercial buildings. These preservatives leave a paintable, nonstaining surface. However, borates should be used only for above-ground applications that are continuously protected from liquid water. Chromated copper arsenate (CCA) treatment was formerly widely used but is now being replaced by CA, ACQ, and SBX because of concerns over possible harmful health effects of CCA. Cuts and borings on treated wood made at the job site should be field-treated with copper napthanate having a minimum of 2% metallic solution in accordance with American Wood Preservers' Association (AWPA) Standard M4.

Fire-Retardant Treated Wood

Wood impregnated under pressure with a fire-retardant chemical is classified as fire-retardant-treated wood (FRTW). After treatment, the fire retardant chemical remains in the wood indefinitely. When the wood temperature reaches that of a fire, a chemical reaction occurs. In this reaction, the fire-retardant chemical reacts with the combustible gases and tars normally generated by a wood fire and converts them to carbon char, carbon dioxide, and water. The use of fire-retardant wood often reduces the cost of wood structures due to reduced fire insurance rates. The use of FRTW wood may also eliminate the need for fire sprinklers in concealed spaces of wood structures, thus further reducing construction costs. The FRTW treatment also provides additional termite and decay resistance to the wood.

Glued Laminated Timber

Glulam, glued laminated timber (Figure 11–1), is composed of layers of wood 2 in. (5 cm) or less in thickness which are glued together to form a solid structural member. Glued laminated timber has several advantages over sawn timber. It provides a way to manufacture wood structural members of great size, curved as well as straight. Since the individual wood pieces used for lamination are rather thin, they can be readily dried to a moisture content that produces a dimensionally stable member of high strength. The strength of a glued laminated timber member can be closely controlled by placing high-strength lumber in areas of high stress and lower-strength lumber in areas of lower stress. This practice reduces the cost of the structural member. The production of glued laminated timber under carefully controlled conditions results in precisely dimensioned structural members of high strength at a minimum cost.

Glued laminated members are widely used in large buildings such as churches, auditoriums, shopping centers, and sports arenas, as well as in industrial plants. The radial arch structure shown in Figure 11–2 has a clear span of 240 ft (73 m). Other structural applications range from bridge beams to power transmission towers. Reference 1 provides data on standard sizes and allowable stresses for glued laminated timber.

Plywood

Plywood is a wood structural material formed by gluing three or more thin layers of wood (veneers) together with the grain of alternate layers running perpendicular to each other.

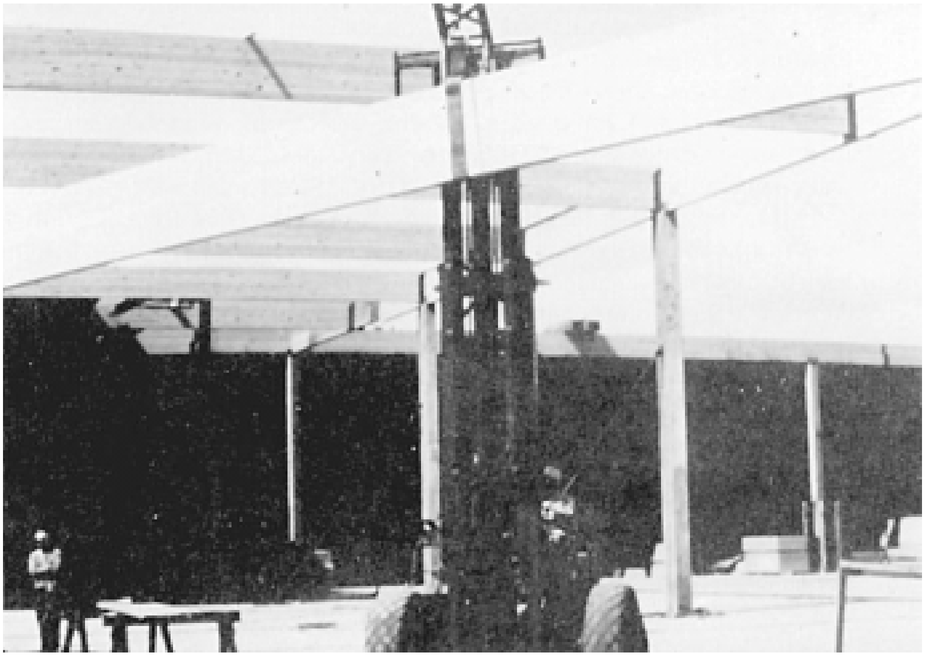


Figure 11–1 Glued laminated timber beam. (Courtesy of American Institute of Timber Construction)

This process results in a material having a high strength/weight ratio which can be produced in a wide range of strength and appearance grades. Grading rules established by APA—The Engineered Wood Association divide wood veneers into groups 1 through 5, based on strength and stiffness, with group 1 having the highest strength characteristics. In addition to the basic Exterior and Interior type classification, Engineered Grades and an Identification Index indicating the maximum allowable span of the member under standard loads are incorporated in the grading rules. Exterior-type plywood is manufactured with waterproof glue and higher-grade veneers than those used for Interior-type plywood.

Surface appearance grades of N, A, B, C, and D are available, with grade N being of the highest appearance quality. Plyform, a grade of plywood intended for use in concrete formwork, can be manufactured in two grades, class I and class II. Class II is most readily available. High-Density Overlay (HDO) and Medium-Density Overlay (MDO) plywoods have an abrasion resistant resin-fiber overlay on one or both faces. Plywood with rough-sawn, grooved, or other special faces is available for siding and other uses where appearance is a major consideration. The usual size of plywood sheets in the United States is 4 ft by 8 ft (1.2 m by 2.4 m). Thicknesses of ⅜ in. (1.0 cm) to 1⅛ in. (2.9 cm) are available. Plywood is available with tongue-and-groove edges for use in floor construction. Plywood design specifications are given in reference 11. Plywood applications and construction guidelines are described in reference 3.

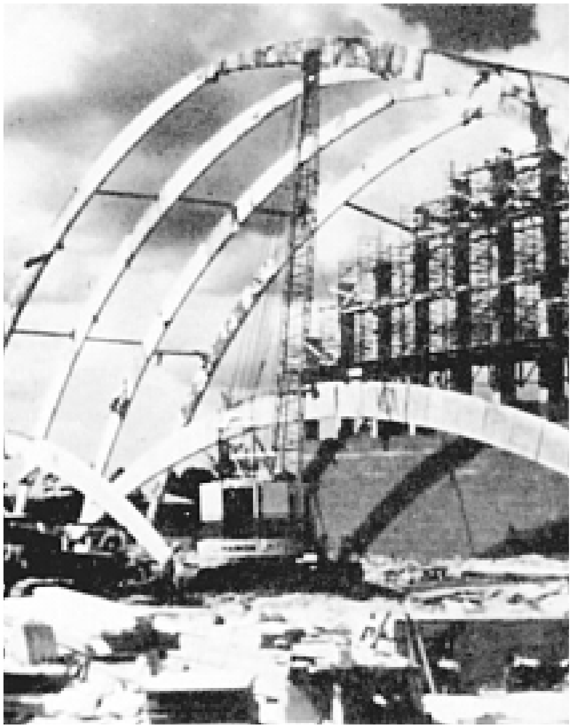


Figure 11–2 Erecting large glued laminated timber arches. (Courtesy of American Institute of Timber Construction)

Other Wood Products

Faced with a declining supply of large old growth timber, the U.S. forest products industry has developed a number of wood products to replace conventional lumber. These products combine selected portions of lower quality wood with adhesives to produce a higher quality wood product. Such products are often referred to as *Engineered Wood.* In addition to plywood and glued laminated timber, these products include laminated veneer lumber (LVL), I-joists, parallel strand lumber (PSL), laminated strand lumber (LSL), particleboard, waferboard, and oriented strand board.

Laminated veneer lumber is similar to plywood but consists of thin veneer about 1⁄16 to 1⁄10 in.(1.6 to 2.5 mm) thick with all plies and grains parallel to the length. It is produced in billets as large as 2 ft (610 mm) wide, 80 ft (24 m) long, and up to 4 in. (100 mm) thick. Billets are then cut to form lumber of the desired width and length.

I-joists or *wood I-beams* consist of plywood or oriented strand board webs bonded to sawn wood or laminated veneer lumber flanges. They are lighter but stronger than conventional sawn joists or beams. They can be manufactured in lengths exceeding 60 ft (18.3 m).

Parallel strand lumber (PSL) is produced by cutting logs into long strands, drying them, and treating them with a resin adhesive. The strands are then aligned parallel to each other, microwave heated, and pressed into solid billets. The process uses virtually the entire tree so there is little wood waste in the process.

Laminated strand lumber is produced by a process similar to that used for parallel strand lumber but uses wood strands about 12 in. (305 mm) long. After being treated with adhesive, the strands are pressed together using a steam-injection pressing process.

Particleboard is produced in sheets by bonding wood chips together with resin. The usual panel size is 4 ft × 8 ft (1.2 m × 2.4 m). Usual thicknesses are ¼ in. to 1½ in. (6 to 38 mm).

Waferboard is similar to particleboard except that it is manufactured from larger wood chips.

Oriented strand board is built up in layers like plywood. However, each layer consists of wood strands bonded together by a resin.

11–3 FRAME CONSTRUCTION

Frame construction utilizes studs [typically spaced 16 or 24 in. (0.4 or 0.6 m) on center], joists, and rafters to form the building frame. Framing members are usually of 2 in. (5 cm) nominal thickness. This frame is then covered with siding and roof sheathing of plywood or lumber. Frame construction is widely used in the United States for single-family residences, as well as for small multiple-family residences, offices, and shops. Building codes frequently specify procedures or minimum dimensions to be used in frame construction. The procedures described in this section are those widely recommended in the absence of specific code requirements. The two principal forms of frame construction, platform frame construction and balloon frame construction, are described next.

Platform Frame Construction

Platform frame construction is illustrated in Figure 11–3. In this type of construction, the subfloor of each story extends to the outside of the building and provides a platform for the construction of the building walls. This method of framing is widely used because it provides a good working platform at each level during construction and also permits preassembled wall sections to be quickly set in place once the subfloor is completed.

The principal framing members are identified in Figure 11–3. In this example, the first floor joists are supported by sills (placed on top of foundation walls) and ledger strips attached to the girder. Wall panels are composed of sole plates (or soles), studs, and top plates. Double top plates are used for bearing walls (walls that support a load from an upper level).

Balloon Frame Construction

In *balloon frame construction,* exterior wall studs extend all the way from the sill to the top of the second floor wall, as shown in Figure 11–4. The outside ends of second-floor joists

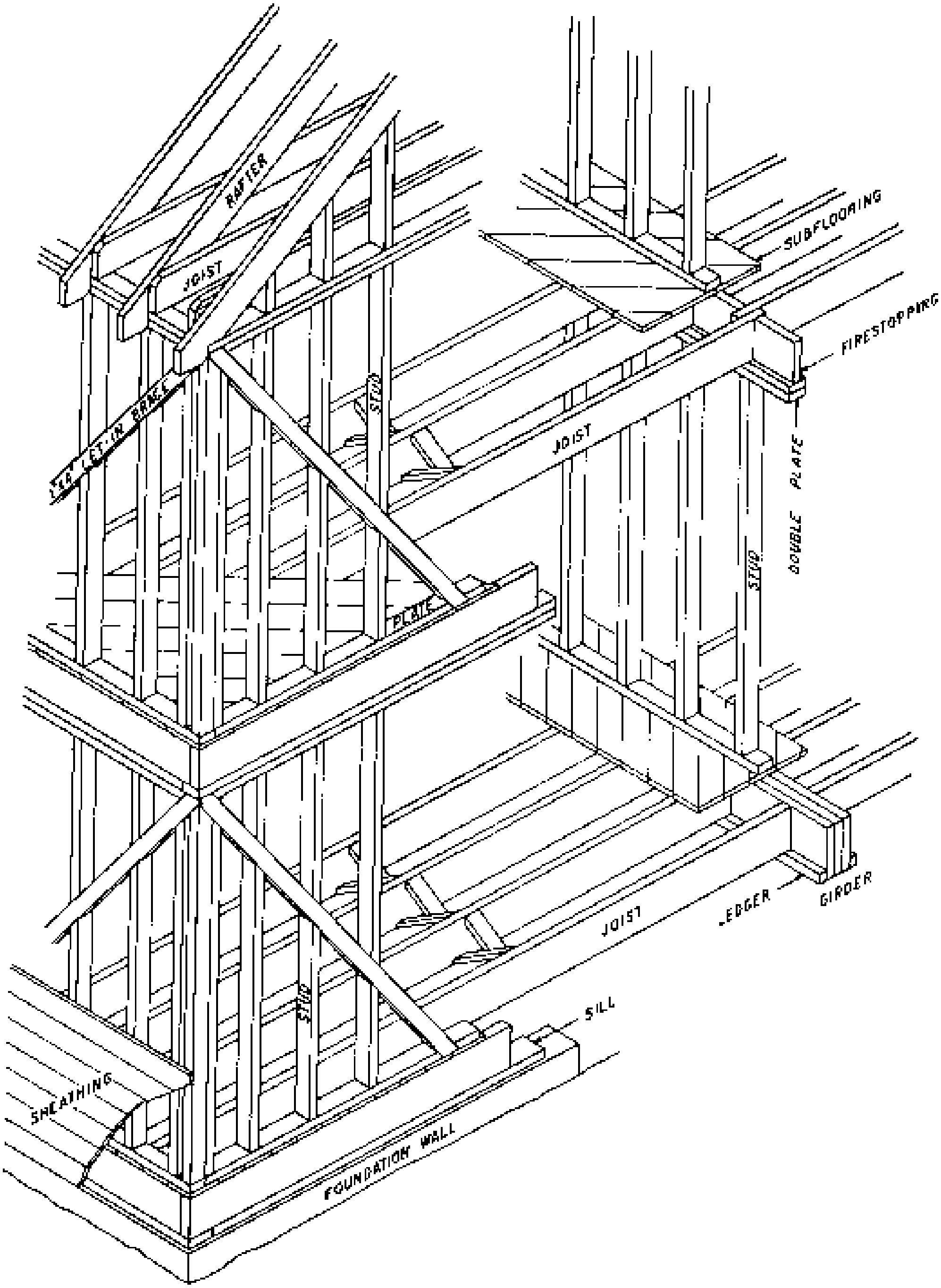


Figure 11–3 Platform frame construction. (Courtesy of American Forest and Paper Association)

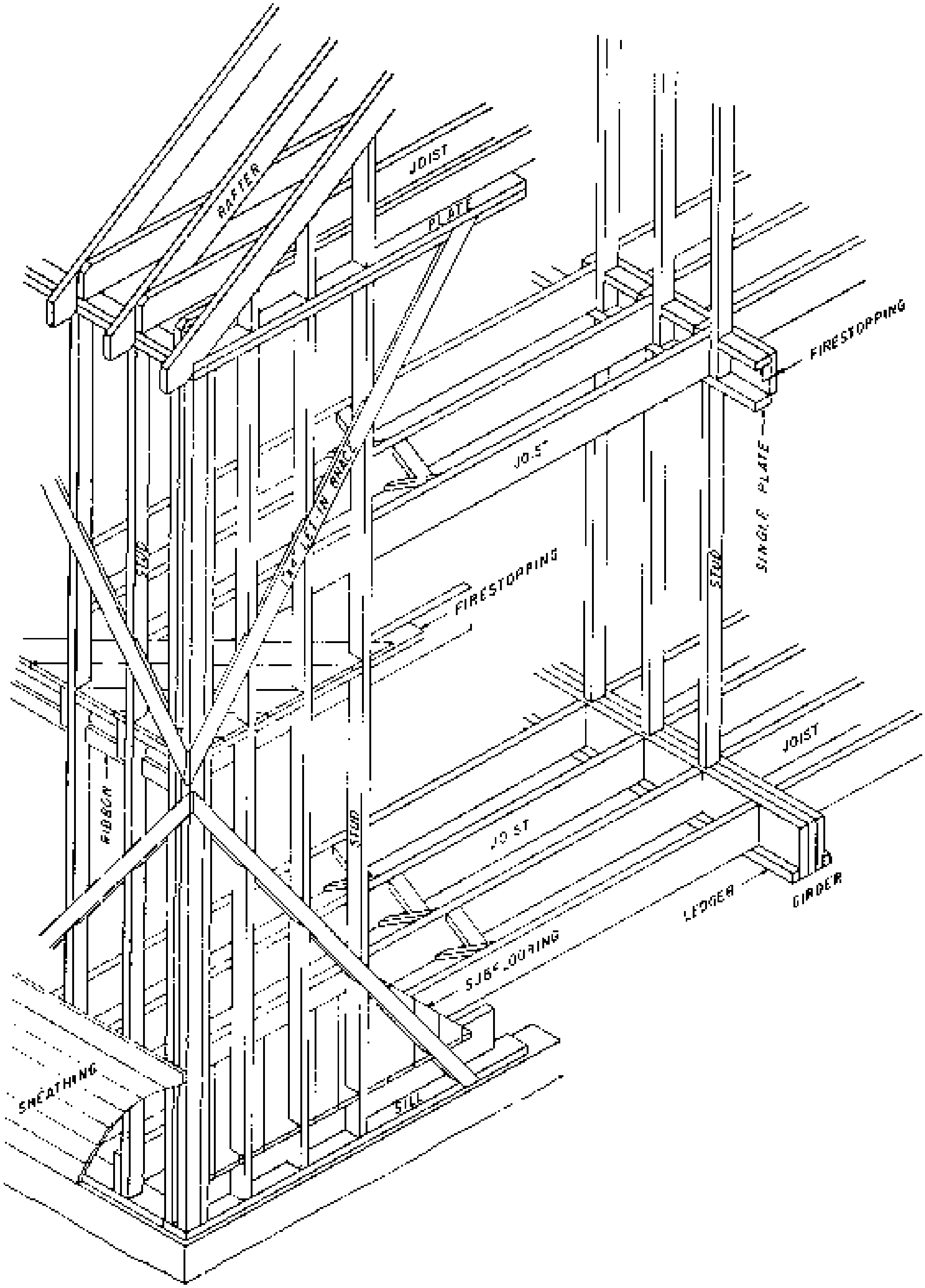


Figure 11–4 Balloon frame construction. (Courtesy of American Forest and Paper Association)

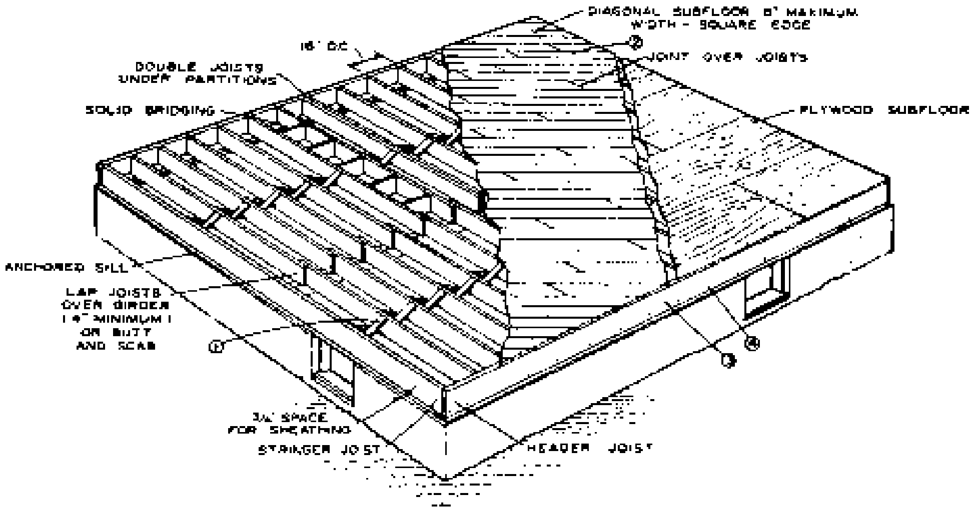


Figure 11–5 Floor framing for platform frame construction. (U.S. Department of Agriculture)

are supported by ribbon strips notched (or let-in) into the studs. Balloon framing is especially well suited for use in two-story buildings that have exterior walls covered with masonry veneer, since this method of framing reduces the possibility of movement between the building frame and the exterior veneer.

Foundation and Floor Construction

Platform frame construction supported by foundation walls is illustrated in Figure 11–5. In this illustration the floor joists are lapped and rest on top of the girder rather than on the ledger strip used in Figure 11–3. Notice also the use of a header joist (or band) to close off the exterior end of joists. Lateral bracing (bridging or cross bracing) between joists may be either solid bridging or diagonal bridging as shown. Board or plywood subflooring may be used as shown in Figure 11–5. Notice that board subflooring should be placed at an angle of 45° to the joists to provide additional stiffness to the floor structure and to permit the finish flooring to be laid either parallel or perpendicular to the joists. When carpeting or other nonstructural flooring is used, subflooring may be eliminated by using a combined subfloor-underlayment of plywood. The APA Glued Floor System, in which plywood is glued to the joists, has been developed by APA—The Engineered Wood Association to reduce subfloor cost and to increase the stiffness of the floor system.

Floor (flat) trusses and wood I-beams (Figure 11–6) are increasingly being used for floor support in place of floor joists due to their light weight and high load capacity. Although solid timber or glulam beams may be used to replace joists, built-up wood I-beams are more often used due to their lighter weight. Wood I-beams commonly use nominal 2 × 2 in. (50 × 50 mm), 2 × 3 in. (50 × 75 mm), or 2 × 4 in. (50 × 100 mm) top and bottom

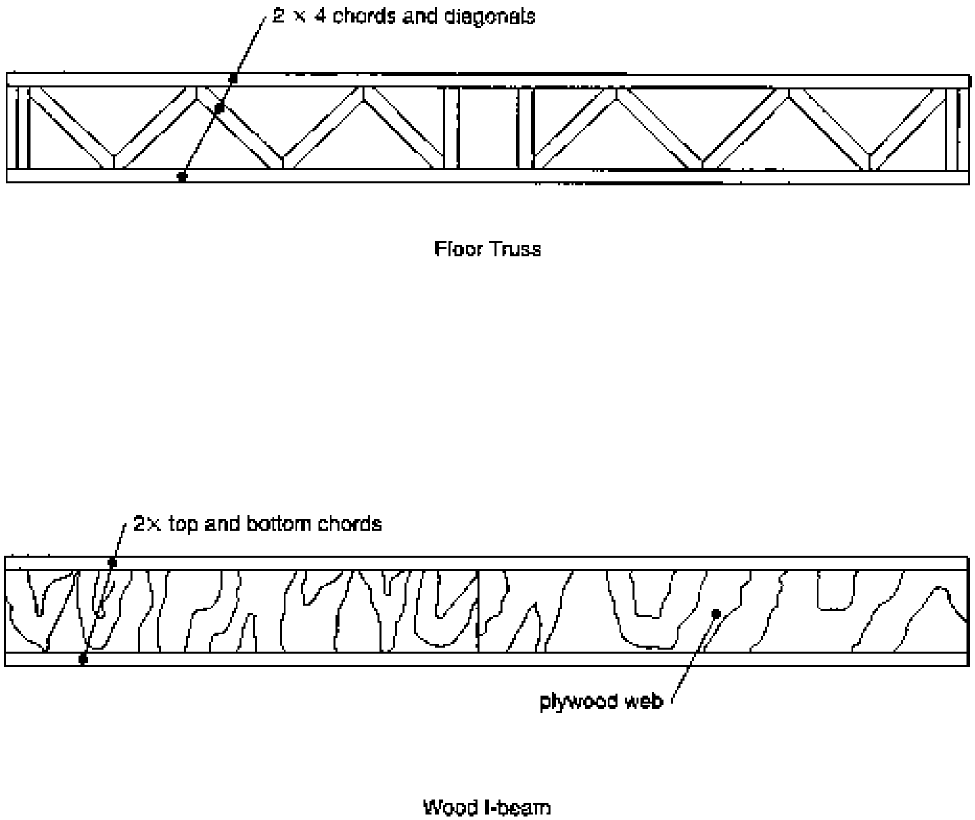


Figure 11–6 Floor truss and wood I-beam.

flanges with ⅜ in. (9.5-mm) plywood webs. The characteristics of floor trusses are similar to those of other trusses described later in this section. Floor trusses commonly use nominal 2 × 4 in. (50 × 100 mm) chords and webs to produce a truss 3½ in. (89 mm) wide. The openings between truss webs facilitate the installation of utility lines and ducts.

Most safety precautions applying to the erection of floor trusses are similar to those described later for roof trusses. However, as floors supported by floor trusses provide a convenient surface for storage of materials during construction, the following additional precautions should be observed. *Never stack materials on unbraced trusses.* Even after trusses have been braced and decked, be careful to stack materials against or directly over load-bearing walls and distribute the load over as many trusses as possible. See reference 4 for additional information.

Figure 11–7 illustrates slab-on-grade construction using a separate foundation wall. Notice the use of rigid insulation on the interior face of the foundation wall and under the edge of the floor slab to provide a thermal barrier. Figure 11–8 illustrates slab-on-grade construction using a foundation beam poured integrally with the floor slab. Such construction is

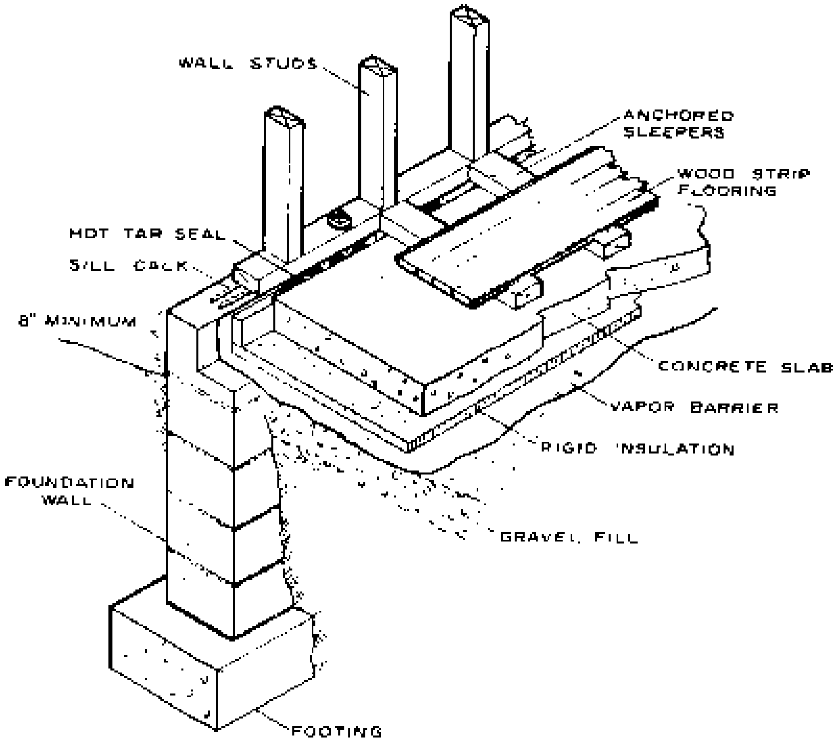


Figure 11–7 Slab on grade with foundation wall. (U.S. Department of Agriculture)

also referred to as *thickened-edge slab construction.* Finish flooring of wood, carpeting, vinyl, or other material may be applied directly to the top of the slab or it may be supported on *sleepers,* as illustrated in Figure 11–7. Notice the use of a vapor barrier to prevent ground moisture from rising through the slab.

Framing Details

Two methods of supporting joists are illustrated in Figures 11–3 and 11–5. A minimum bearing length of 1½ in.(38 mm) along the joist should be provided when joists rest on wood or metal beams. The bearing length should be increased to 3 in. (76 mm) for bearing on masonry. Framing anchors or joist hangers may be used in place of a ledger strip to support joists, as shown in Figure 11–9.

The use of both solid and diagonal bridging to provide lateral bracing of joists is illustrated in Figure 11–5. Prefabricated metal diagonal bridging with integral fastening devices is also available for standard joist spacings. Bridging between joists is not required when the Glued Floor System is used.

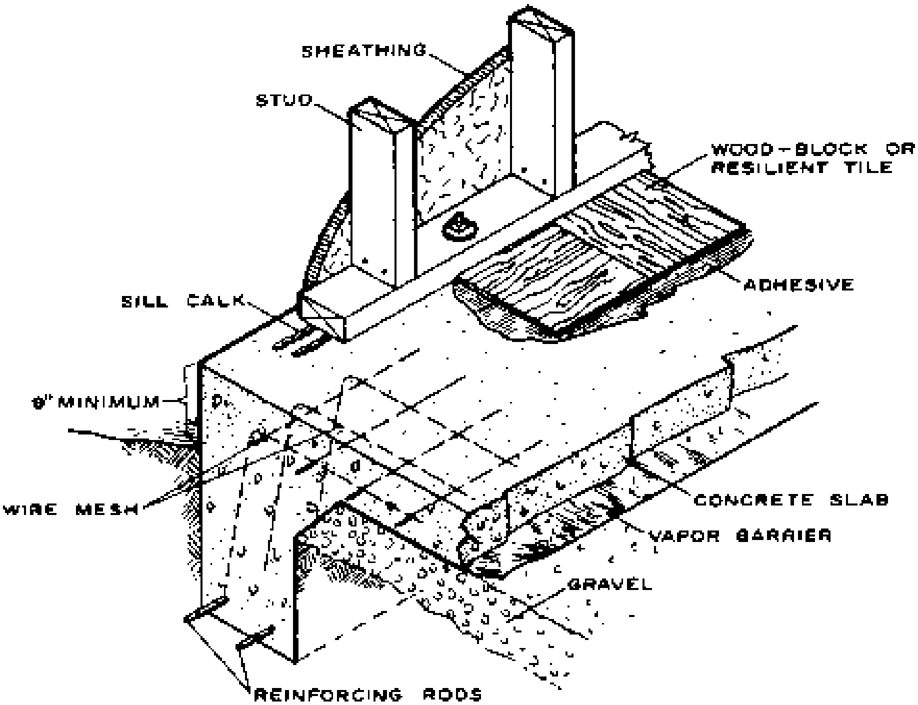


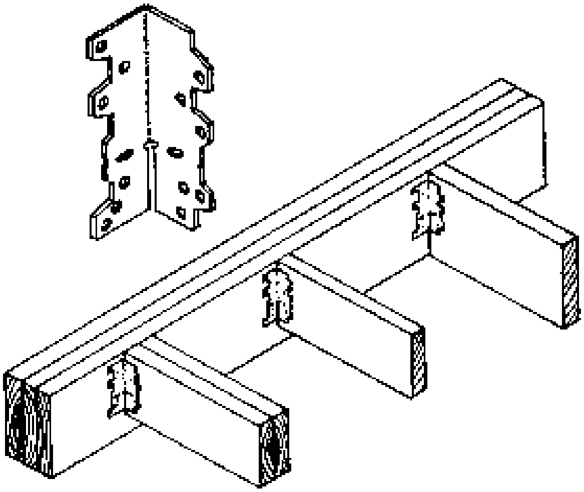
Figure 11–8 Combined slab and foundation. (U.S. Department of Agriculture)

Typical platform frame construction of an exterior wall including a window opening is illustrated in Figure 11–10. The load on the top of the window opening is carried by a *header,* which is in turn supported by double studs at the sides of the opening. Note the use of *let-in braces* (braces notched into the studs) to reinforce the wall at building corners. Plywood panels may be used as sheathing at building corners to replace corner braces. Corner braces are not required when full plywood wall sheathing is used.

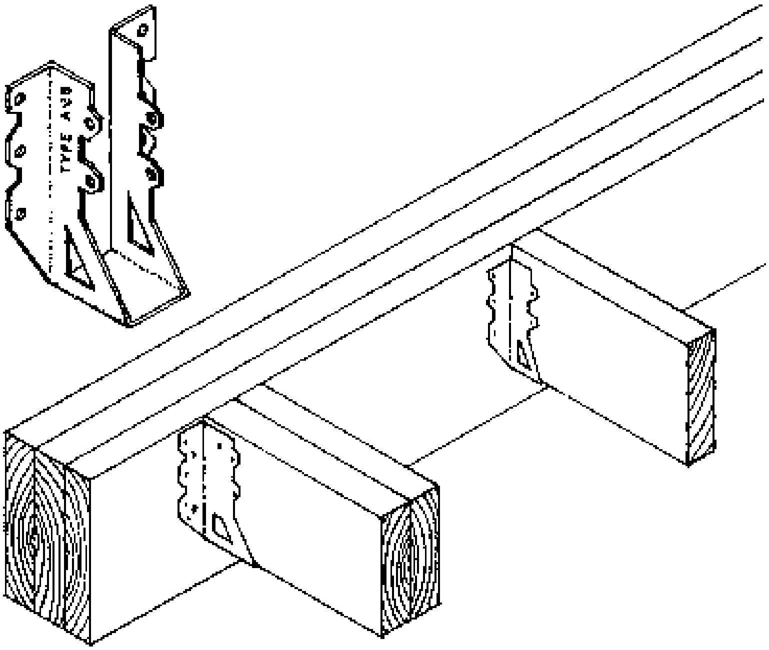
Roof Construction

One method of roof construction, called *joist and rafter framing,* is illustrated in Figure 11–11. Rafters are notched where they rest on wall plates and are held in place by nailing them to the wall plates or by the use of metal framing anchors. The *collar beam* shown is used to assist in resisting wind loads on the roof.

Roof trusses are now widely used in wood frame construction in place of rafter framing. The use of roof trusses permits interior walls to be nonbearing because all roof loads are supported by the exterior walls. Additional advantages of prefabricated roof trusses over rafters include high strength, economy, controlled quality, less skilled labor required on-site, and an open web design which facilitates installation of plumbing, electrical, and HVAC systems. Components of common roof trusses are illustrated in Figure 11–12. While



All purpose framing anchors.



Joist hangers.

Figure 11–9 Joists supported by joist hangers and framing anchors. (Courtesy of TECO, Washington, DC 20015)

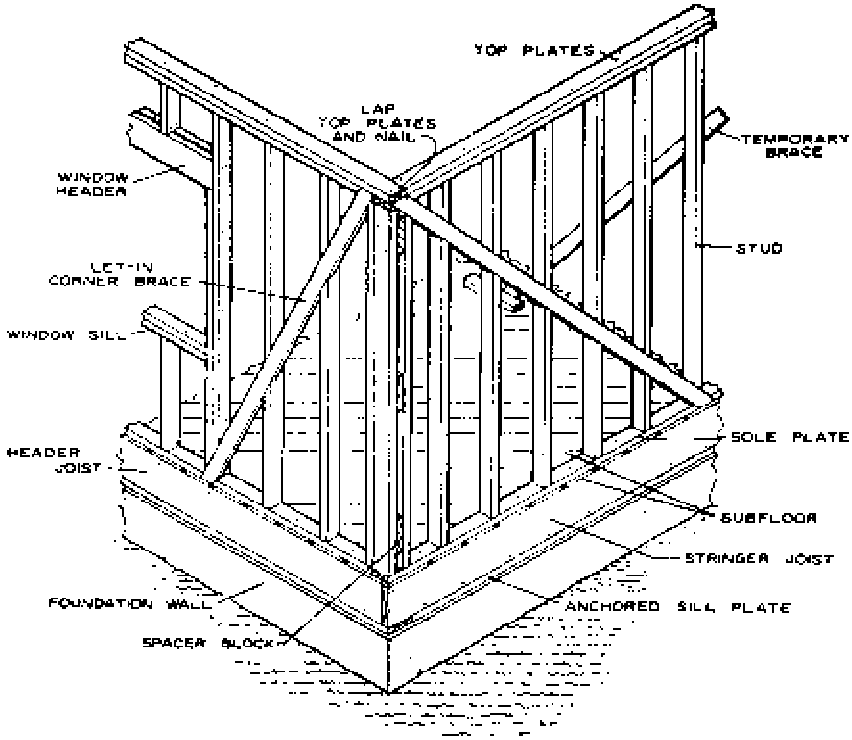


Figure 11–10 Exterior wall framing, platform construction. (U.S. Department of Agriculture)

there are many types of trusses, some of the more common types of roof trusses are illustrated in Figure 11–13.

Roof sheathing normally consists of plywood or nominal 1-in. (25-mm) boards applied perpendicular to the rafters or trusses. Roofing is applied over the roof sheathing to provide a watertight enclosure.

Handling and Erecting Roof Trusses

Care must be taken to avoid damage to trusses while transporting, storing, or erecting them. They are particularly vulnerable to damage by excessive lateral bending which can damage joints and truss members. Since trusses are commonly delivered to the erection site in bundles, they should be left bundled until needed. When stored horizontally, trusses should be placed on blocking placed at intervals of not more than 10 ft (3.1 m) on a level surface and covered if possible to minimize weather damage. When trusses are stored vertically, truss bundles should be braced to prevent overturning, which could result in truss damage or injury to workers.

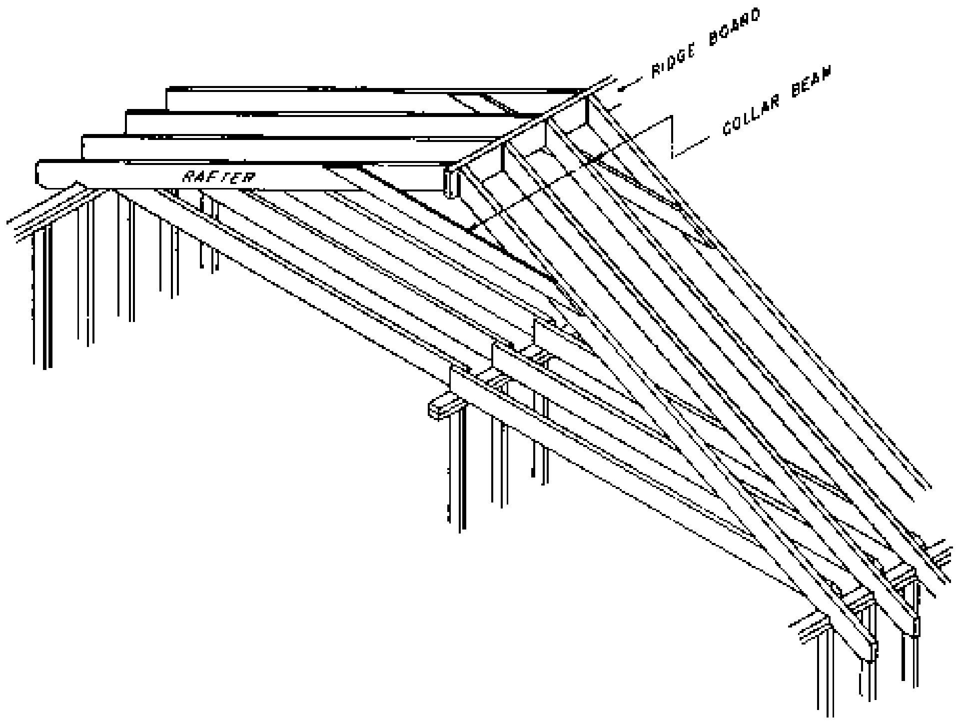


Figure 11–11 Roof framed with rafters and ceiling joists. (Courtesy of American Forest and Paper Association)

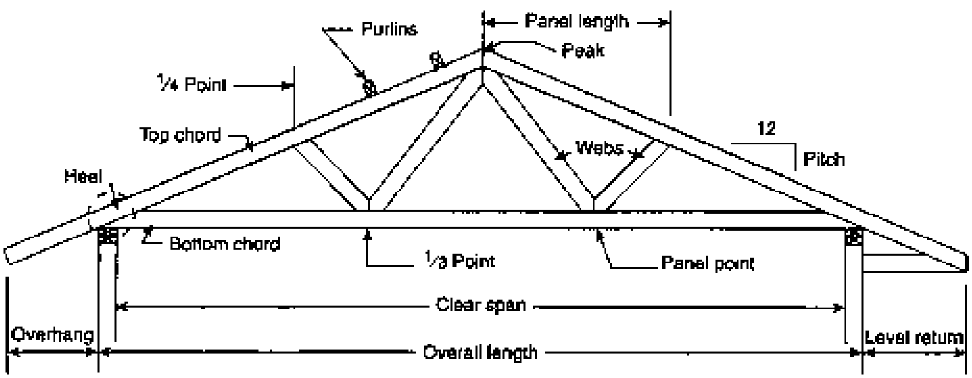


Figure 11–12 Truss components. (Courtesy of Alpine Engineered Products, Inc.)

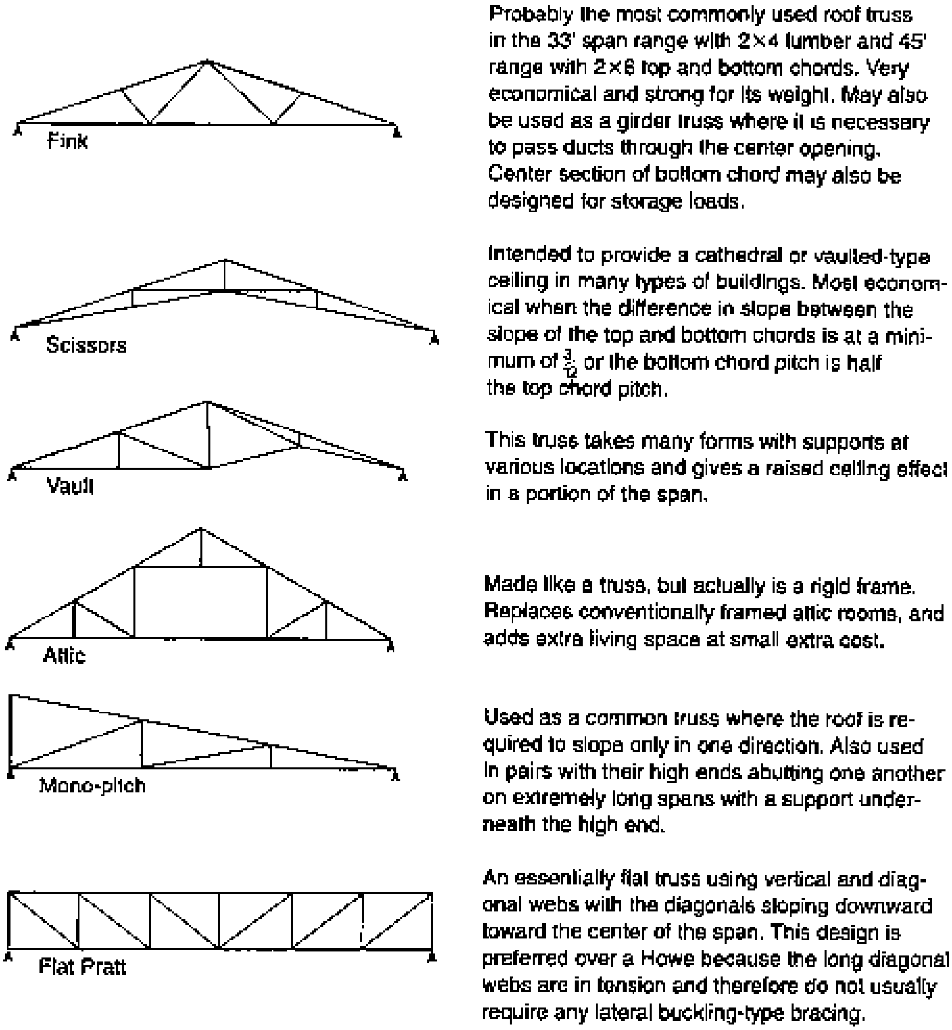


Figure 11–13 Common types of roof truss. (Courtesy of Alpine Engineered Products, Inc.)

Short trusses (under 40 ft or 12 m) can usually be erected satisfactorily by hand. A recommended procedure for erecting trusses manually is to lift them into place in a peak down position, rotate them into place with the peak up, and fasten them into place. The amount of lifting required can be minimized by installing a board ramp from the ground to the top of the wall and shoving the truss up the ramp. Longer trusses should be lifted into place using a crane or forklift together with appropriate slings or spreader bars. Suggested procedures for lifting a truss with a crane are illustrated in Figure 11–14. Do not use a plain

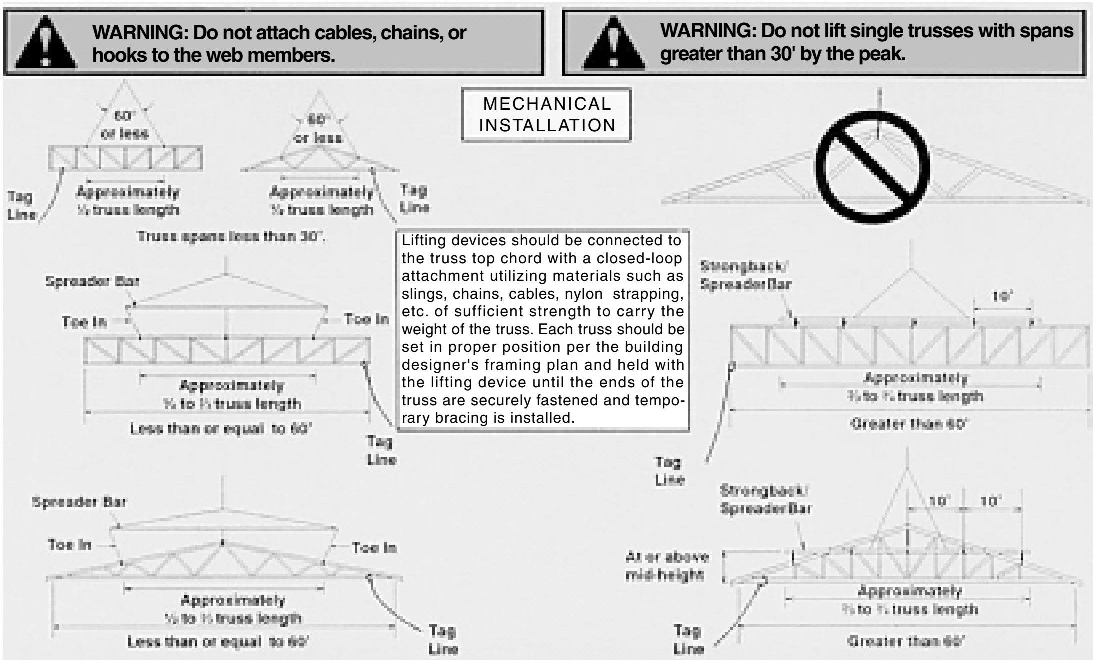
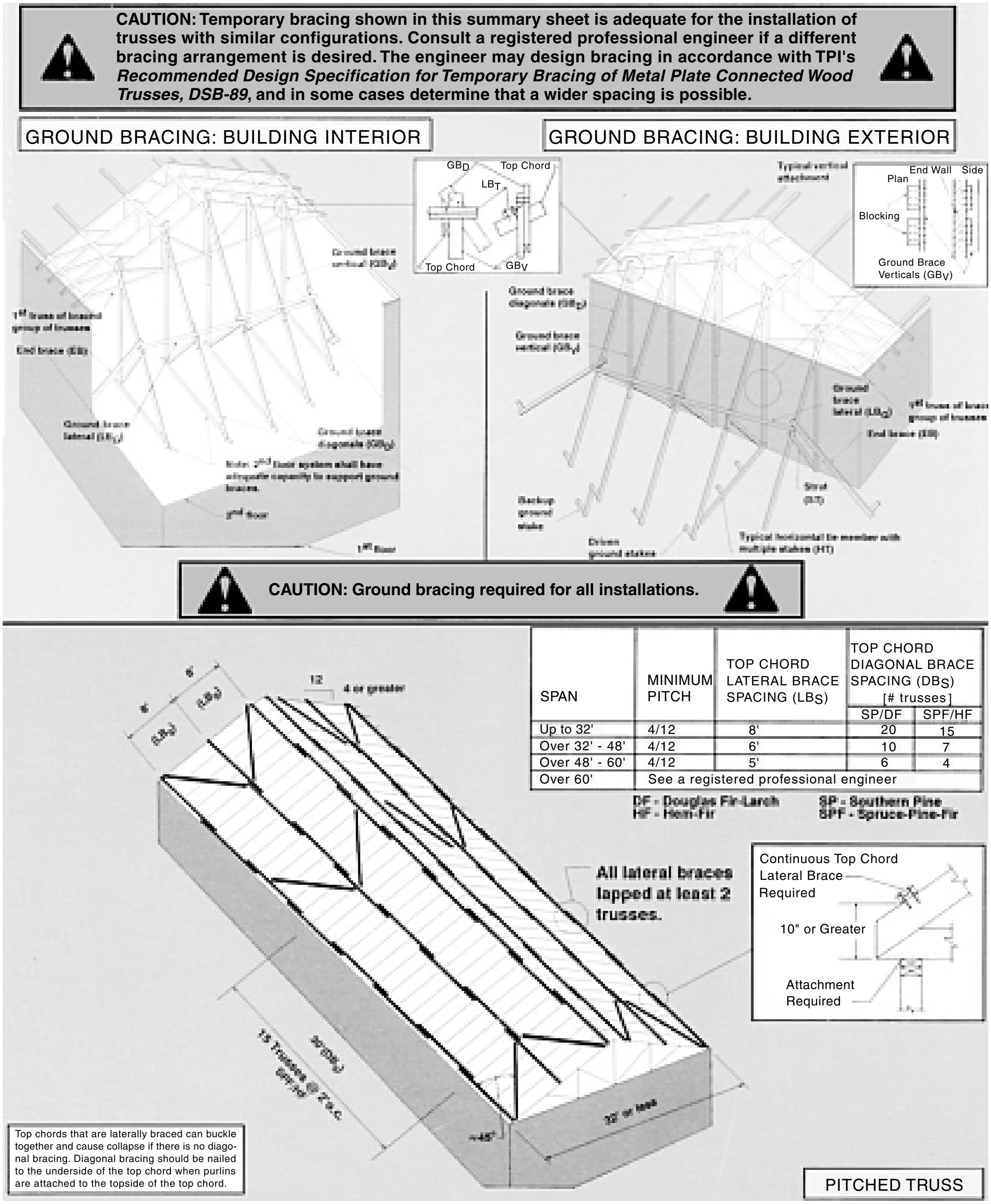


Figure 11–14 Lifting trusses by crane. (Reproduced from HIB-91, courtesy of Truss Plate Institute, Inc.)

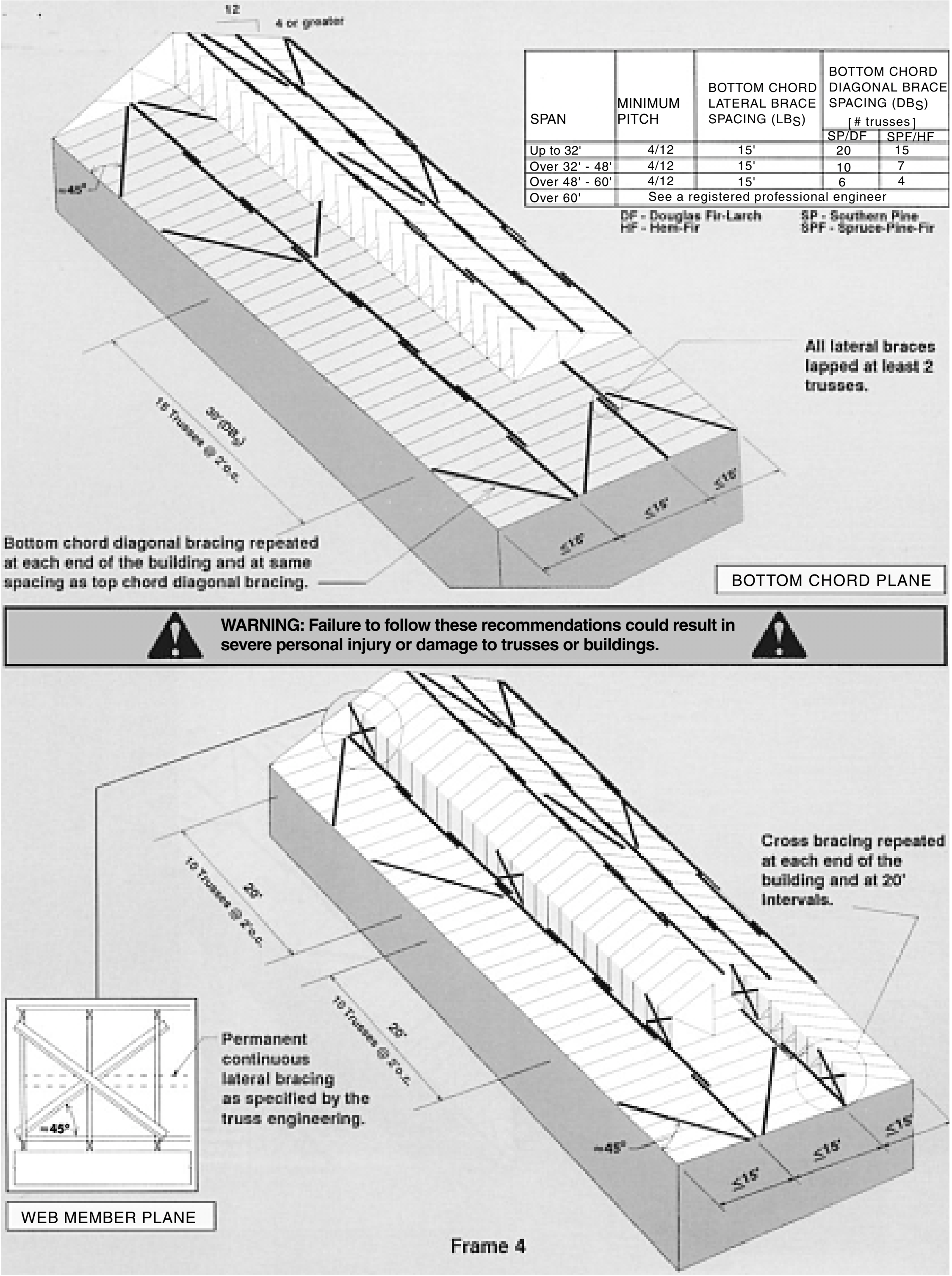
hook (illustrated in Figure 3–31) hooked directly onto the top chord of the truss. Such a procedure applies a twist to the truss which may damage the truss. In addition, the hook may slide laterally and any slack in the lifting line will release the hook. The crane operator should swing loads slowly and smoothly and avoid jerks when starting or stopping. A tag line should always be used when lifting a truss by crane. This will help control the swing and guide the truss into place while reducing the chance of injury to workers. Reference 4 provides additional guidance on handling and erecting wood trusses.

Proper lateral bracing of trusses during erection is critical to safety and the structural integrity of the roof. Although the truss designer will specify the permanent bracing required, the builder must provide temporary bracing until the permanent bracing is installed. Proper bracing of the first end truss is particularly important to obtain the correct alignment of the truss system. After bracing the end truss, the remaining trusses must be braced in the following three planes: top chord (sheathing) plane, web (vertical) plane, and bottom chord (ceiling) plane. Some suggestions for the proper bracing of trusses are provided in Figure 11–15 and reference 4. A suggested checklist for truss installation is shown in Figure 11–16. Common truss installation errors identified by the Wood Truss Council of America are shown in Figure 11–17.



SPAN	MINIMUM PITCH	TOP CHORD LATERAL BRACE SPACING (LBS)	TOP CHORD DIAGONAL BRACE SPACING (DBS) [# trusses]	
			SP/DF	SPF/HF
Up to 32'	4/12	8'	20	15
Over 32' - 48'	4/12	6'	10	7
Over 48' - 60'	4/12	5'	6	4
Over 60'	See a registered professional engineer			

Figure 11–15 Bracing roof trusses. (Reproduced from HIB-91, courtesy of Truss Plate Institute.)



SPAN	MINIMUM PITCH	BOTTOM CHORD LATERAL BRACE SPACING (LB_S)	BOTTOM CHORD DIAGONAL BRACE SPACING (DB_S) [# trusses] SP/DF	SPF/HF
Up to 32'	4/12	15'	20	15
Over 32' - 48'	4/12	15'	10	7
Over 48' - 60'	4/12	15'	6	4
Over 60'	See a registered professional engineer			

DF - Douglas Fir-Larch
HF - Hem-Fir
SP - Southern Pine
SPF - Spruce-Pine-Fir

Figure 11–15 (continued)

BE SURE TO BRING COPY OF TRUSS DESIGN DRAWINGS FOR READY REFERENCE

		OK	REJECT
A.	**JOBSITE STORAGE (if applicable)**		
1.	Are trusses protected against foul weather?	☐	○
2	Truss bundles intact?	☐	○
3.	Trusses supported out of mud, dirt and standing water?	☐	○
B.	**BRACING & ERECTION**		
1.	Truss handling techniques proper? (See HET-80)	☐	○
2.	Adequate temporary bracing installed during erection? (See BWT-76)	☐	○
3.	Are loads being applied to trusses prematurely?	☐	○
4.	Is permanent bracing installed as shown on Architect or Engineer's framing plan?	☐	○
C.	**CONFIGURATION**		
	Does truss match design drawing?	☐	○
		☐	○
		☐	○
		☐	○
		☐	○
	If sealed drawings are required has seal been affixed?	☐	○
D.	**SOURCE**		
	Is truss manufacturer same as supplier of design drawings?	☐	○
	Where code requires approved third party quality control inspection, does inspector's stamp appear on trusses?	☐	○

		GRADE OK	GRADE REJECT	SIZE OK	SIZE REJECT
E.	**LUMBER SIZES & GRADES**				
	Do they match or better design drawing requirements in:				
1.	Top chord?	☐	○	☐	○
2.	Bottom chord?	☐	○	☐	○
3.	Web members?	☐	○	☐	○
4.	Special webs (if required)?	☐	○	☐	○

		OK	REJECT
F.	**TRUSS CONNECTORS**		
1.	Is connector plate manufacturer the same as specified on drawing?	☐	○
2.	Is connector plate size and gauge as specified on all joints?	☐	○
3.	Are any joints missing plates?	☐	○
4.	Plate position on joint and slotted hole direction in accordance with design?	☐	○
G.	**INSTALLATION**		
1.	Cantilevered trusses positioned in correct direction?	☐	○
2.	Interior bearing trusses properly positioned?	☐	○
3	Flat trusses right-side up?	☐	○
4.	Are all the end walls straight enough to ensure safe and proper bearing?	☐	○
5.	Have any of the wall dimensions (thickness of walls) or placement of walls changed to something other than the dimensions called for on the drawing?	☐	○
6.	Are trusses being properly nailed to bearing plates, or are the correct type of hangers and fastenings called out in shop drawings being properly applied?	☐	○
7.	Are any holes being drilled into the webs or chords?	☐	○
8.	Verify location and details of extra trusses required (if any) to handle concentrated loads, stair headers, etc.	☐	○
9.	Is truss camber oriented in correct direction (see truss drawings)?	☐	○
10.	Is on-center spacing correct?	☐	○
H.	**MISHANDLING & ALTERATION**		
1.	Damage due to mishandling?	☐	○
2.	Connector plates buckled?	☐	○
3	Missing or broken members?	☐	○
4.	Cut, notched, or altered members?	☐	○

Wood Truss Jobsite Inspection Check List is only a guide and cannot cover all points and conditions. All points and conditions should comply with sound engineering judgment and construction procedures.

Figure 11–16 Checklist for truss installation. (Courtesy of Alpine Engineered Products, Inc.)

Common Installation Errors

1. Cantilever trusses installed backward.
2. Parallel chord trusses installed upside down.
3. Trusses, designed for interior bearing walls, installed backward.
4. Large concentrated loads that do not land on panel points.
5. Girder trusses not fastened together.
6. Girder trusses incorrectly fastened together. (Truss ply-to-ply connections are specified in the truss design drawing.)
7. Use of incorrect girder hangers.
8. Common trusses incorrectly fastened to truss girders. (Truss-to-truss connections are specified in the truss design drawing.)
9. Trusses installed in the wrong location.
10. Gable end trusses installed without continuous bottom chord support or web member bracing.
11. Un-braced and unsheathed truss top chords beneath over framing.
12. Conventionally framed hip ends of the building supported on common trusses not designed for hip framing. This condition requires a girder truss or special truss design for the specific load condition.
13. Trusses spaced wider than the design specifications.
14. Using two standard floor trusses at locations that required specially designed floor truss girders.
15. Cutting of trusses at the roof fireplace opening instead of installing the fireplace girder trusses designed for such openings.
16. Trusses with web members or chords drilled for the use of lag screws to support sprinkler loads that have not been included in the design of the truss.
17. Trusses with webs removed by plumbers and mechanical trades.
18. Trusses repaired without following the truss repair drawings provided by the truss designer.
19. Truss chord or web members drilled or notched for the passage of electrical wires, plumbing lines and/or mechanical duct work.

Figure 11–17 Common truss installation errors. (Information provided courtesy of the Wood Truss Council of America (WTCA). This information is from WTCA's *Metal Plate Connected Wood Truss Handbook,* 3rd ed., 2002. For more information, contact WTCA at 608/274-4849 or visit www.woodtruss.com.)

Truss Damage and Repair

Banded trusses shipped from the truss fabrication plant make up a rigid assembly which is not easily damaged. However, damage may occur when the assembly is struck by a fork-lift or when carelessly unloaded. More often, damage occurs when unbanded trusses are handled carelessly during repositioning, erection, or installation. Trusses may also be damaged when they roll over or "domino" by falling against each other during erection before being properly braced. Any damaged truss should be inspected by an engineer to determine repair needed. Dominoed trusses should not be repaired because hairline cracks which are difficult to detect often occur. Web and chord members should never be drilled or notched without approval of the truss design engineer. Truss web members should never be removed.

Siding

Exterior frame walls are most often covered with wood or plywood siding or a masonry veneer applied over sheathing. Sheathing may consist of nominal-1-in. (2.5-cm) boards placed diagonally, plywood, or nonstructural sheathing. Sheathing may be omitted when plywood siding is applied in accordance with the recommendations of APA—The Engineered Wood Association. Such construction is referred to as *single-wall construction.* To make a watertight enclosure, joints in the siding of single-wall construction must be caulked, lapped, battened, or backed with building paper.

Brick veneer siding over plywood sheathing is shown in Figure 11–18. Note that building paper is not required over plywood sheathing when an air space and weep holes are provided. However, building paper should be used over wood sheathing. A stucco exterior wall finish over plywood sheathing is illustrated in Figure 11–19.

Typical types of wood siding are shown in Figure 11–20. Note the nailing methods used. Plywood siding over sheathing is shown in Figure 11–21.

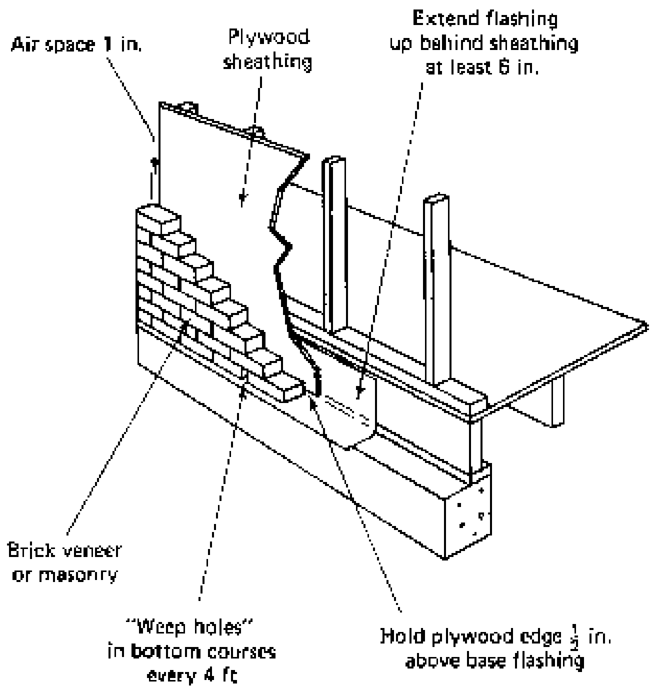
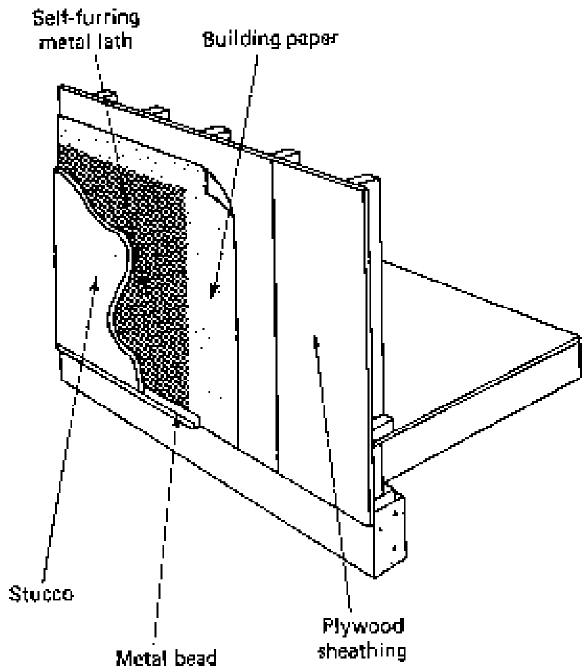


Figure 11–18 Brick veneer wall. (Courtesy of APA—The Engineered Wood Association)

Figure 11–19 Stucco over sheathing. (Courtesy of APA—The Engineered Wood Association)



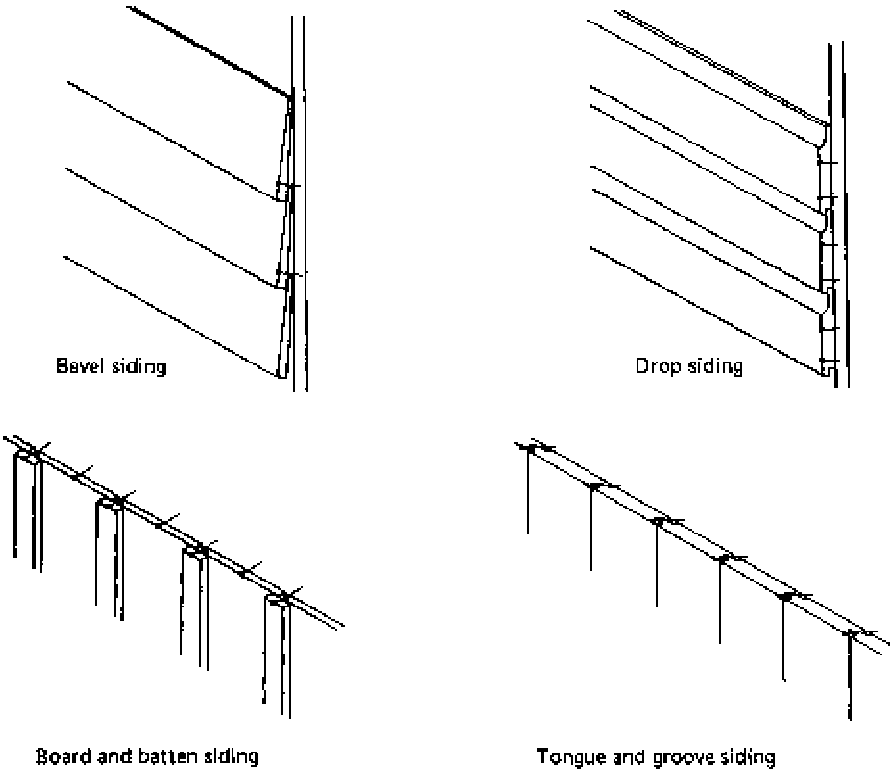


Figure 11–20 Common types of wood siding. (Courtesy of American Forest and Paper Association)

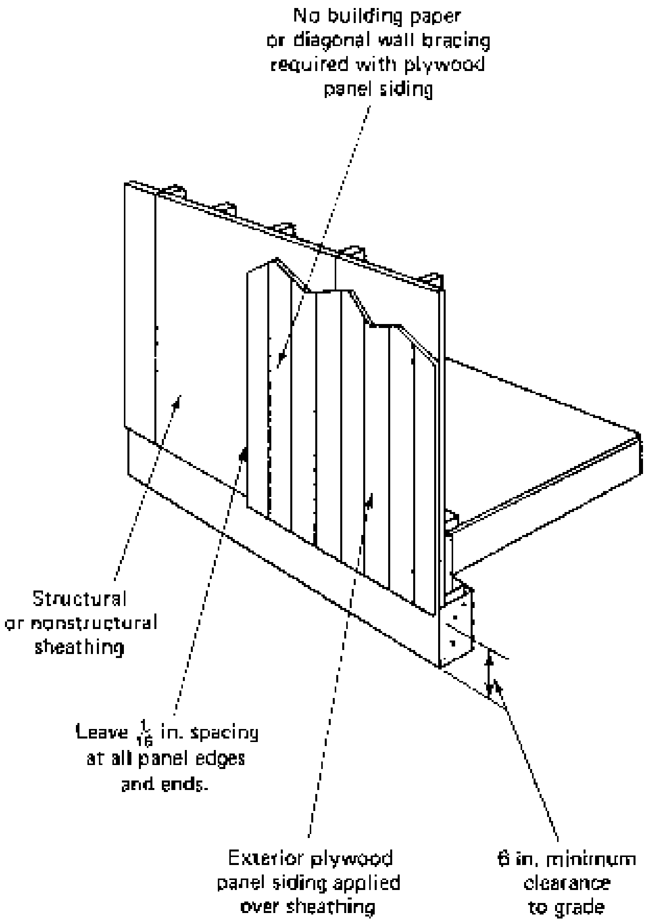


Figure 11–21 Plywood siding over sheathing. (Courtesy of APA—The Engineered Wood Association)

Plank-and-Beam Construction

Plank-and-beam construction (or post-and-beam construction) is a method of framing in which flooring and roof planks (usually nominal-2-in. lumber) are supported by posts and beams spaced up to 8 ft apart. This is essentially a lighter version of the heavy timber construction described in Section 11–4. Plank-and-beam framing is contrasted with conventional framing in Figure 11–22. In plank-and-beam construction, supplementary framing (not shown) is provided in exterior walls to support siding, doors, and windows.

Several advantages are claimed for this method of framing, the principal one being the reduction in framing labor cost due to the smaller number of framing members required. The system also produces a distinctive architectural effect that many people find attractive. Some construction details for plank-and-beam framing of a one-story residence are shown in Figure 11–23.

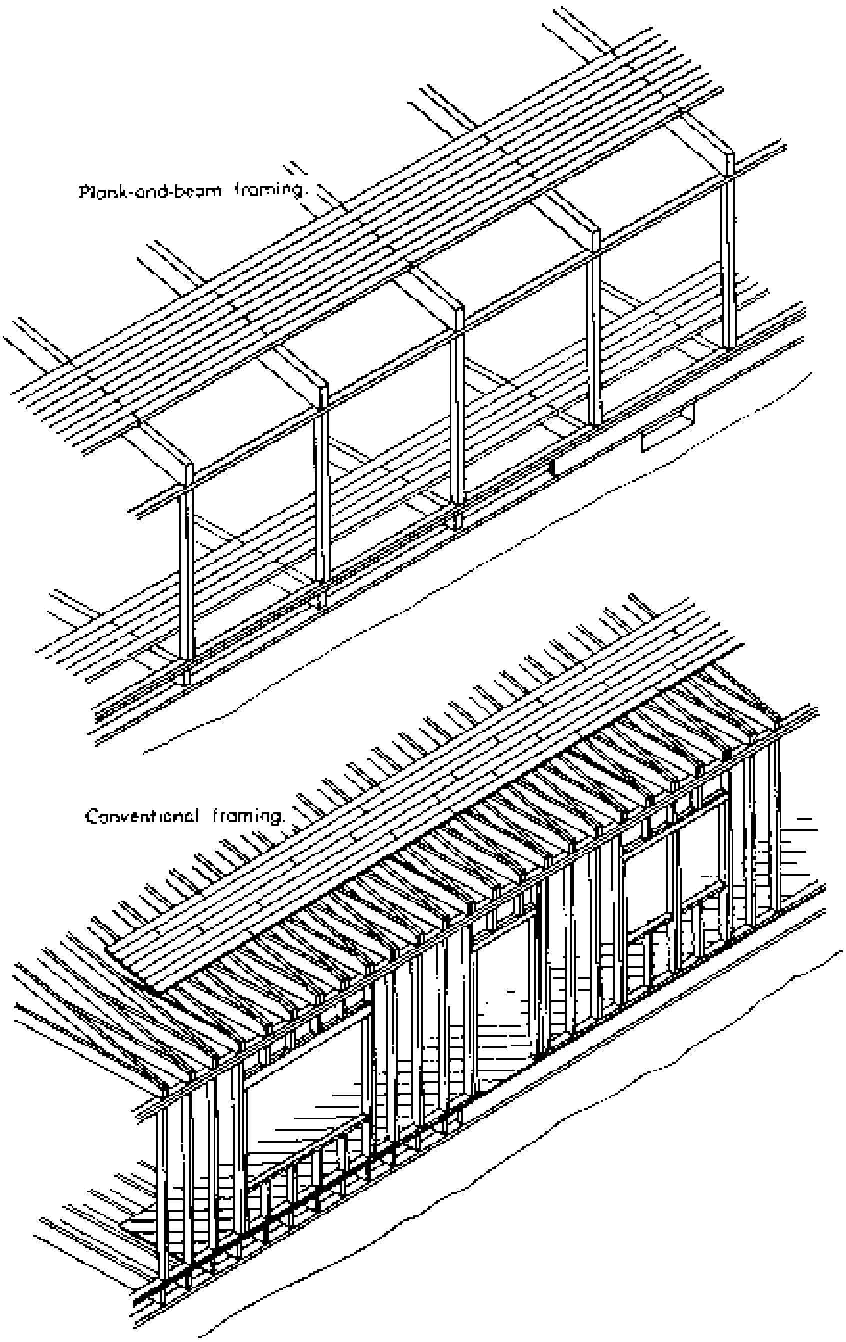


Figure 11–22 Comparison of plank-and-beam and conventional framing. (Courtesy of American Forest and Paper Association)

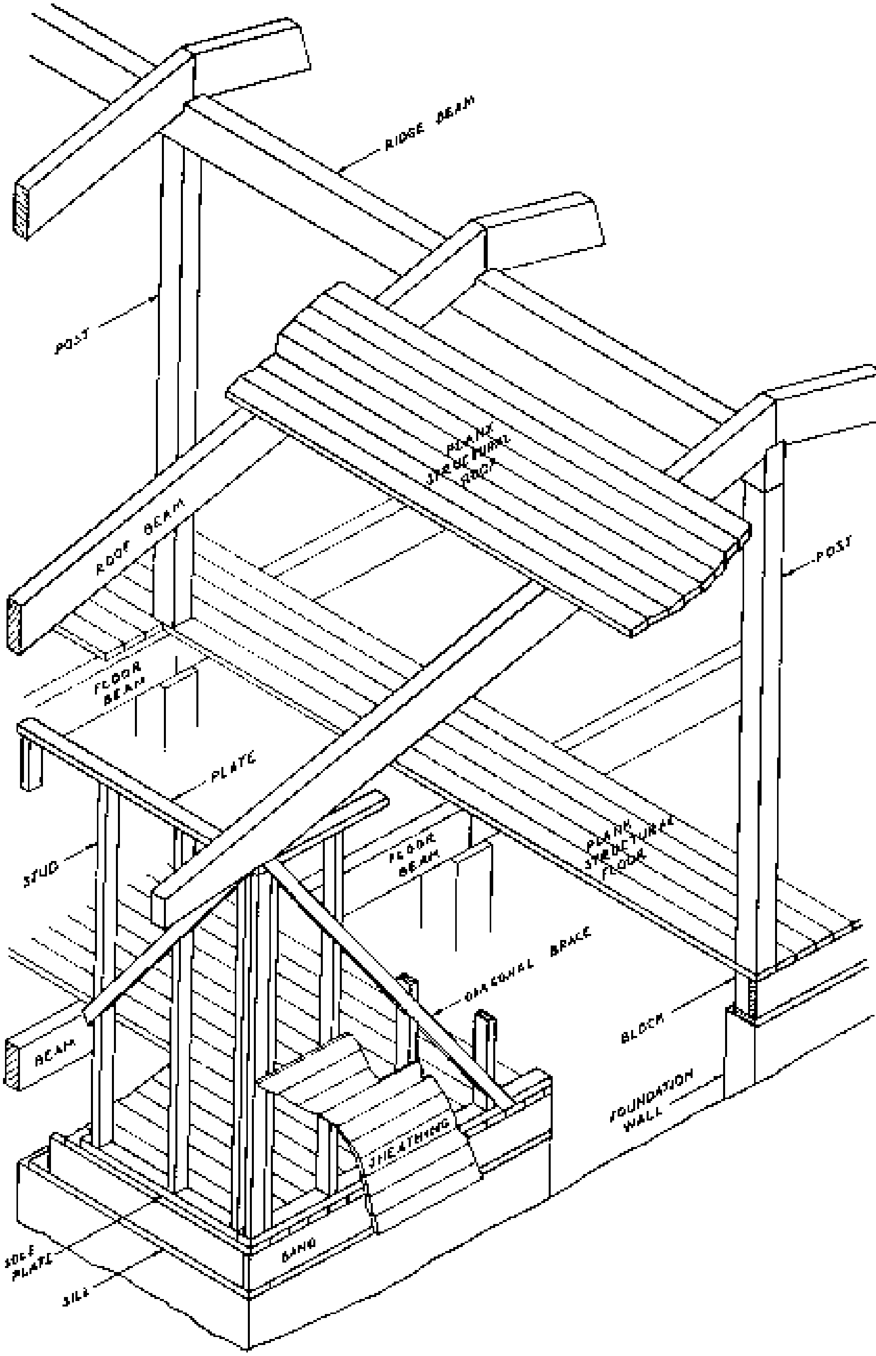


Figure 11–23 Plank-and-beam framing for one-story house. (Courtesy of American Forest and Paper Association)

11–4 TIMBER CONSTRUCTION

Buildings

The term *heavy timber construction* originally identified a multistory structure whose structural members (except for exterior walls) were primarily composed of timber. Such structures were widely used for industrial and storage purposes. Today heavy timber construction indicates the type of wood building construction that carries the highest fire-resistance classification. Such high fire resistance is obtained by specifying construction details, the minimum sizes of wood structural members, the composition and minimum thickness of floors and roofs, the types of fasteners and adhesives used, and the fire resistance of walls, as well as by prohibiting concealed spaces under floors and roofs.

Both glued laminated and sawn timber are used in modern heavy timber construction. Modern structures are often only one story in height. Such construction is widely used for schools, churches, auditoriums, sports arenas, and stores, as well as for industrial and storage buildings.

A typical multistory building of traditional heavy timber construction is illustrated in Figure 11–24. Some construction details recommended by the National Forest Products Association for roof beam and column connections are shown in Figure 11–25. Such details are typical of the practices that are specified to attain the high fire resistance of heavy timber construction. Some typical varieties of modern heavy timber buildings are illustrated in Figures 11–26 to 11–28. Figure 11–26 shows a rigid arch structure using glued laminated timber arches that are supported at ground level. A barrel arch roof using curved glued laminated timber arches supported by exterior piers is depicted in Figure 11–27. A bowstring roof truss supported by wood columns is used in the building of Figure 11–28. The knee brace shown in Figure 11–28 may be eliminated when plywood roof sheathing is used and the building's perimeter frame is designed to carry lateral loads.

Bridges

Timber bridges have been used throughout recorded history to span streams and valleys. Major types of timber bridge structures include trestle bridges, truss bridges, and arch bridges. *Trestle bridges* consist of stringers whose ends are supported by timber or pile bents, as illustrated in Figure 11–29. Loads are transferred to the stringer by decking laid across the stringers. Note the use of sway bracing (or cross bracing) on the bents of Figure 11–30. Tower bents consisting of several parallel bent frames and connected by bent caps and longitudinal bracing may also be used. Stringers may be fabricated of sawn or glued laminated timber or other materials. Girder, truss, and arch bridges are capable of spanning greater distances than can trestle bridges. Wood girders are usually fabricated of glued laminated timber. The trusses used in timber *truss bridges* are similar in design to those used for roof trusses. Truss designs frequently used include parallel chord trusses, triangular trusses, and bowstring trusses.

Timber *arch bridges* utilize arches built up from wood members. Arches are usually fabricated of glued laminated timber. A highway overpass whose glued laminated timber

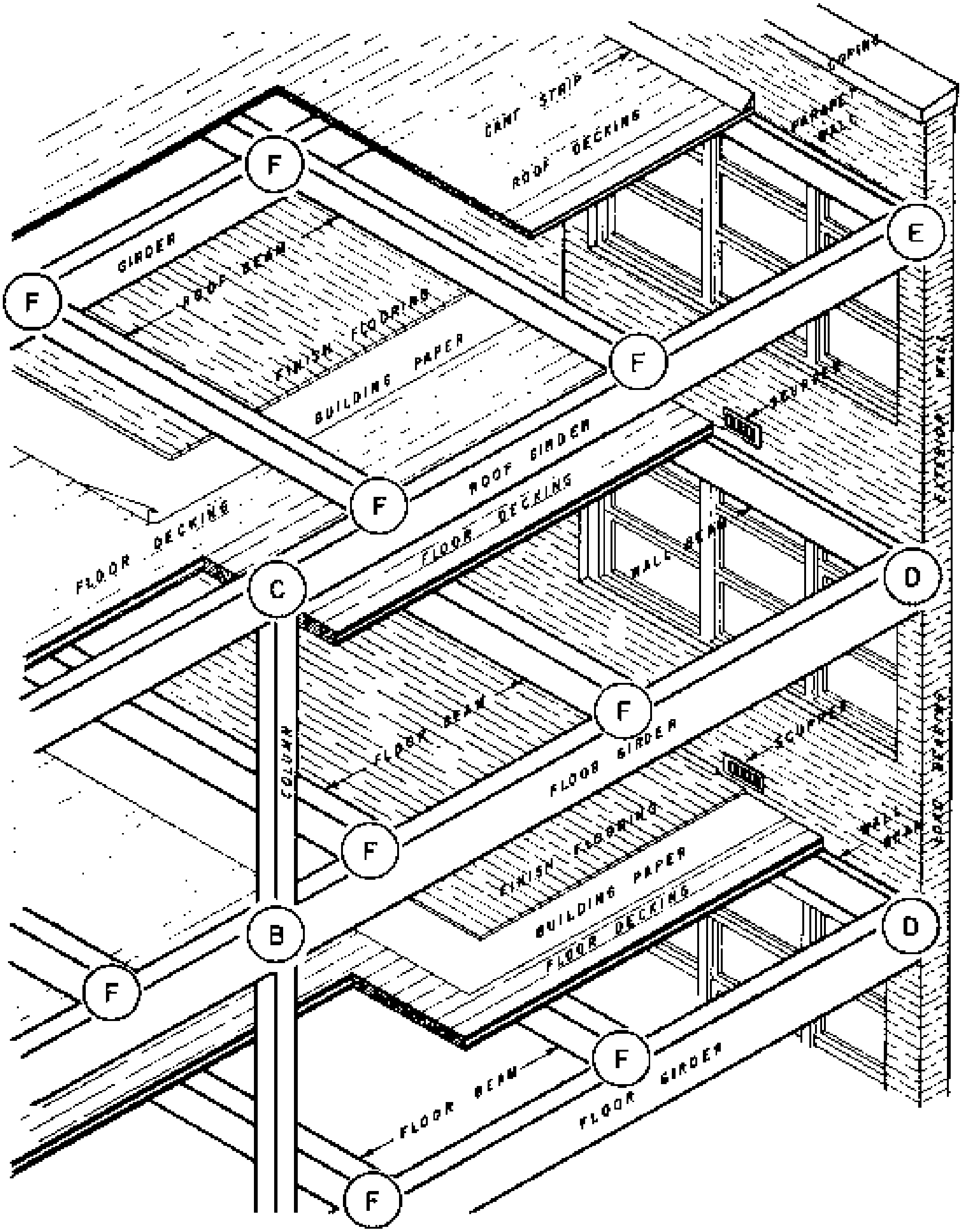


Figure 11–24 Traditional heavy timber construction. (Courtesy of American Forest and Paper Association)

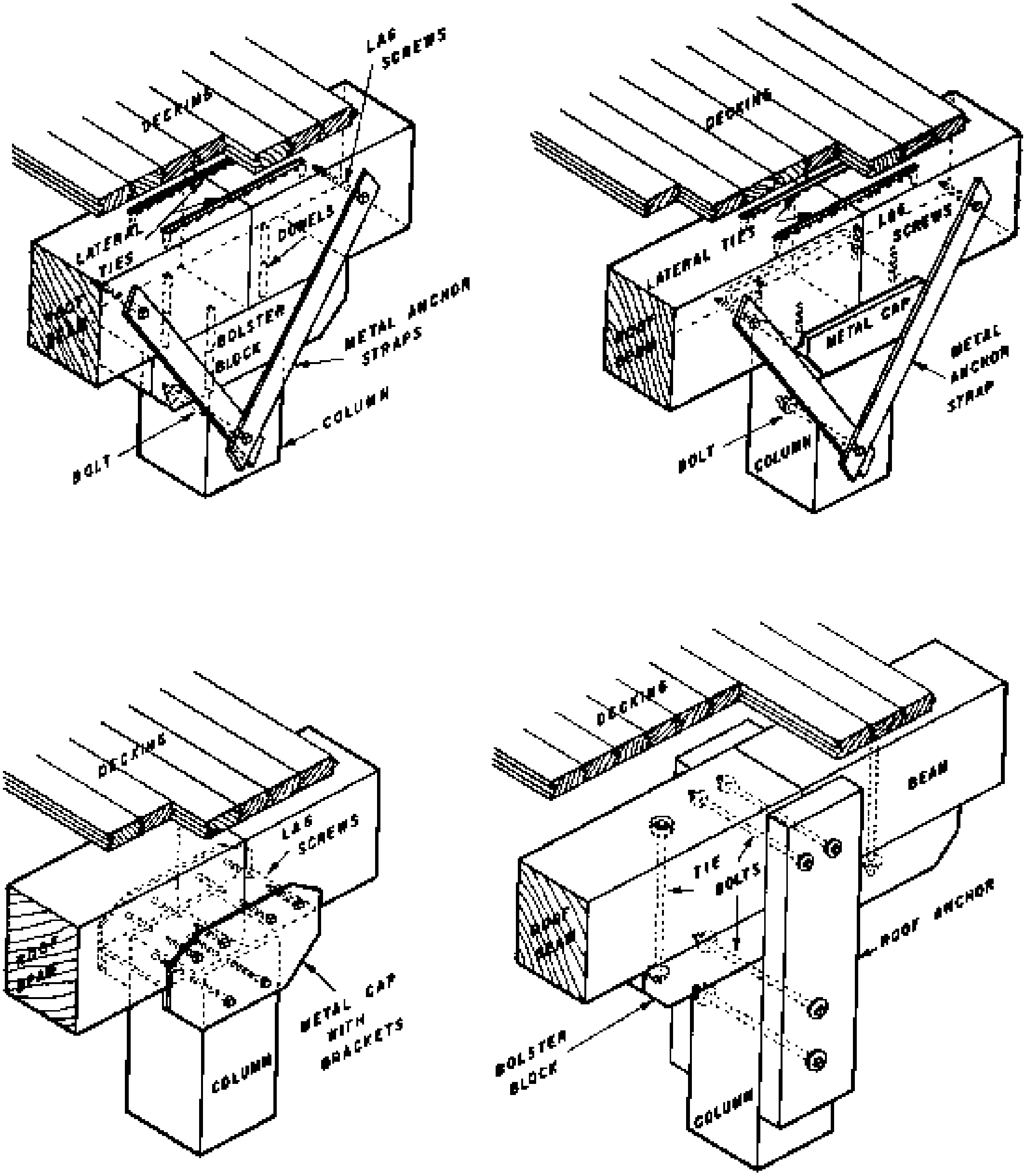


Figure 11–25 Typical roof beam and column connection details. (Courtesy of American Forest and Paper Association)

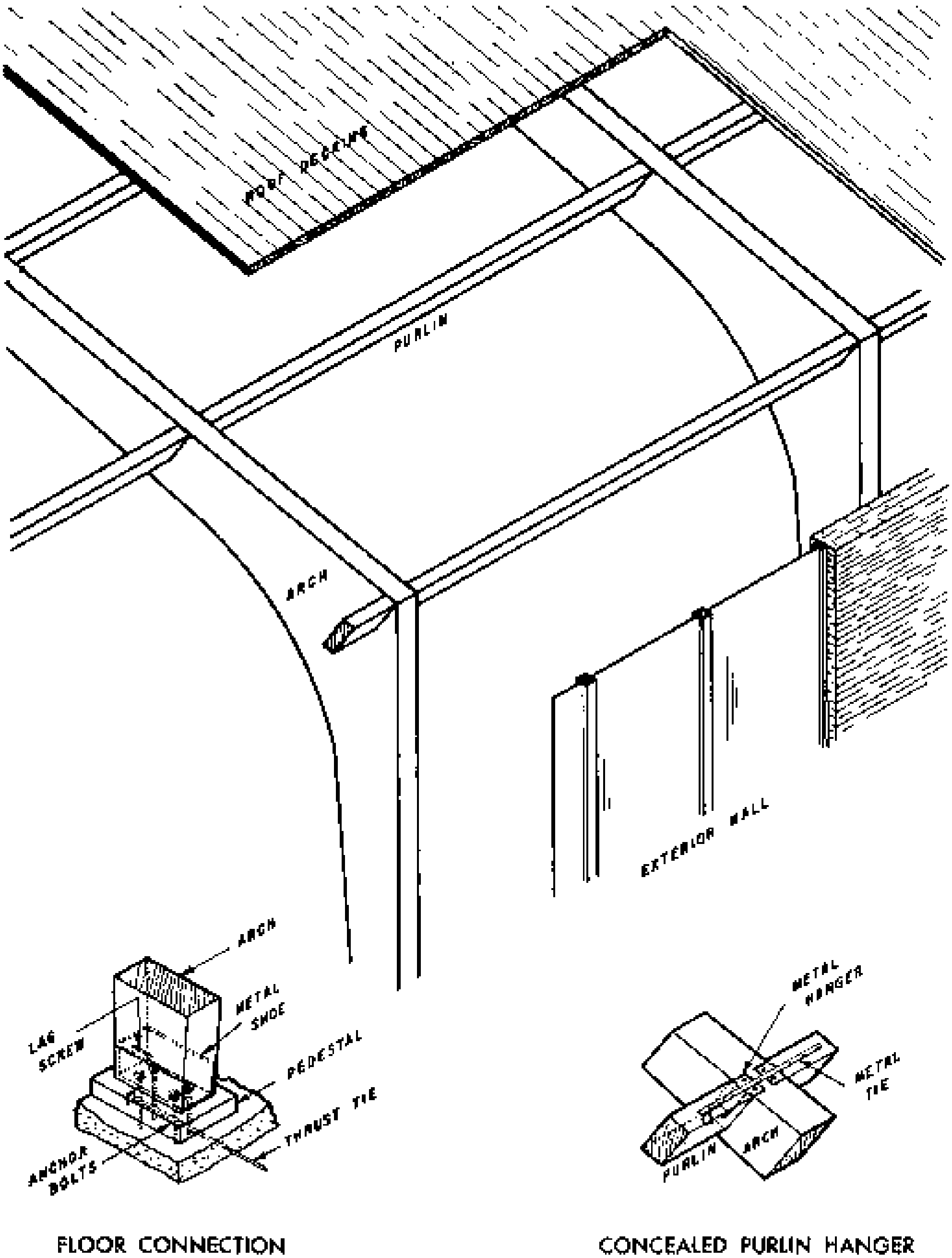


Figure 11–26 Rigid arch frame supported at floor. (Courtesy of American Forest and Paper Association)

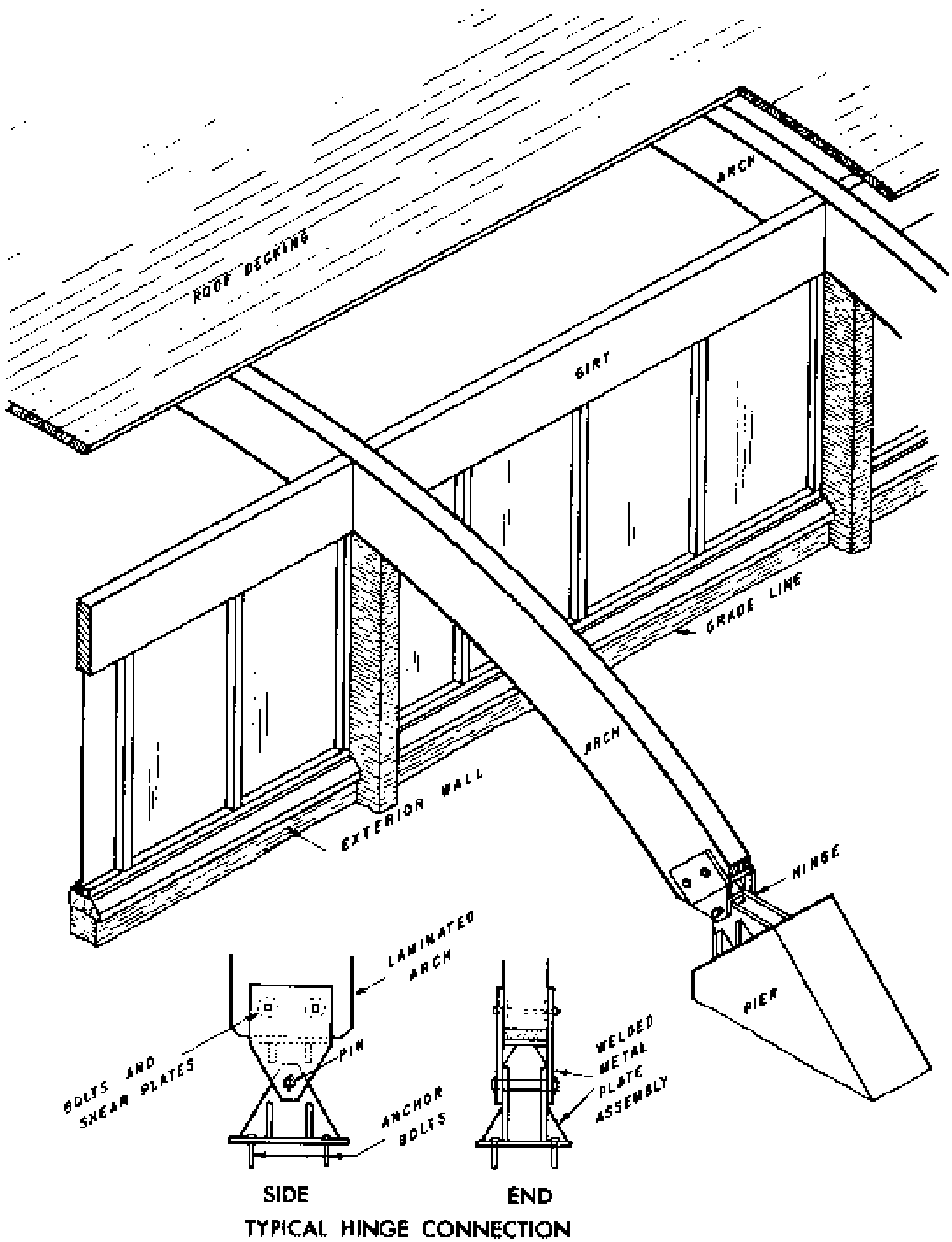
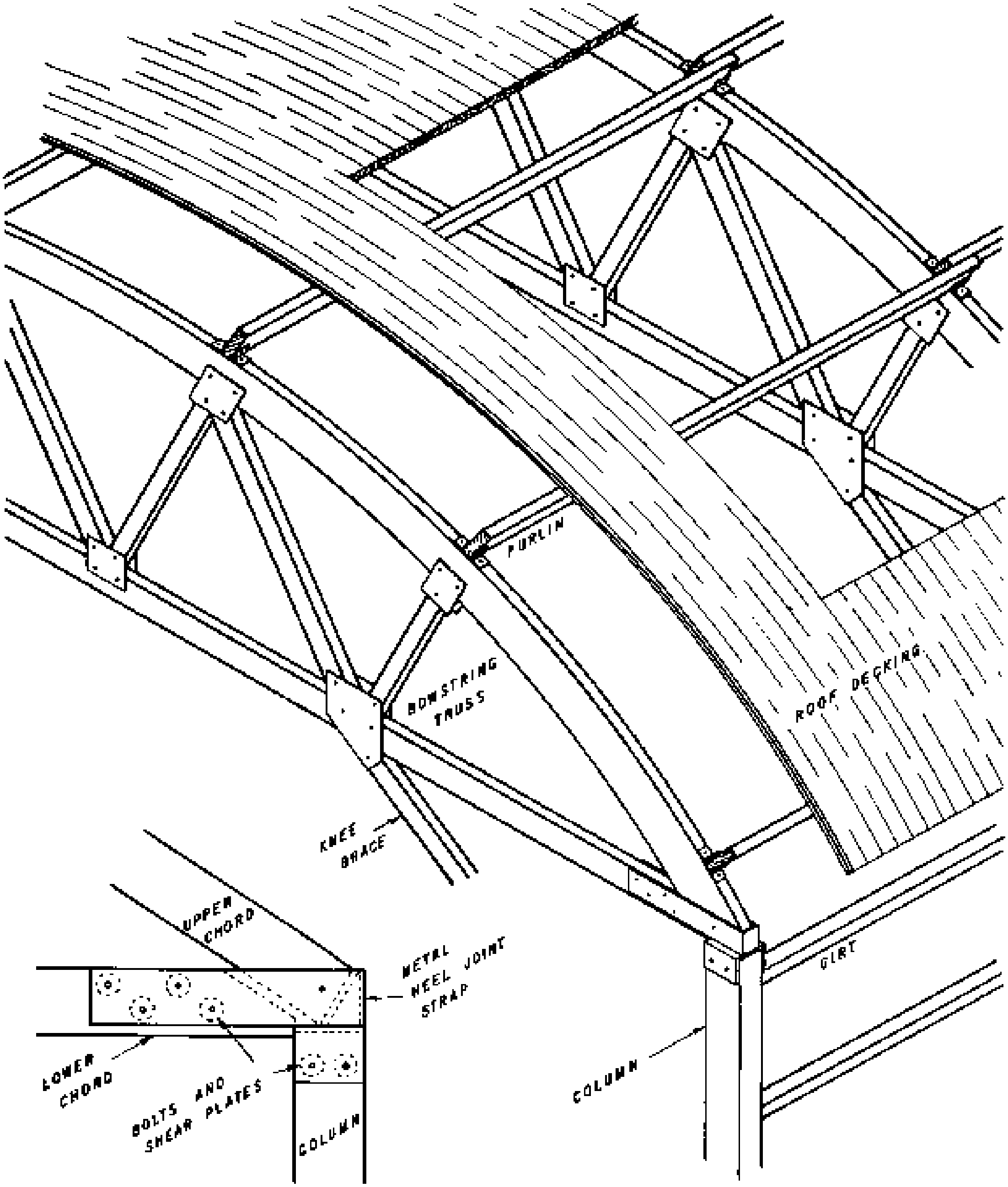


Figure 11–27 Barrel arch frame supported by exterior pier. (Courtesy of American Forest and Paper Association)



COLUMN AND TRUSS CONNECTION

Figure 11–28 Bowstring roof truss supported by wood column. (Courtesy of American Forest and Paper Association)

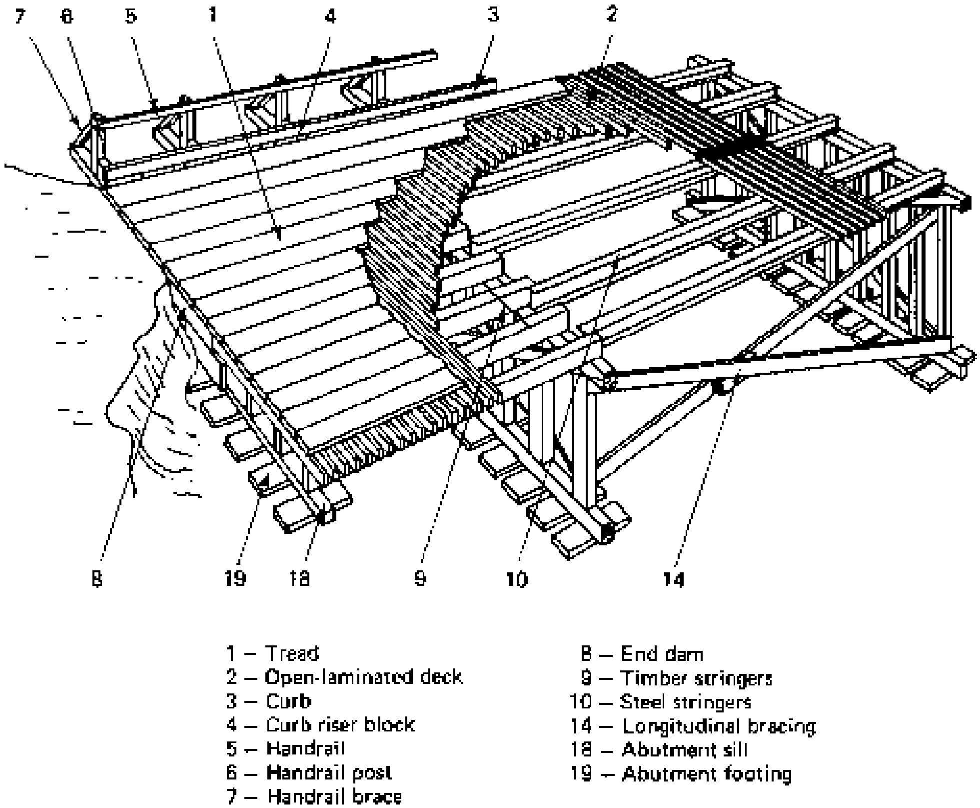


Figure 11–29 Timber trestle bridge with frame bent. (U.S. Department of the Army)

arches span 155 ft (47 m) is shown in Figure 11–31. Note the smaller bridge, that utilizes a curved continuous-span glued laminated timber girder 170 ft (52 m) long.

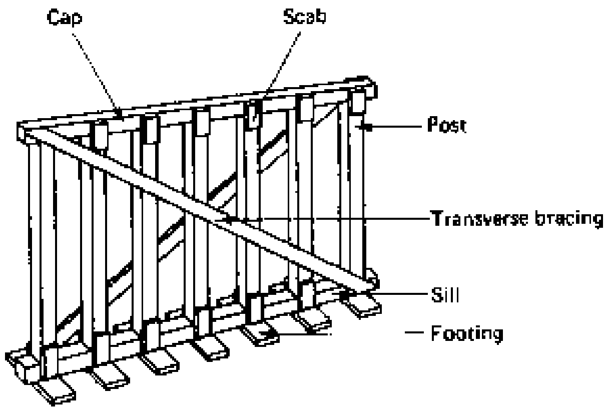
Other Structures

Timber construction is often used for many other types of structures, such as tanks, water towers, observation towers, and power transmission towers. Timber crossarms are sometimes used on metal power transmission towers because of wood's good dielectric properties.

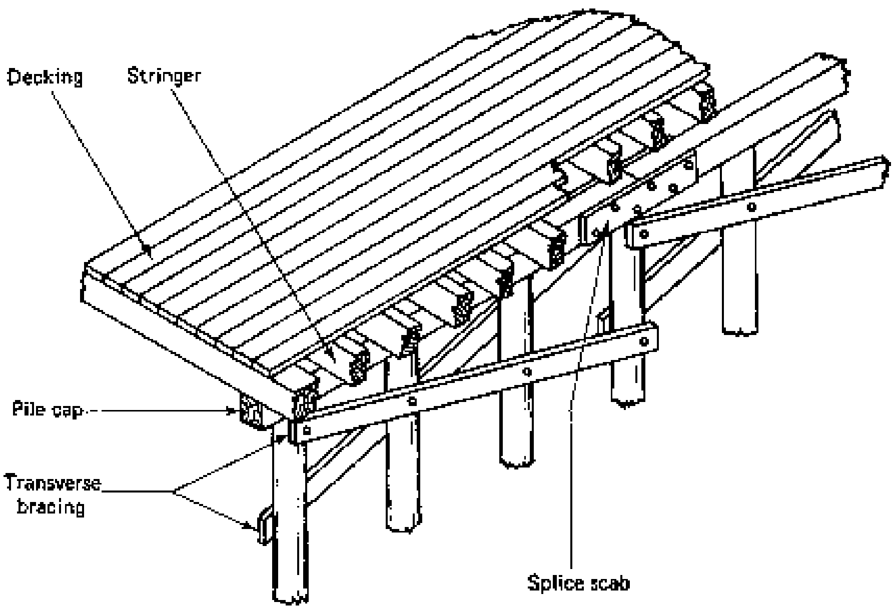
11–5 FASTENINGS, CONNECTIONS, AND NOTCHING

Fastenings

As in any mechanical system, a wood structure cannot develop the full strength of its members unless connections between members are at least as strong as the members themselves. There are a number of types of fasteners used to join wood members, the most common being nails and wood screws. Sizes of common wire nails are presented in Table 11–1. Other



Timber trestle bent



Pile bent

Figure 11–30 Typical timber trestle and pile bridge bent.

major types of fasteners include bolts, lag-screws, spikes, dowels, and drift-bolts (or drift-pins). Major factors controlling the allowable strength of mechanical fasteners include the lumber species, the angle of the load with respect to the wood grain, the size of the member perpendicular to the load, the distance of the fastener from the edge of the wood, and the spacing of fasteners. Methods for determining the allowable load on common wood fasteners are given in references 1 and 7.

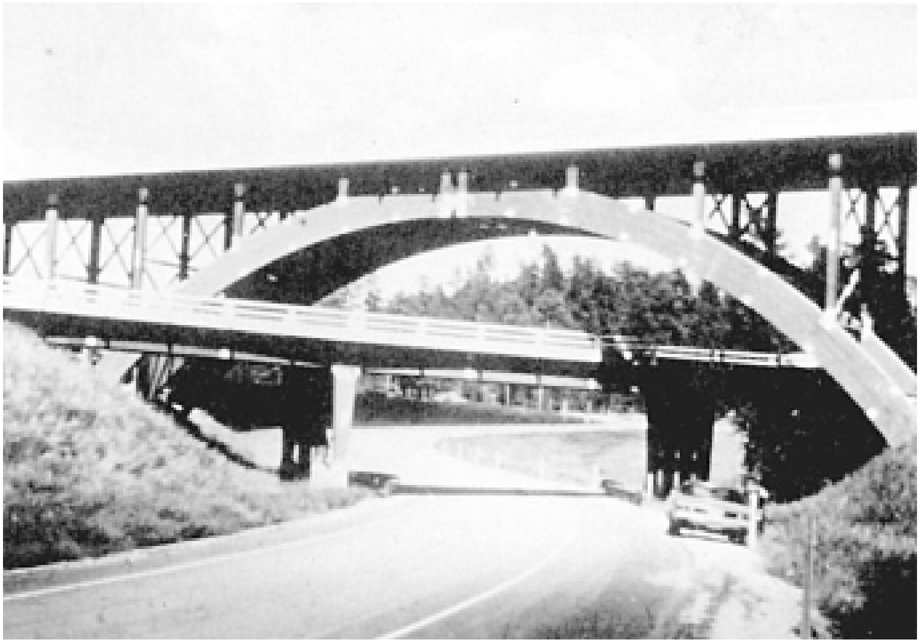


Figure 11–31 Highway bridges supported by glued laminated timber beams. (Courtesy of American Institute of Timber Construction)

Table 11–1 Common wire nail sizes

Size: Penny (d)	Wire Gauge	Length in.	Length cm
4	12½	1.50	3.8
6	11½	2.00	5.1
8	10¼	2.50	6.4
10	9	3.00	7.6
12	9	3.25	8.3
16	8	3.50	8.9
20	6	4.00	10.2
30	5	4.50	11.4
40	4	5.00	12.7
50	3	5.50	14.0
60	2	6.00	15.2

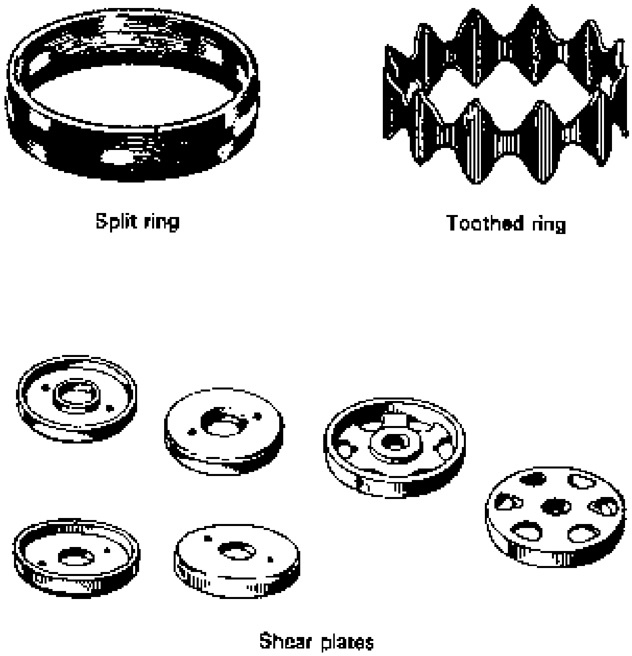


Figure 11–32 Typical timber connectors. (Courtesy of American Forest and Paper Association)

Connectors

To provide the most efficient use of materials and labor while providing the required strength, a number of special timber connectors have been developed. Major types of timber connectors include split-ring connectors, toothed-ring connectors, and shear plates. These are illustrated in Figure 11–32. These connectors use a bolt or lag screw to join the wood members and place the connector under compression. Split-ring connectors and shear plates fit into grooves precut into the wood members. Toothed-ring connectors are forced into the wood under the pressure of the bolt joining the members.

Light-metal framing devices are available in a wide range of types and sizes, some of which are illustrated in Figure 11–33. Light-metal connector plates may incorporate integral teeth or may use nails for load transfer. All-purpose framing anchors may be used for a variety of connections, such as rafters to wall plates and studs to top and sole plates.

Notching and Boring of Beams

Notching the top or bottom of a beam will seriously reduce its bending strength. In short, heavily loaded beams, horizontal shear stress may be critical. The safe vertical reaction on an end-notched beam (such as a joist) which is notched on the tension side (as shown in Figure 11–34) may be calculated as follows:

$$R_v = \frac{2F_v b d_e^2}{3d} \quad \textbf{(11–1)}$$

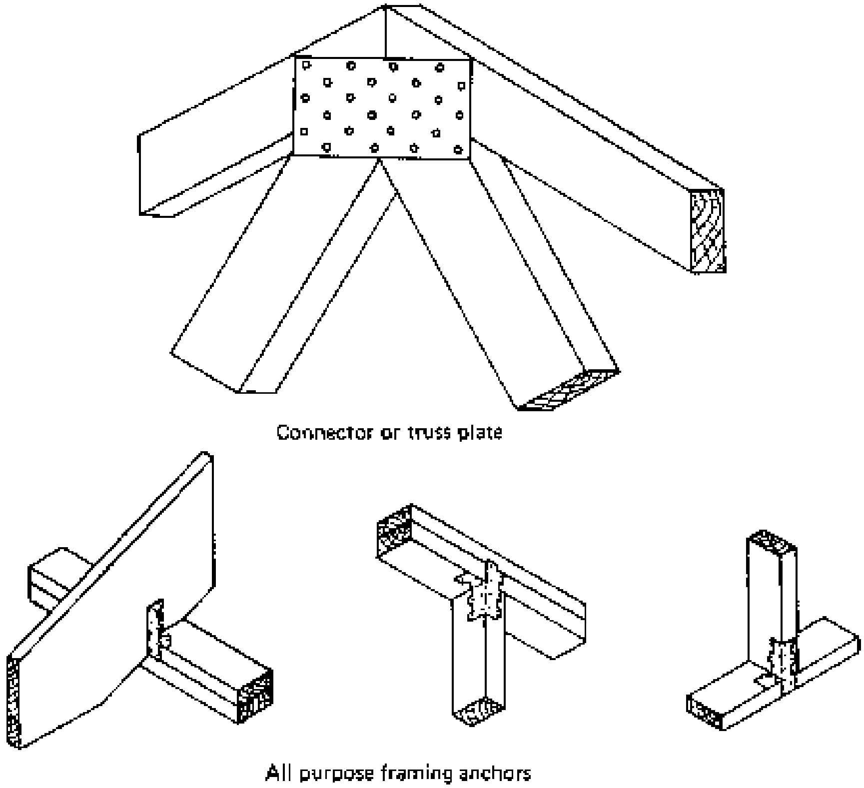
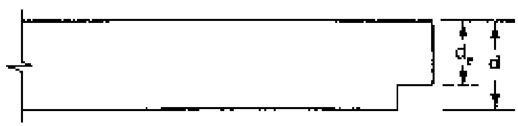


Figure 11–33 Typical light-metal framing devices. (Courtesy of TECO, Washington, DC 20015)

Figure 11–34 End notching of beam.



where R_v = safe vertical end reaction (lb)
F_v = allowable shear stress (psi)
b = width of beam (in.)
d = depth of beam (in.)
d_e = depth of beam above notch (in.)

When the notch is curved, or is beveled over a distance greater than d_e, Equation 11–2 may be used in lieu of Equation 11–1 to calculate the maximum allowable end reaction for the beam.

$$R_v = \frac{2F_v b d_e}{3} \tag{11–2}$$

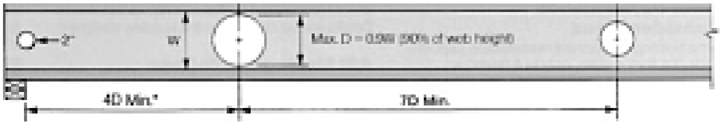


Figure 1. Round hole maximum size and minimum spacing.
Maximum round hole size is 0.9 times the web depth. Any round hole must be located at least 4 diameters from inside face of bearing. Adjacent round holes must be at least 7 diameters of the larger hole apart, center-to-center. A 2" hole may be cut anywhere in the web (pre-punched knockouts are provided 24" o.c.).

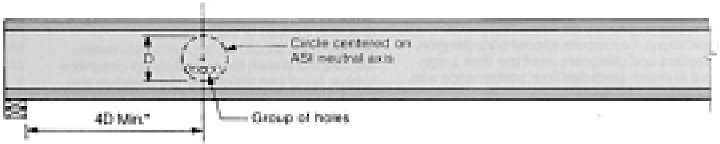


Figure 2. Group of small holes.
A group of small holes must fit inside a circle meeting the limitations for round holes (see Figure 1).

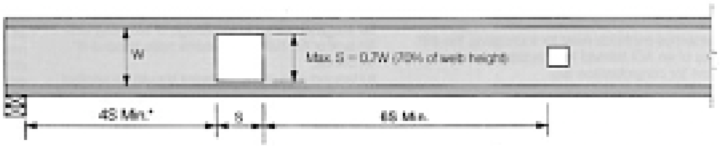


Figure 3. Square hole maximum size and minimum spacing.
Maximum square hole size is 0.7 times the web depth. Any square hole must be located at least 4 times the length of a side from inside face bearing. Adjacent square holes must be at least six times the length of a side of the larger hole apart.

Figure 4. Vertical rectangular hole maximum size and minimum spacing.
Vertical rectangular holes follow the rules for square holes using the longer side for all calculations.

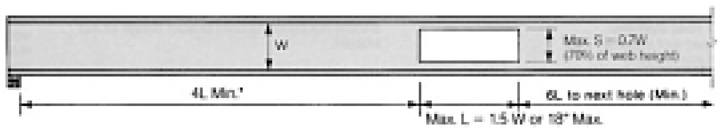


Figure 5. Rectangular hole maximum size and minimum spacing.
Maximum rectangular hole size is 0.7 times the web depth for the shorter side, with the longer side 1.5 times the web depth or 18" at most. Any rectangular hole must be located at least 4 times the length of the longer side from the inside face of a bearing. Adjacent rectangular holes must be at least 6 times the length of the longer long side apart.

Legend

W = Inside flange dimension.

D = Diameter of round opening.

S = Vertical dimension of square or rectangular opening.

L = Horizontal dimension of rectangular opening.

Notes: If adjacent holes have different shapes, the spacing between them is the greater of the two obtained by following the rules for the shapes involved.

Recommendations in figures 1 thru 5 apply only to simple support, uniform load situations. Exceptions to the criteria shown in figures 1 thru 5 may be possible. Make special inquiry to your ASI distributor.

Figure 11–35 Cutting openings in wood I-beams. (Courtesy of Alpine Engineered Products, Inc.)

When it is necessary to notch joists to provide passage for piping or electrical cables, the following limits should not be exceeded without a design analysis of the joist. Notches in the top or bottom of joists should not exceed one-sixth of the joist depth and should be located less than one-third of the joist length from either end of the joist. The diameter of holes bored in joists should not exceed one-third of the depth of the joist and should not extend closer than 2 in. to the top or bottom edge of the joist.

Some suggested guidelines for cutting openings in wood I-beams are presented in Figure 11–35.

PROBLEMS

1. A nominal 2 × 10-in. (50 × 250-mm) floor joist has the end notched on the bottom to a depth of 3 in. (76.2 mm). The notch is beveled over a distance of 6 in. (152 mm). If the allowable shear stress of the joist is 185 psi (1275 kPa), what is the maximum safe vertical reaction at the end of the joist?
2. How does exterior-type plywood differ from interior-type plywood?
3. What precautions should be observed in storing roof trusses at the construction site?
4. What purpose does a *collar beam* serve in a roof framed with rafters and ceiling joists?
5. Explain the major safety hazards involved in erecting the roof trusses for a two-story frame building.
6. What is FRTW wood? What advantages does it have over conventional lumber?
7. Explain the limitations which should be observed when boring holes in joists for the passage of pipe or electrical conduit.
8. Briefly describe the following wood products and their uses.
   a. Laminated veneer lumber.
   b. Wood I-beam.
   c. Particleboard.
9. Sketch and briefly explain the construction of a *thickened-edge slab.*
10. Develop a computer program to calculate the safe vertical end reaction of an end-notched beam (Equations 11–1 and 11–2). The program input should include the allowable shear stress, depth of notch, and distance over which the notch is beveled. Using your program, solve Problem 1.

REFERENCES

1. American Institute of Timber Construction. *Timber Construction Manual,* 5th ed. Hoboken, NJ: Wiley, 2005.
2. Anderson, L. O. *Wood-Frame House Construction* (Agriculture Handbook No. 73). U.S. Department of Agriculture, Washington, DC, 1975.

3. *APA Design/Construction Guide: Residential & Commercial.* APA—The Engineered Wood Association, Tacoma, WA.
4. *Guide to Good Practice for Handling, Installing & Bracing Metal Plate Connected Wood Trusses* (BCSI 1-03). Wood Truss Council of America and Truss Plate Institute, Madison, WI, 2003.
5. *Heavy Timber Construction Details* (Wood Construction Data No. 5). American Forest and Paper Association, Washington, DC, 1971.
6. *I-Joists for Residential Floors.* APA—The Engineered Wood Association, Tacoma, WA.
7. *Manual for Wood Frame Construction* (Wood Construction Data No. 1). American Forest and Paper Association, Washington, DC, 1988.
8. *National Design Specification for Wood Construction.* American Forest and Paper Association, Washington, DC.
9. Nunnally, S. W., and J. A. Nunnally. *Residential and Light Building Construction.* Upper Saddle River, NJ: Prentice Hall, 1990.
10. *Plank-and-Beam Framing for Residential Buildings* (Wood Construction Data No. 4). American Forest and Paper Association, Washington, DC, 1970.
11. *Plywood Design Specification.* APA—The Engineered Wood Association, Tacoma, WA.
12. *Wood Handbook: Wood as an Engineering Material.* Forest Products Society, Madison, WI, 1999.