CHAPTER 3

FRAMING—STRUCTURAL COMPONENTS

SECTION I—WOOD FRAMING

3.1.1 General

The structural components of frame buildings must be strong enough and sufficiently rigid to transfer dead and live loads to the building foundations without excessive deflection or sidesway. Dead loads are those which result from the weight of the structure. Live loads are those induced by external forces such as wind, earthquake, snow, inhabitants, furniture, equipment, or impact. These loads are variable. They are usually not applied over long periods. They could be moving loads or stationary, uniformly distributed or concentrated.

3.1.2 Framing System

The major framing systems in use for wooden buildings are known as the balloon frame and the platform frame. There are modifications of these systems; however, the fundamental principles fall into these two categories.

3.1.2.1 *Balloon Frame.* The balloon frame is light, economical, and simple to construct. The sills are laid on the foundation and anchored in place. First-floor joists are spiked in place on the sill, and the cornerposts are set in position on the sill and temporarily braced. See figure 8-1. The studs, which run the full height of the exterior wall from sill to plate, are spiked in position on the sill held near their upper end by temporary boards nailed across them. A horizontal board called a ribbon is set into the studs and cornerposts at the proper height to form a base for the second-story floor joists. The joists are supported in place by the ribbon and nailed to the studs. The tops of the studs and the cornerposts are sawed off level and capped with a plate. The plate joins the top of the studs to form a base for the roof rafters. The exterior sheathing is then nailed in place to brace the frame.

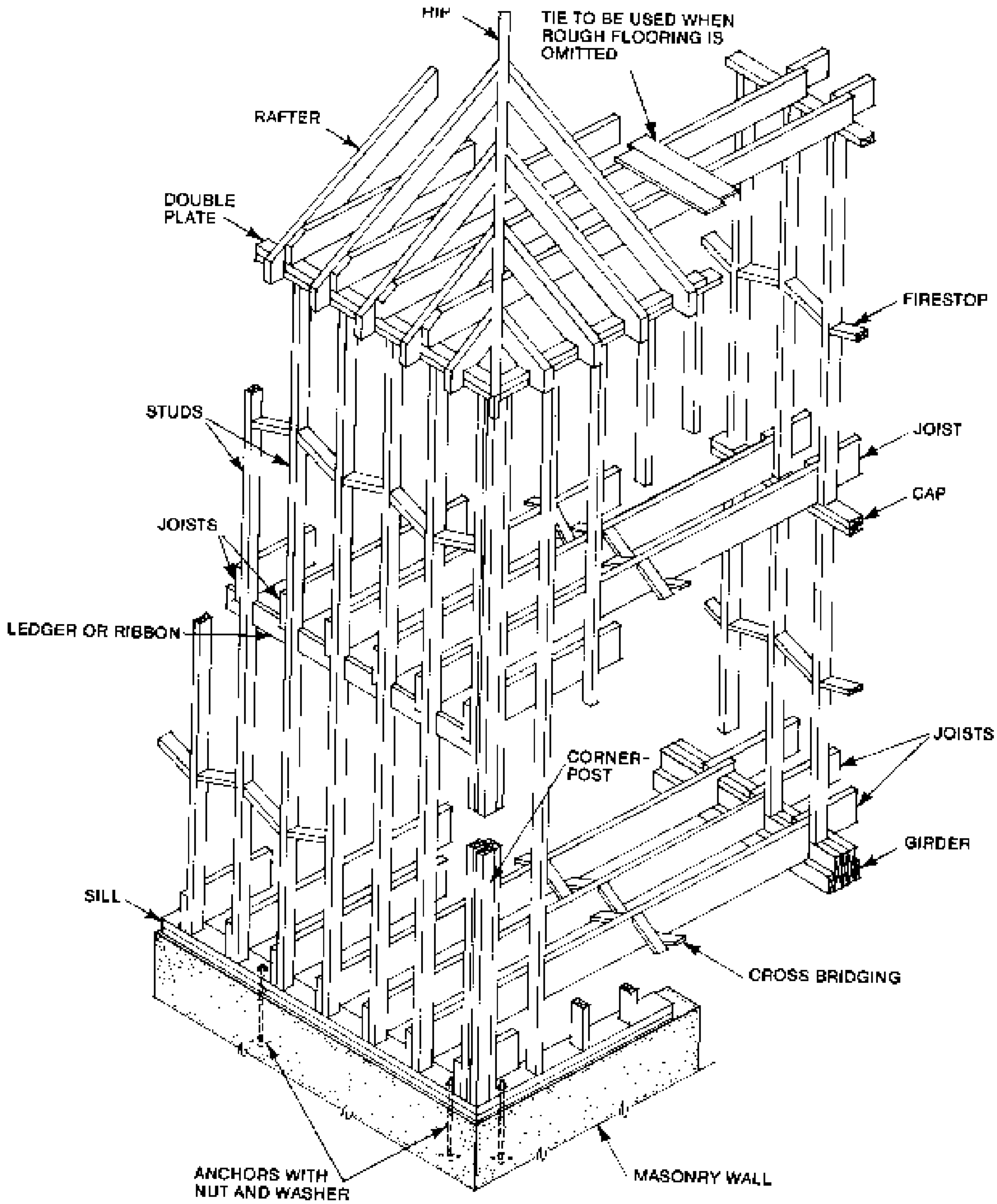


Figure 3-1. BALLOON FRAMING.

3.1.2.2 *Platform Frame.* The platform frame is more rigid and heavier than the balloon frame. Laying the sills and placing the first-story floor joists are accomplished in the same manner as for the balloon frame. A header is placed across the end of the floor joists, and the subfloor is laid. This forms a platform. Next, a soleplate is laid on the edge of the platform the one-story~high studs capped by a plate are put in place. See figure 3-3. This soleplate, stud, and top-plate unit is normally assembled in horizontal position on the platform and raised as a unit. Second-floor joists are then spiked in place on the top plate, and the entire sequence is repeated. Sheathing is applied to the exterior face. Due to the panel method of construction used in this system, it lends itself to prefabrication techniques.

3.1.2.3 *Bracing.* Greater rigidity is obtained in both systems by using heavier members, by installing horizontal bridging between the studs, and by setting diagonal braces into the studs from the sill to the top of the cornerposts to brace the walls.

3.1.2.4 *Sheathing Board.* Diagonal wooden sheathing has been largely replaced by patented sheathing panels. These panels, which can be insulation, vapor barrier, and water repellent combined into one unit, also provide adequate structural bracing when applied as directed by the manufacturer.

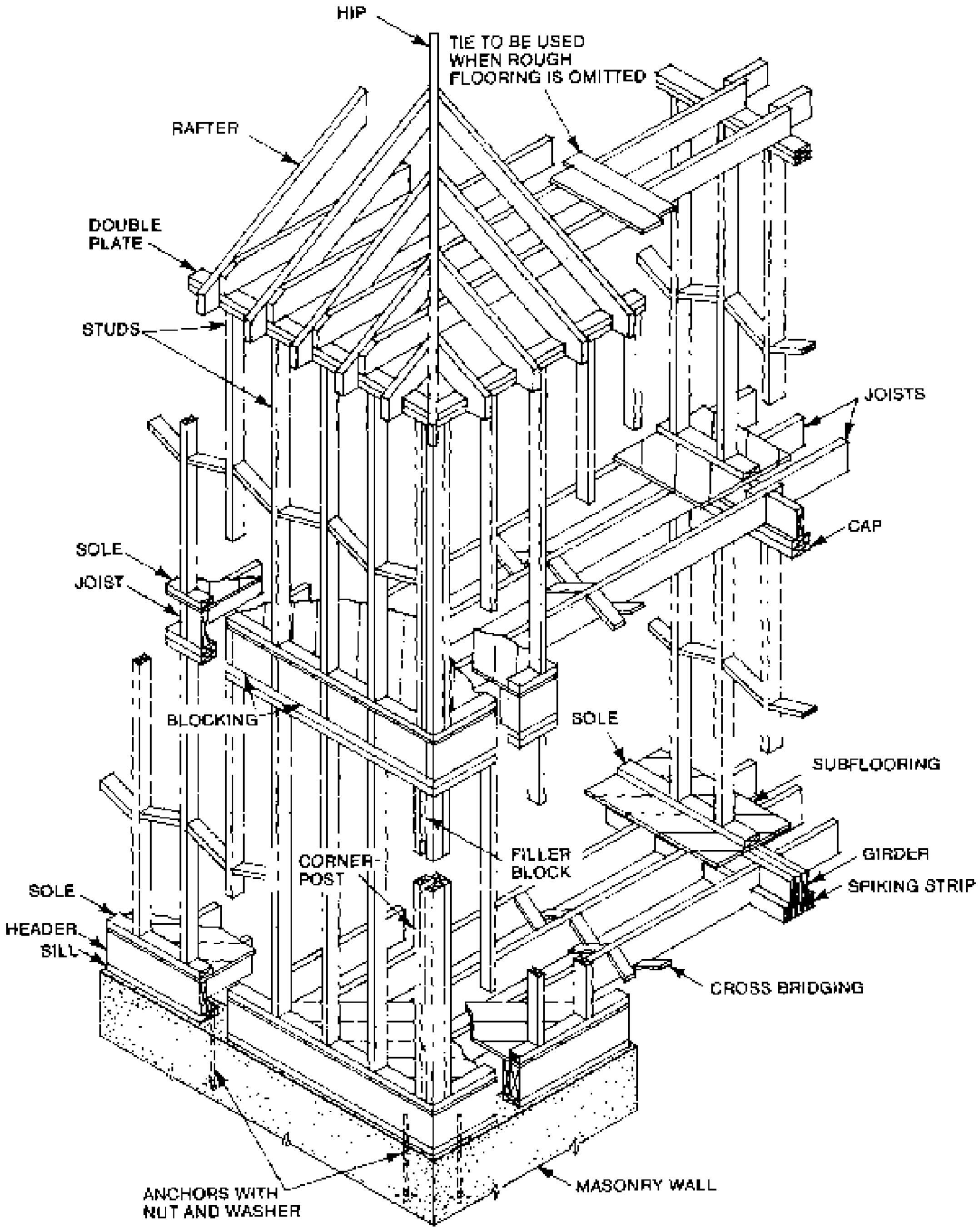


Figure 2-2. PLATFORM (or WESTERN) FRAMING.

3.1.3 Sills

The inspection and timely repair of sills set on foundation walls, posts, or columns is an important factor to the maintenance of any structure. As in the case of uneven settlement of foundation, severe damage can be inflicted on a basic building structure by displacement, deterioration or other things which discount the ability of the sill to maintain the upper components in their fixed, designated positions. Many lesser, but troublesome and expensive repair and replacement problems can arise, such as wall and ceiling cracks and misaligned doors and windows.

3.1.3.1 *Typical Sills.* Figure 3-3 shows types of sills commonly set on posts, piers, and walls. The imposed loads and pier spacings determine sill sizes. Built-up or laminated sills are made up of two or more members solidly spiked together with joints over supports, always staggered and with corners, as shown in figure 3-3. Note that because dimensions and heights are measured from the in-place sill, it is carefully cut, fitted, and laid level on the piers or wall. On concrete or masonry walls, the sill is placed on mortar and secured with wall anchors. The maintenance personnel should pay special attention to specially framed sill corners, as shown in figure 3-4.

3.1.3.2 *Sill Replacement.* When inspection and engineering consideration dictate that sills should be reinforced, reset, or replaced, good carpentry practices will be followed.

a. Three-Piece Laminated Sill. See figure 3-3. Nail from each side with twentypenny nails, two near each end of each piece, with others spaced horizontally not more than 32 inches and staggered near top and bottom from opposite sides; nailing is on 16-inch centers. Stagger all joints over supports. Toenail sills to posts (or caps if used) with two or more nails on each exposed side. Wood caps (when used) are nailed to tops of posts with at least three or more twentypenny nails. When a four-piece sill is used, the additional member is nailed to the three-piece sill with the same size and spacings as above.

b. Solid-Timber Sill. See figure 3-3. Sills of solid timber should be set on posts or piers with halved joints over supports. Nail each lapped joint with three or more nails long enough to penetrate through most of the lower half of joint. Sills are set level on a mortar bed. Butting ends of single sills are toenailed with tenpenny nails. Lap double-sill members at corners, and nail with ten-penny nails. Anchor bolts of the appropriate size and set one near each end of each piece and at intermediate spaces of about 4 feet. Sills are set and secured in place, as shown in figure 3-3. In balloon and braced frame construction, the lower ends of studs extend down and sit on wall sill. Studs are toenailed to place with two eightpenny or larger nails on each wide fence. Joists are toenailed to sills and nailed directly to studs with tenpenny nails. Subfloor is nailed with threepenny nails. In western or platform framing, sills are bedded and anchored as shown in figure 3-4. Joists and headers are set and nailed to sills. Subfloor, laid diagonally, is followed by bottom plate to which studs are toenailed.

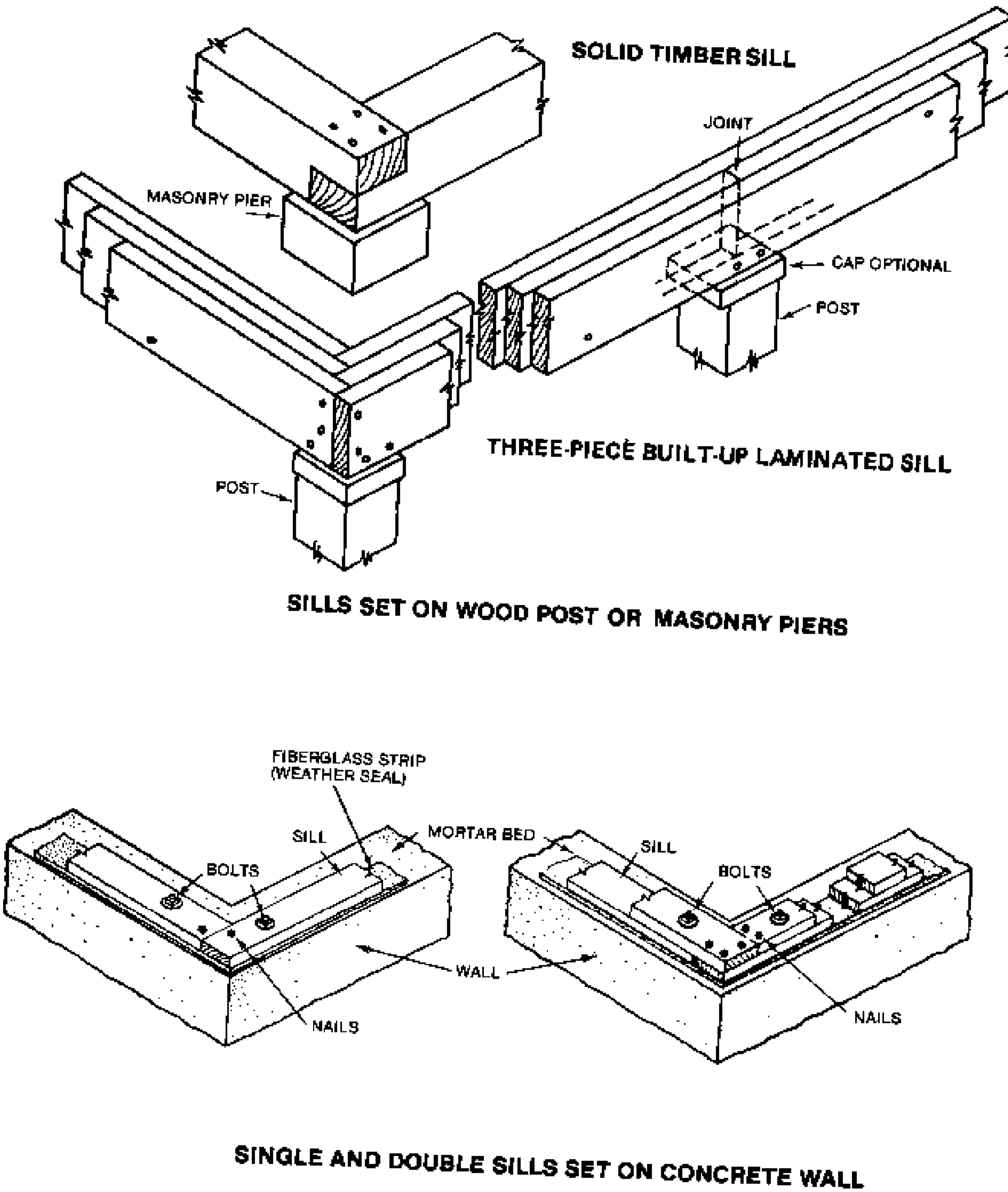


Figure 3-3. TYPICAL SILLS.

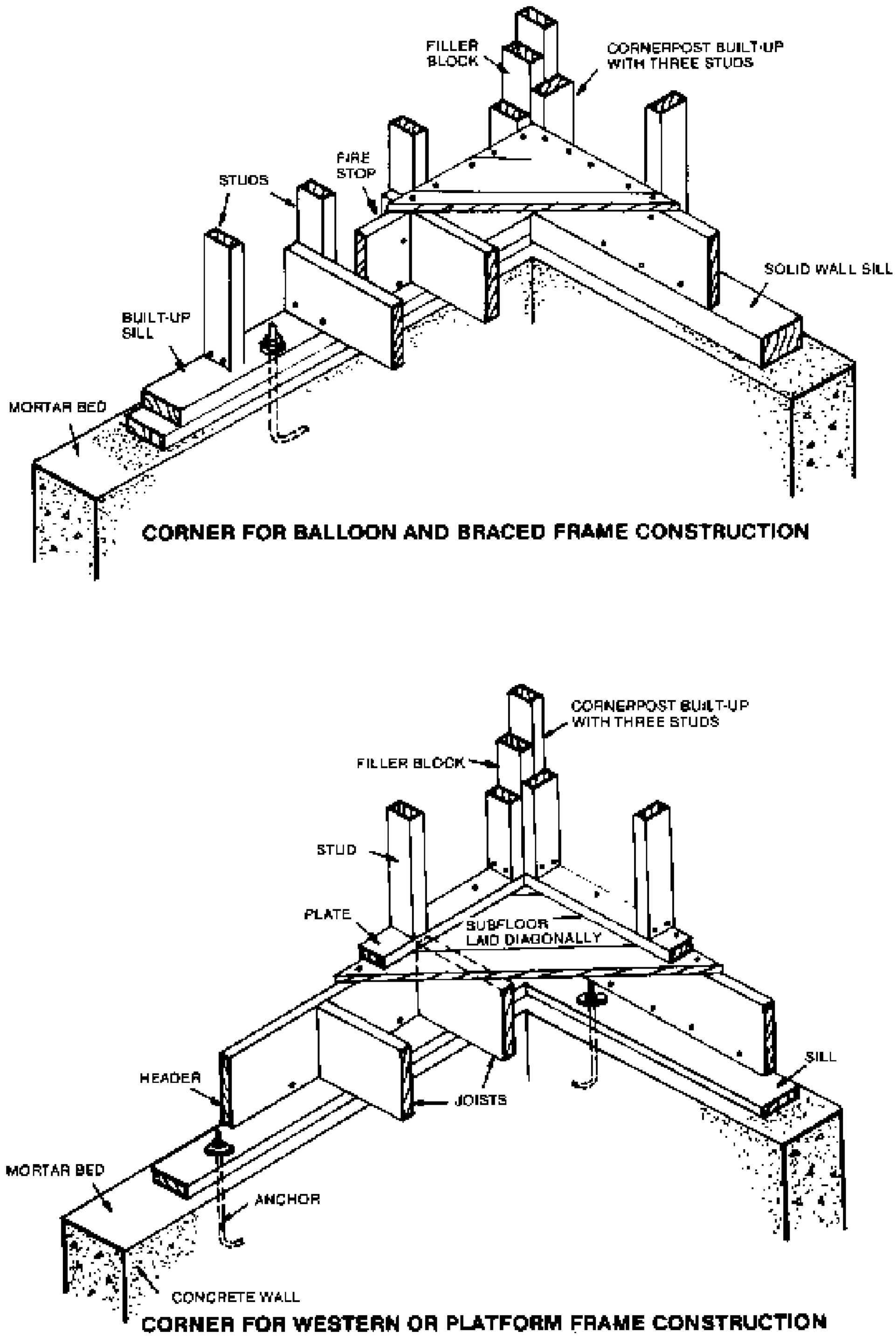


Figure 3-4. FRAMED SILL CORNERS.

3.1.3.3 *Maintenance of Sills.* Inspect wood sills periodically for soundness (see paragraph 3.1.4), rodent and insect damage (see Tri-Services Manual, "Military Entomology Operation Handbook"), and rot. In addition, they should be kept to correct grade by use of shims and mortar pointing, and in correct alignment by reinforcing plates, extra tiedowns or other means. Timbers exposed to ground moisture or severe weathering must be treated often enough to prohibit deterioration. Measures for ventilation and other means, as presented in chapter 2 of this manual, for overcoming or offsetting moisture condition must be followed, as well as general good housekeeping and safety procedures.

3.1.4 Posts and Columns

Posts and columns are the vertical members which transmit loads directly to the foundations. They are the "legs" of the building and must be strong enough not only to transmit the vertical loads to the foundation (sills) but also to resist lateral or side forces, such as wind and seismic forces if present.

3.1.4.1 *General Maintenance.* Posts and columns below grade or in contact with the earth must be treated with a preservative to resist decay and termite damage. They should be plumb, in good alignment, sound, and free of mold or other fungus growths. Make periodic and thorough inspection of all posts or columns in contact with the ground. Areas under floors which are supported on posts should be well ventilated and drained so that moisture is present only for a minimum period of time.

a. Columns. Columns differ from posts only in their length, and usually columns are considered to be above grade for support of second- or upper-story floor and roof loads. In buildings which are finished (covered with plaster, wallboard, sheathing, siding, and other material), it is difficult to inspect and repair damage to columns. When it is obvious that columns are out of plumb and alignment, covering material should be removed and a thorough examination made. Failure or cracks of covering material may occur independently of failure or movements in columns. When the possibility of such a condition exists, sufficient covering shall be removed to examine the columns, beams, and other structural components involved. When a determination has been made, repair and replace covering.

b. Posts. Inspection of posts will include a test for soundness by jabbing the post on all four sides with an ice pick or other sharp instrument. The amount of penetration is the indication of its soundness. On most softwood species, such as pine or fir, the pick should not enter more than ½ inch; for hardwood, such as gum or oak, the pick should not go in more than ¼ to **d** inch.

3.1.4.2 *Corrective Measure&* Corrective measures for wood posts and columns consist mainly of the following items:

a. Plumbing and Aligning. If inspection reveals that posts are out of plumb or alignment, shore the floor above with jacks or other devices. Plumb and realign the post. If foundations are not level because of uneven settling, correction is required before any attempt is made to plumb or realign posts or columns.

b. Seasoning Checks. Posts and columns usually are of timber which has not been air- or kiln-dried. This results in seasoning checks which are caused by separation of the wood fibers by drying. Checks are not usually a cause for replacement, but they should be carefully noted as to location, depth, and width of check. If continued investigations indicate these openings or checks are increasing in size, they should be carefully examined by an engineer for possible replacement.

c. Structural Failure. When inspection indicates that columns or posts show signs of failure from overloading, examination of the posts of columns should be made by a structural engineer. His recommendations should be incorporated to provide adequate repairs or replacement.

3.1.5 Floor Girders, Beams, and Joists

Girders and beams are those structural components of floors which span from column to column or wall to wall, and transmit vertical loads to their bearings. These loads may be introduced into the girders by beams, joists, planks, or other surfaces.

3.1.5.1 *Seasoning Checks.* Large size girders, beams, and joists are made of lumber that is not kiln dried. Consequently, it is normal to expect seasoning checks as the wood loses its moisture. Detailed inspection of these checks should be carefully recorded as to size, location, and depth. If records indicate any increase, stitch bolts may be required. (See paragraph 3.4.10.2 for a discussion of the proper use of stitch bolts.)

3.1.5.2 *Structural Failures.* Beams or joists, which have failed in bending but have sound wood surrounding the failure, may be repaired by fastening adjacent pieces (scabs) to the sides of the failed member.

3.1.5.3 *Repair Consideration.* There are many methods which can be used to reinforce girders, beams, and joists. The selection of the proper methods should be determined by the loads to be carried, the costs, clearances, and accessibility.

3.1.5.4 *Bridging.* Bridging is added to stiffen floor-framing members (joists). Spring floors may sometimes be stiffened by adding or repairing existing bridging, by adding joist, or by utilizing heavier framing. See figure 3-5.

a. Open Bridging. When bridging is in place, it is tightened by driving nails completely through the bridging and into the joist.

b. Solid Bridging. Solid bridging must be cut accurately and fitted neatly between the joists to assure resistance to individual movement of the joists. This type of bridging may also be utilized as a fire stop if correctly positioned in the floor (see paragraph 3.1.8).

3.1.6 Special Beams

Special beams in floor frames to provide openings are called headers and trimmers. Figure 3-6 illustrates a method of adding structural strength to a floor opening using headers and trimmers.

3.1.6.1 *Framing with Special Beams.* Joists may be framed into these members in several ways:

a. Ledger-type framing. See figure 3-7.

b. Metal joist hangar framing. See figure 3-8.

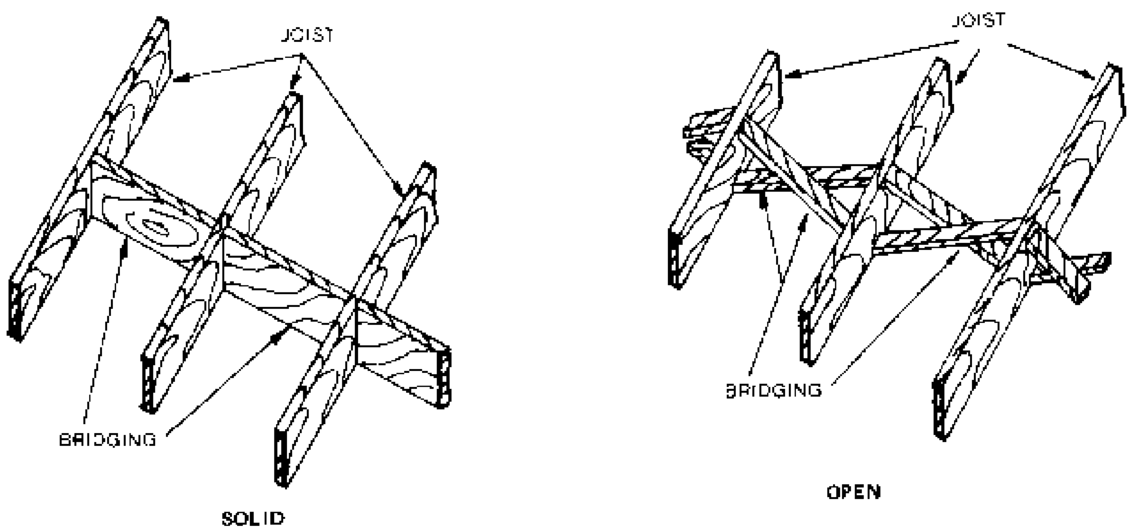


Figure 3-5. BRIDGING (OPEN AND SOLID).

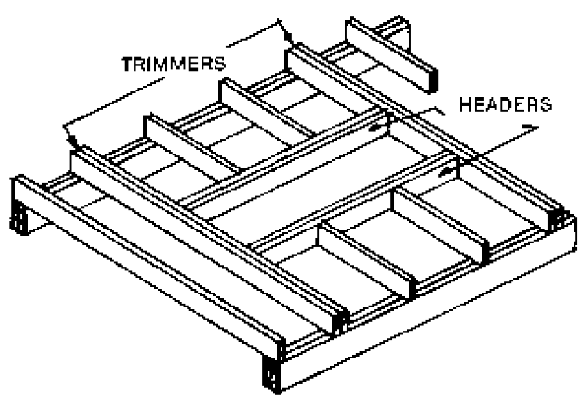


Figure 3-6. SPECIAL BEAMS—HEADERS AND TRIMMERS.

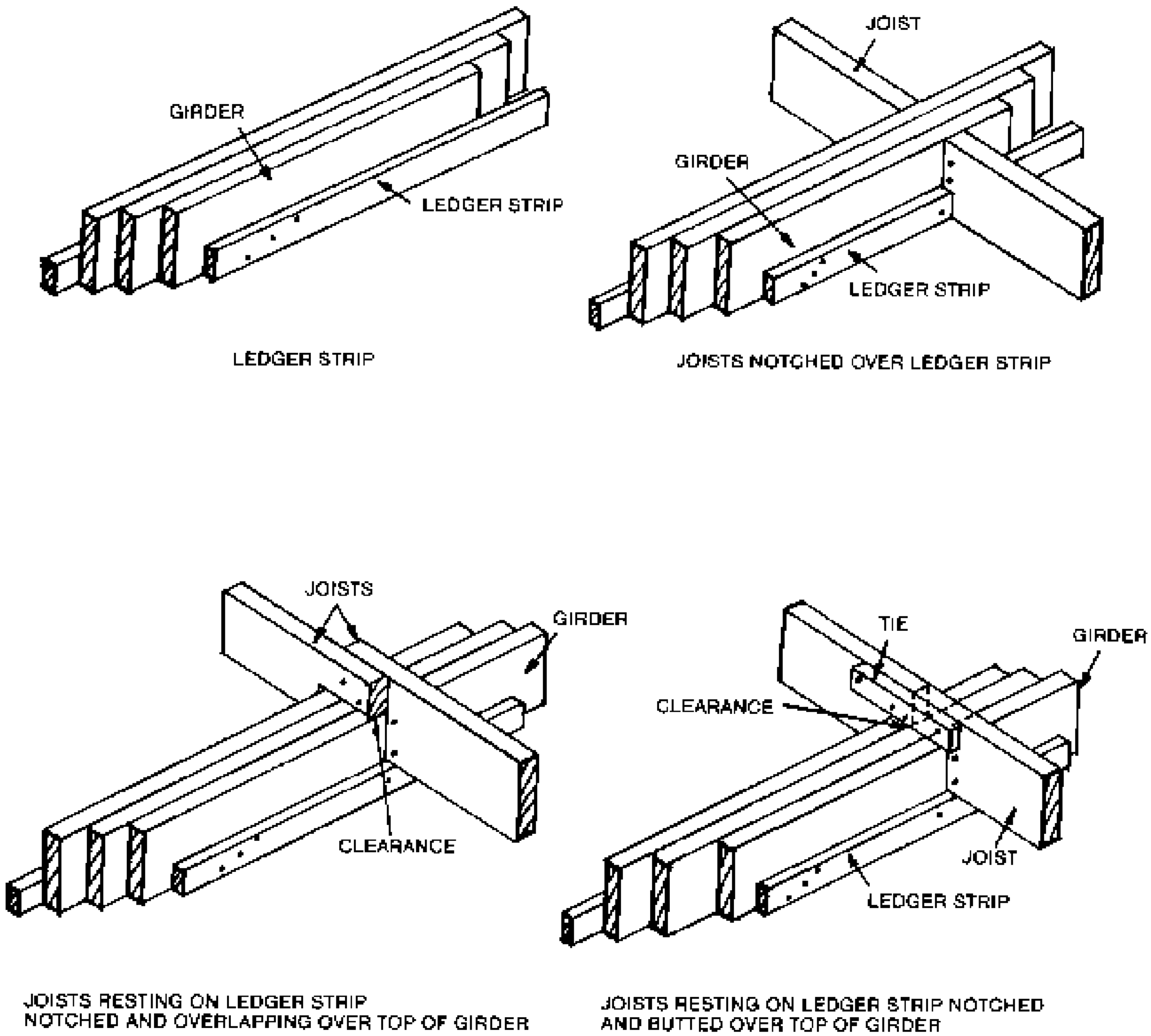


Figure 3-7. LEDGER—TYPE FRAMING.

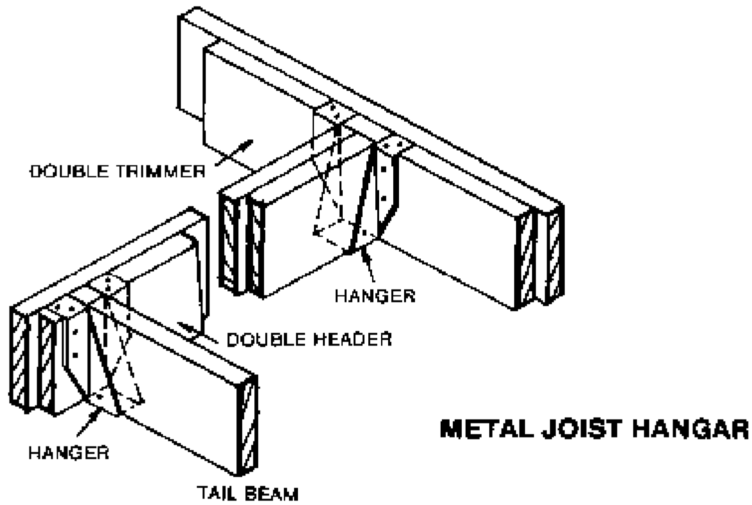


Figure 3-8. METAL JOIST HANGER FRAMING.

c. Metal anchor framing. See figure 3-9.

3.1.6.2 *Methods.* Where joists are framed into headers, and headers to trimmers, the connections are determined by the load requirements and care exercised to minimize the effects of unequal shrinkage as much as possible.

a. Framing Anchors. Framing anchors, if sufficient for load requirements, will provide the least relative movement due to shrinkage, which is most important if plaster or rigid types of ceiling covers are used. See figure 3-8.

b. Other Methods. If other methods are used to frame joists into headers and headers to trimmers, reinforcement and additional load capacity can be secured by adding ledgers, hangars, or framing anchors.

3.1.7 Workmanship

When repairs of framing and structural components are necessary, it is extremely important that careful consideration by given to appropriate methods of jacking and shoring in order to bring all members into proper alignment before corrective or reinforcing methods are applied.

3.1.8 Stops

An essential part of construction safety is the maintenance, and where necessary, the installation of fire stops. Fire stops are obstructions deliberately placed in concealed airspaces to block passage of hot gases and flames from one area to another. Sometimes these stops serve a dual purpose, such as for solid bridging, but in any event they must not be inadvertently deleted during repair processes. Fire stops are not confined to wood construction but may also be of concrete, brick, gypsum, mineral wool, or other substances.

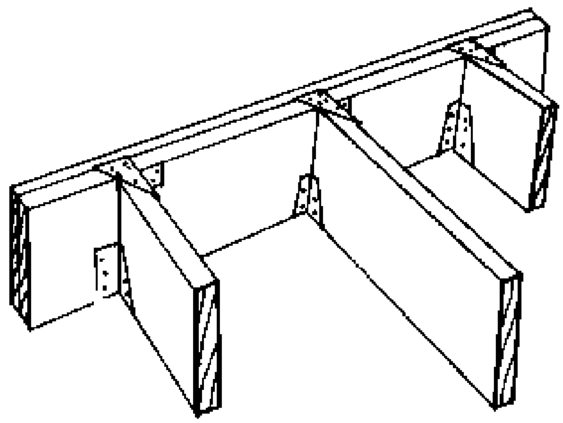


Figure 3-9. METAL ANCHOR FRAMING.

3.1.9 Other Trades

Where addition, alteration, rehabilitation or repair of electrical, plumbing or other utilities involves cutting, notching, or alteration of framing or structural components, it is important that repairs provide necessary reinforcement as required by the installation engineer.

SECTION II—WALL AND PARTITION FRAMING

3.2.1 General

There are two general types of framing. They are western or platform and balloon frame construction. Basic types of framing are discussed in the preceding section. The major components of wall and partition framing used in each system are similar and are described as follows:

3.2.1.1 *Studs.* The main structural elements of walls and partitions are usually termed studs. The ends of these vertical pieces usually bear on a horizontal bottom plate and are capped by a double top plate, as shown in figure 3-10.

3.2.1.2 *Cornerposts.* Cornerposts, as illustrated in figure 3-11, can be constructed in various ways.

3.2.1.3 *Ledgers and Ribbons.* Second- and third-story joists rest on double plates, ledgers or ribbons, which are horizontal pieces of wood supported by the studs and cornerposts.

3.2.2 Framing Maintenance and Repair

Failure of wall framing is usually related more to major structural faults elsewhere in the construction than to defects in the framing itself. Determining the best repair procedure depends on the use of the building, extent of damage, life expectancy of the structure, and possible future uses. Frequently, it is possible to accept distortion, warping, and settling of the structure, and to make wall framing repairs necessary to overcome cracking of plaster, surface irregularities, sticking of doors and windows, and other localized faults.

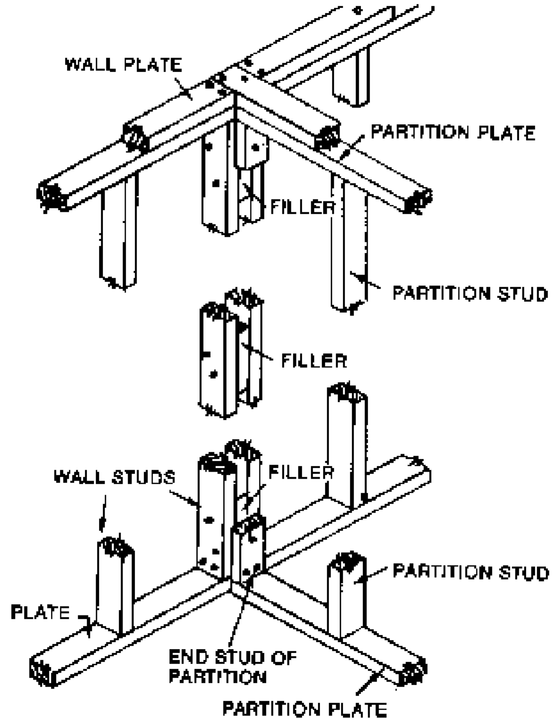


Figure 3-10. WALL CONSTRUCTION, SHOWING STUDS AND PLATES.

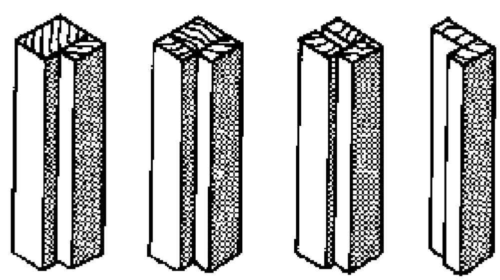


Figure 3-11. TYPES OF CORNER POST CONSTRUCTION.

3.2.2.1 *Locating Dislocated, Warped, or Broken Framing Members.* If some of the evidence listed in the preceding paragraph is apparent, tapping the interior wall surface can be helpful in locating dislocated, warped, or broken framing components. Plaster, dry wall, paneling, or similar interior wall material will be removed and the damaged member replaced or repaired.

3.2.2.2 *Methods of Repair* Warped studs can frequently be returned to original alignment with additional bridging. Headers, lintels, and sills can be returned to horizontal position by proper shimming. Any major structural repairs or replacements such as the latter should not be undertaken in load-bearing walls without first removing the load from the wall under repair by adequate shoring and jacking. The same precaution would apply in remodeling activities, where new doors, arches, or windows are being made. Framing repairs and replacement techniques for walls and partitions are, in general, similar to the procedures used in correcting floor-support failures. Some of the methods are as follows:

a. Trussing and shimming.

b. Split rings and shear plates.
c. Yoke angles, clamps, and stitch bolts.
d. Bracing and bridging.
e. Scabs.
f. Splicing
g. Tightening bolts and renailing

3.2.3 Framing Around Openings

As discussed in the preceding paragraphs, framing around openings can be directly affected by other structural failures. Figure 3-12 details these framing components to aid in a better understanding of repair and replacement considerations. It is apparent that repair to these sections involves removing trim surrounding wall surfaces, windows or doors, insulation, vapor barriers, and similar building components.

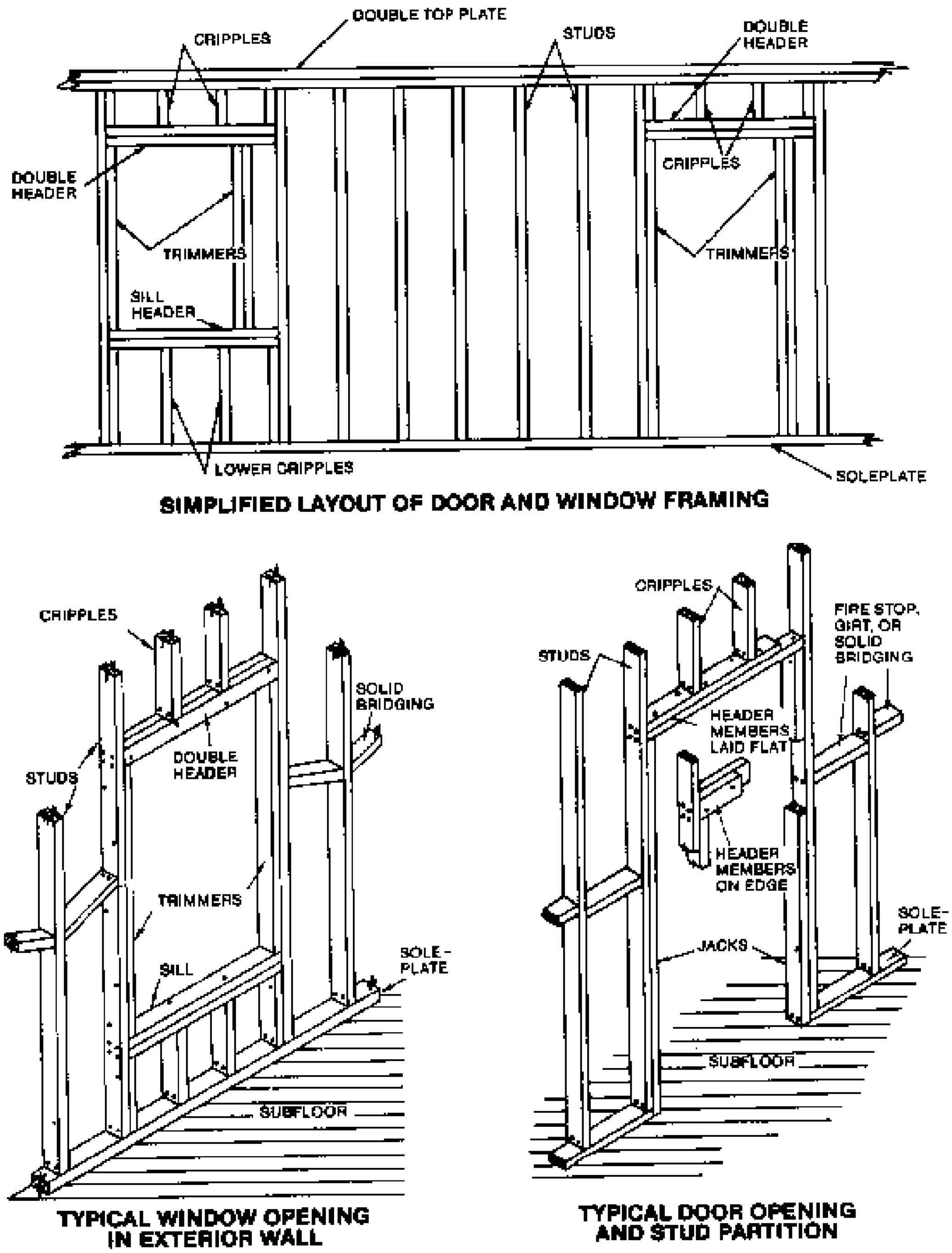


Figure 3-12. FRAMING AROUND OPENINGS.

SECTION III—STEEL FRAMING

3.3.1 General

Some of the advantages of steel framing include ease of construction and freedom from shrinkage, decay, and insect infestation.

3.3.2 Lightweight Steel Framing

For smaller buildings, lightweight-steel framing assemblies are in common use. Figure 3-13 shows a typical lightweight steel framing system. Maintenance of this type of framing is primarily concerned with tightening fittings, preventing corrosion, and checking for deflection and twisting of members.

3.3.3. Structural Steel Framing

Heavy-steel framing is used in many major buildings and related structures. Routine maintenance is limited to regular painting, tightening of fittings, and periodic inspections to check for deflected, twisted, or damaged structural members. Except for the above procedures, the installation engineer or higher echelons will be consulted prior to instituting maintenance or repair measures on heavy-steel structural systems.

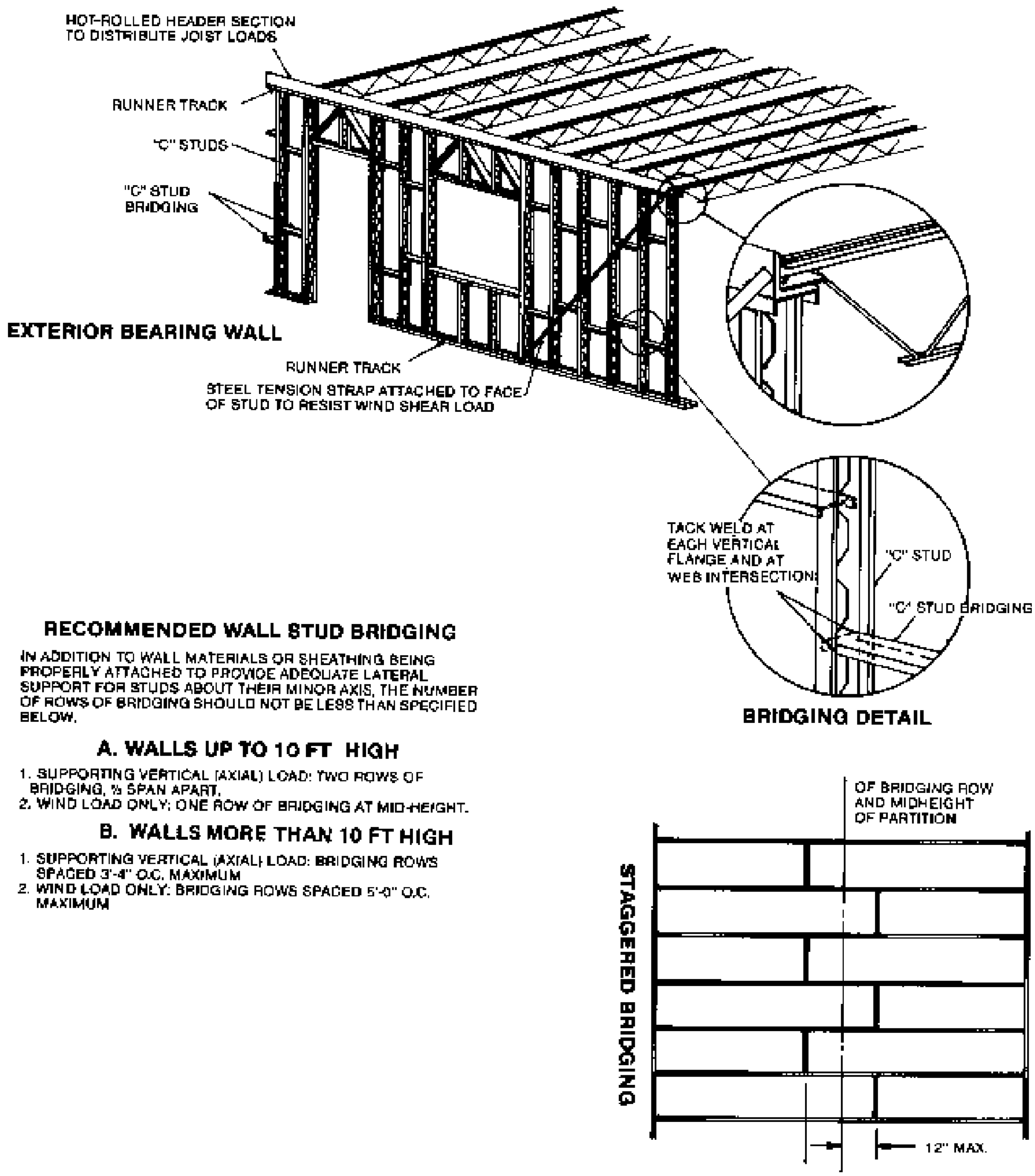


Figure 3-13. METAL FRAMING SYSTEM.

3.3.4 Steel Studs

Steel studs are being used extensively in gypsum board nonload bearing partitions. They compare favorably with wood studs for the same type of construction. However, steel studs offer the additional advantage of being noncombustible. These studs are formed from steel sheets conforming to Federal Specifications QQ-S-698 and QQ-S-700D and are galvanized or provided with a protective coating. Steel studs are C-shaped, formed from material having a minimum nominal thickness of 0.021 inch with a web dimension of not less than 2½ inches. Larger web dimensions are available depending on the partition thickness desired. Steel stud flanges are not less than $1^{5}/_{16}$ inches wide, with each flange having a stiffening lip bent parallel to the stud web. Stiffening lips are not less than 1/4 inch wide with turned or folded edges. Some steel studs are fabricated with preformed holes (knockouts) in the web to accommodate utility lines. See figure 3-14.

SECTION IV—ROOF FRAMING

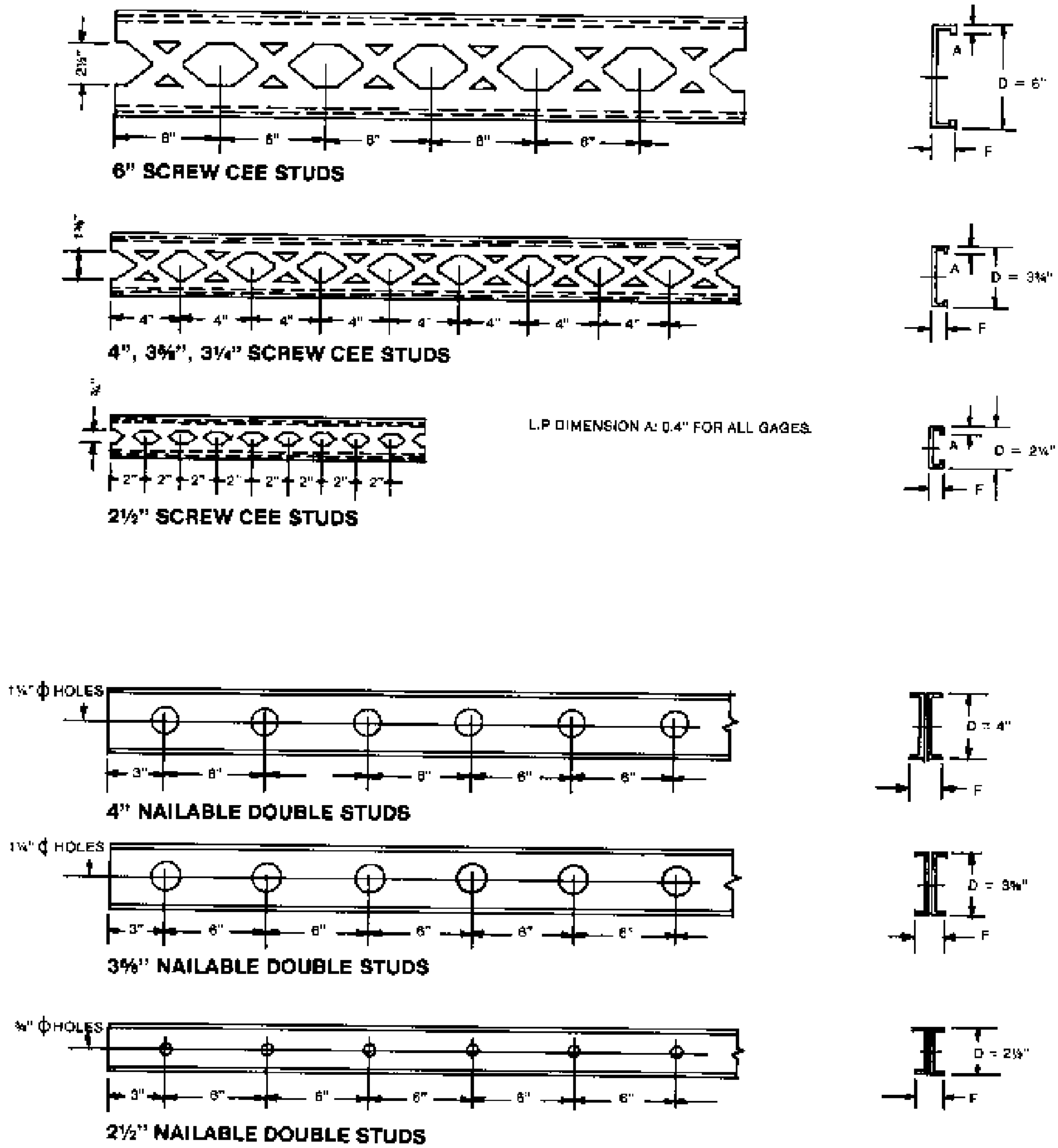


Figure 3-14. FABRICATED STEEL STUDS.

3.4.1 General

Rafters, roof trusses, roof beams, purlins and girders support roof loads in much the same way asjoist beams and girders support floor loads. The notable difference is that pitched roofs must resist lateral forces such as those caused by wind.

3.4.2 Types of Roofs

Roofs can be classified in types according to their shapes and also according to their structural limitations. The shapes include flat; pitched (such as shed or lean-to types); curved such as that provided by bowstring trusses or circular arches; or mansard, which is a combination of a steep-pitched and shallow-pitched roof. Roofs which are supported on exterior walls and at a ridge or bearing at some intermediate point are usually referred to as frame roofs: Those that are truss- or arch-supported at the exterior walls on other trusses or columns are referred to as trussed roofs.

3.4.3 Frame Roofs

Rafters are the structural members of a frame roof. Figure 3-15 illustrates the terminology for frame roofs. Frame roofs vary widely, from the simple shed or lean-to type of flat roof to complicated hipped and gabled roofs, which provide for projections in walls which are at right angles to the main gable. Figure 3-16 shows some of the common types of frame roofs.

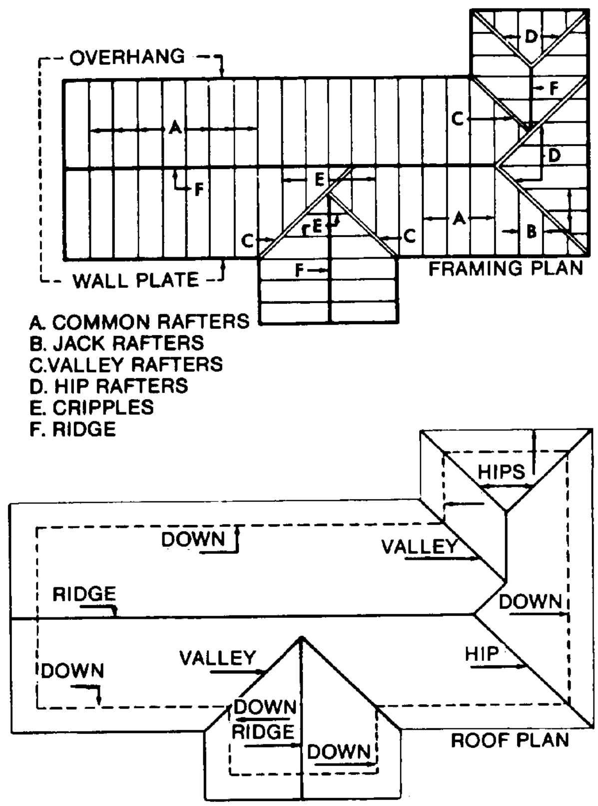


Figure 3-15. ROOFING TERMS AND TYPES OF RAFTERS.

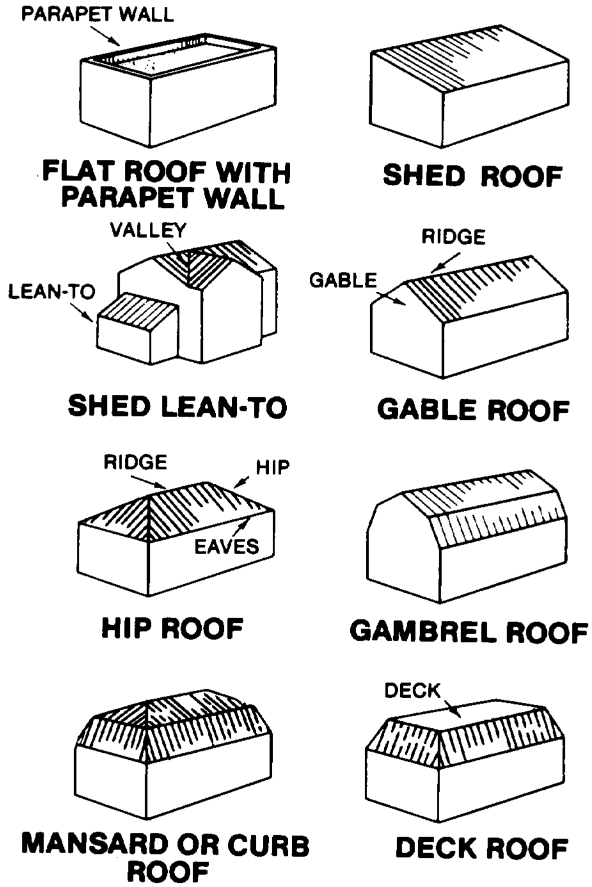


Figure 3-16. FRAME ROOF TYPES.

3.4.4 Frame Roof Maintenance

3.4.4.1 *Roof Rafters.* Rafters are generally more accessible to inspection than other structural members of a frame building because they are usually uncovered on the underside where defects and failures can be visually detected. Warped, twisted, or broken rafters can be replaced, or if the roof surface is sound they may be repaired. Warped and twisted rafters can be straightened by adding solid bridging and bracing, while broken pieces can be scabbed without harm to the roof covering.

a. Rafter Spread. Sustained overload on pitched roofs is usually manifested in spreading the rafters with the consequent sag in the ridge line. Examination of the connection of rafters to the plate will be included in an inspection of roof framing.

b. Slippage. If rafters moved outward on the plate, they can be brought back to line by pulling the ends of the rafters together with rods and turnbuckles or other devices.

c. Thrust. The same effect would be noticeable if the exterior walls were moved outward by thrust from the rafters. This condition can be remedied in the same manner as for slippage.

d. Anchorage. Anchorage of the rafters to the top plate is best accomplished by applying framing anchors, such as shown in figure 3-17.

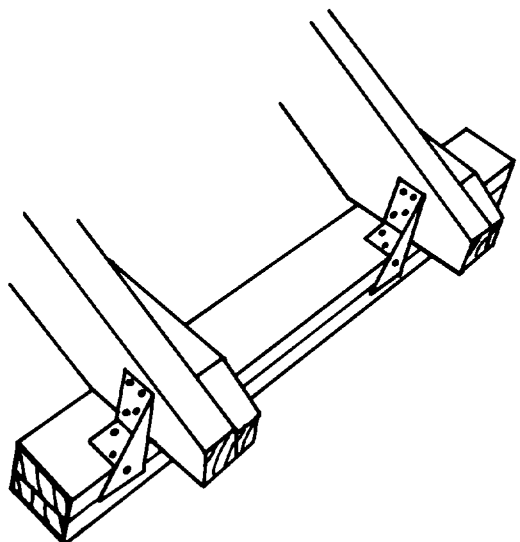
3.4.4.2 *Decay.* Rafters, sheathing and other roof-framing members which are damaged by decay must be replaced. One of the most prevalent causes of extensive roof maintenance is roof-framing failure. Leaky roofs no longer protect the framing, thus allowing weathering and eventual decay. Roofs therefore will be inspected periodically and repairs to surface coverings made immediately upon detection of failure. See Tri-Services Manual, "Maintenance and Repair of Roofs."

3.4.4.3 *Ventilation.* Areas under the roof and above the ceiling will be well ventilated. Air vents will be kept free from obstruction so that condensation does not contribute to decay of the roof members. See paragraph 4.2.5 for information on ventilation.

3.4.4.4 *Sheathing.* Sheathing under the roof covering should be inspected for movement, decay, and warping or cupping. It is sometimes necessary to redrive nails to tighten sheathing and prevent cupping of the individual pieces. Threaded nails of various types are useful since they have more withdrawal resistance than plain shank nails. Where it is necessary to renail sheathing, roof repairs will be made in accordance with Tri--Services Manual, "Maintenance and Repair of Roofs."

3.4.5 Roof Trusses

Figure 3-18 illustrates the more common types of trusses and indicates the character of the stress for typical loadings.



RAFTER CONNECTORS

Figure 3-17. RAFTER ANCHORAGE TO PLATE.

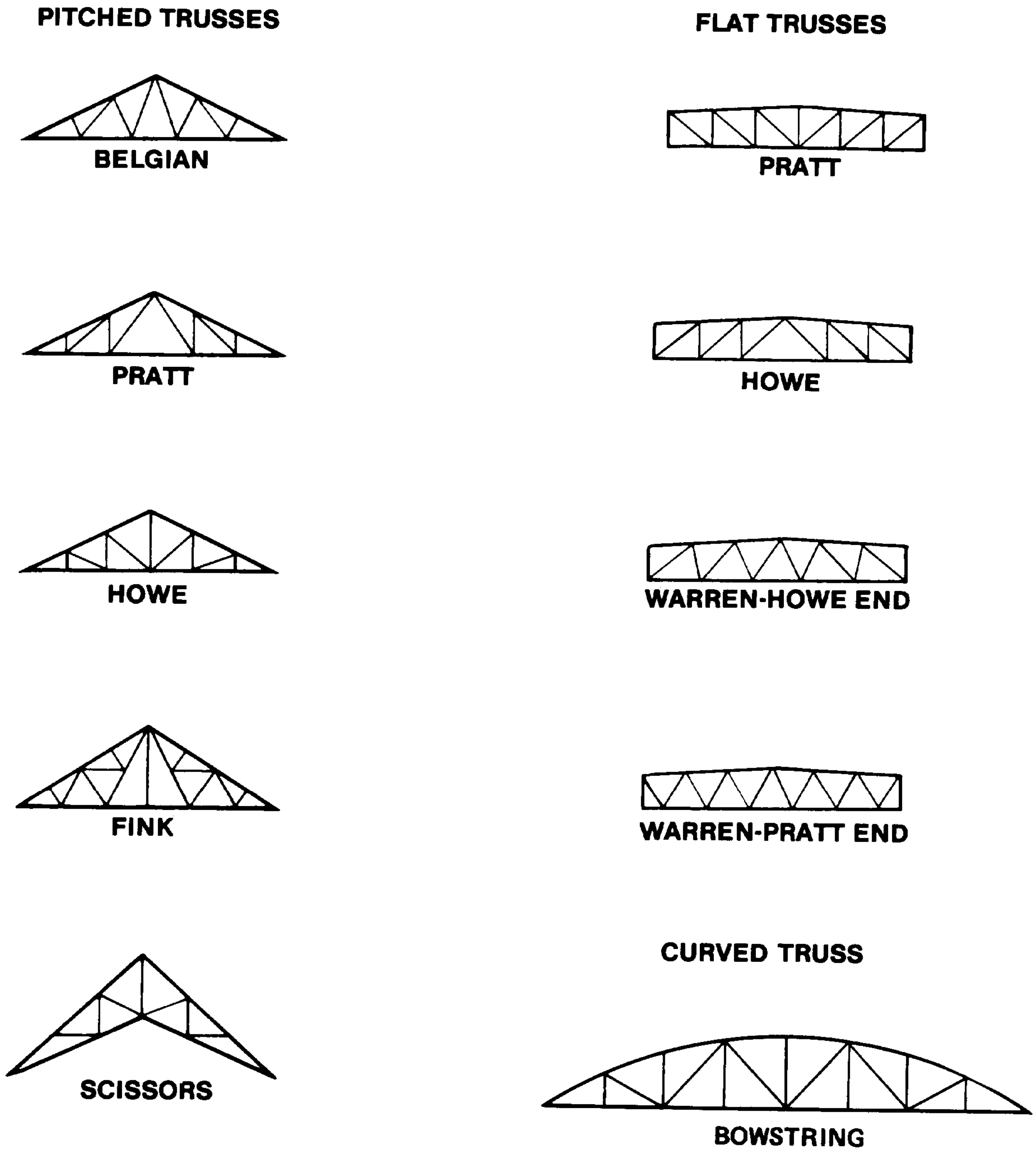


Figure 3–18. COMMON TYPES OF ROOF TRUSSES.

3.4.5.1 *Flat Trusses.* Most commonly used for long spans are the flat-type Pratt trusses, with spans up to 120 feet. Both the Pratt and Warren flat-type trusses, as well as the Howe Truss, are characterized by relatively high stress in the web members in relation to the chord member stresses.

3.4.5.2 *Bowstring or Curved Trusses.* Bowstring trusses are generally found in the smaller hangars, warehouses, and some recreational buildings. These trusses are characterized by relatively high chord stresses with the web members carrying proportionally lighter stress. The upper chords of bowstring trusses are generally of laminated construction. Failures will be found more often in the chord members. However, this type of truss gives comparatively less maintenance trouble than other types.

3.4.5.3 *Pitched Trusses.* Pitched trusses of the Fink, scissors, and related types are used for short span, usually 60 feet and under. They are found in recreational, chapel subsistence, garage, barracks, and similar type structures.

3.4.6 Timber

Expensive and unnecessary repairs or replacements are sometimes made on timber members that, despite extensive seasoning, still retain the full load-carrying capacity for which they were designed. To properly evaluate the effects of seasoning, a full understanding is required of timber behavior during seasoning, timber construction practices, and the designer's allowances for these factors.

3.4.6.1 *Definitions.*

a. Check: A surface opening caused by seasoning, which does not extend through the thickness of the piece and follows the grain. Severe checking appears as a series of discontinuous cracks progressing from one wood-grain layer to an adjacent layer with none of the separations extending to the other side of the piece. A check is not a matter of concern unless there is a possibility of becoming a split in a critical location. Do not refer to checking as "cracking."

b. Split: An opening which has separated the wood, extending from one surface through the piece to the opposite surface or to an adjacent surface. A split is of most concern when it extends from the tension face of a beam bottom of beam in beam- and post-type construction); or, if the split passes through the bolt or connector area in a truss member. Do not describe the condition as "splitting."

c. Shake: A separation along the grain, most of which occurs between the rings of annual growth. For practical purposes, treat a shake as a particular type of split.

d. Stitch bolt: A small bolt (generally d- or ½-inch diameter) placed in a member to prevent enlargement of checks or splits. Stitch bolts should never be used to close a check.

e. Bolt Area: Area bounded by a line ¼ inch outside the bolthole and extending through the thickness of the wood member, not to be confused with the bolt-bearing area. In bolts without connectors it may be considered as the area covered by the bolthead or nut and washer.

f. Connector Area: Area bounded by a line around the bolt equal in diameter to the diameter of the connector and extending through the thickness of the wood member. Since properly installed connectors cannot be seen, reference must be made to structural detail drawings to determine the size. If drawings are not available the size may be determined by loosening nuts and prying members apart sufficiently to insert a knife or spatula blade and measure them.

g. Saw Kerf. An artificial, predetermined split of limited length made by sawing through parallel to the axis of a piece, thus preventing uncontrolled location and direction of a possible natural split or check. Purpose is the same as a contraction joint in concrete.

h. Compression Member: For purposes of these data a compression member is defined as a member which is loaded axially in compression.

i. Tension Member: A member which is loaded axially in tension.

3.4.6.2 *Lumber Grading.* Lumber is inspected at the mill and strength graded according to visual characteristics, such as knots, shakes, splits, checks, holes, decay, and slope of grain. Working stresses for strength grades are assigned, which include appropriate downward adjustments of clear wood stresses to make allowances for sizes and location of knots, slope of grade, shakes, checks and splits permitted in the particular grade. In general, the working stress for the structural grade of lumber specified has made allowance for checks and splits *normally expected* throughout the life of the piece. These allowable working stresses may be obtained from the "National Design Specifications for Wood Construction," published by the National Forest Products Association.

3.4.6.3 *Seasoning.* Lumber may be either kiln-dried or air-seasoned. Kiln-drying minimizes development of checks and allows selection of pieces with extent of checking predetermined. Kiln-dried dimension lumber in small sizes (4-inch or less thickness) is readily available and usually used. Large-sized (4-inches and up) kiln-dried lumber is usually not available except on special order and after considerable delay. Consequently, large-sized lumber is often installed green and allowed to air-season with large checks and splits being commonplace.

3.4.6.4 *Checking.* Checking most adversely affects the strength of lumber when checks are located at the ends of the piece within the middle third of the depth of a piece used as a beam. Such checking weakens the beam's resistance to horizontal shear. However, horizontal shear only becomes a design consideration in short and relatively thick beams. Another adverse effect occurs when checking is at a steep slope near the tension face of a beam. Such checking reduces the beam's resistance to tension and, if not arrested, could develop into a split. Normally checks are of relatively little importance; their seriousness is a factor only in bending action or in the probability of developing into a split and the relative importance of a split in that location. Appearance alone should not be the deciding factor. The function of the member is the prime factor. Since most members of trusses are designed for axial loads only and not in flexure, checking may largely be ignored (unless usage or design shows the member to be in flexure). Only splits extending through bolt or connector areas need be evaluated.

3.4.6.5 *Shakes.* Shakes occurring in the connector area which might result in separation of a portion from the rest of the piece should be investigated for repair. Other shakes may be disregarded as such and be evaluated as a check or as a split.

3.4.6.6 *Splits*. Splits occurring in compression members, such as columns, may be serious if there is no probability of slippage from wedging action of connectors or bolts and if the split appears to be dividing the member completely into two parts, thus increasing the length-to-depth (lid) ratio. Splits extending into the bolt or connector area of tension members should be investigated and measure. All measurements of split openings should be made at the distance from the bolt, which is the required end distance for the size of connector used. Excess end distance should be ignored. A single split within the connector area, up to $^{3}/_{16}$-inch opening of the splits for a connector of 2 e inch or less and a split of ¼ inch for connectors more than 2 e inch up to 4 inches, may be disregarded. Splits opened up more than of these widths should receive remedial action to curtail further splitting. If there is more than one split in the connector area, the total opening of the splits should not exceed 1½ times that for one split. Splits may be repaired by use of stitch bolts provided that the cross-sectional area removed by boring does not exceed the cross-sectional area occupied by the maximum-size knot permitted in the structural grade of timber used. Clamps consisting of small angles and pairs of bolts alongside the member at the split may also be used. Care should be exercised in tensioning both stitch bolts and clamp bolts snugly. No attempt should be made to close a split or a check as this may cause it to extend on the other side of the joint.

3.4.6.7 *Sagging Beam.* Sometimes a sagging timber beam will appear to be overloaded when it is really not overloaded. An inelastic deformation called creep will give an appearance of excessive deflection at the midpoint. Damage might occur if such a beam is jacked back into a level position. The beam should be checked first to find out if there is any evidence of recent motion. In a real overload, there will be fine breaks revealing unexposed wood fiber or flaking of paint or other finish material. Measurements should be taken and the beam monitored to determine any additional deflection. If it is determined that creep has occurred and the roof deck must be leveled, it should be accomplished by shimming between the beam and the roof deck.

3.4.7 Defects

Discussed below are typical causes of defects usually found in roof trusses. The discussion is mainly concerning wood trusses, since these trusses present the majority of the roof truss problems.

3.4.7.1 *Defective Material.* All lumber incorporated in the trusses should be carefully checked during inspection. A record should be kept of the members containing an excessive number of knots so that particular notice can be made of those members upon subsequent inspections. Specification requirements for structural grade material are that knots will be sound, tight, and not in clusters. The size of the knots should, of course, be limited. It is recommended that the installation engineer acquire, for reference, standard grading rules as published in pamphlet form by the lumber industry for use in determining the quality of material incorporated in the trusses.

3.4.7.2 *Poor Workmanship.* Poor workmanship is evidenced in many ways. Some of the conditions that have been encountered in the past are outlined below for particular emphasis. Lack of precision in drilling boltholes and cutting grooves for timber connectors will cause inadequate gage, edge, and end distances that may reduce the strength of the truss. In some instances the grooves for the timber connectors, although required on one side only, were cut for split rings when it was necessary to use shear plates. Then new grooves were cut which resulted in too much material being removed and the timber not bearing along the exterior rim of the connector. Both the above conditions could weaken the truss and should receive further investigation. Instances were discovered where holes had been drilled for bolts that were never installed. In other cases, bolts of a smaller diameter than the drilled holes were installed. In both the above cases, the correct bolt should be inserted; however, care must be exercised in supporting the truss and binding the joint before removing the undersized bolt. Quite often bolts have been used that were too long or too short. If a bolt is too short, the head of the bolt and the washer may recess into the member, which reduces net area. When a bolt is too long, it may be impossible to tighten the nut enough to obtain a snug connection.

This condition, however, can be remedied by removing the nut and installing additional washers as fillers. Washers on too small an area or thickness have been used between bolthead and timber, resulting in a crushing of fibers or a dishing of the washer. In cases of unusual checking or settlement at particular panel points, an inspection should be made to determine if any timber connectors have been omitted. Conditions may be discovered where timber connector grooves have been cut too deep or too shallow. Both conditions are serious and should be investigated further. Many instances have been observed where the ends of the web members have been cut off flush with the underside of the bottom chord. In some cases this was done so that electric conduits or other mechanical fixtures could be attached to the underside of the chord; in other cases, it was done to increase the ceiling clearance, particularly in garages where the members were in line with entrances where trucks were likely to pass. This reduction of end distance is detrimental to the truss and, in addition to weakening the truss, makes it difficult to repair excessive splitting of the member by installing stitch bolts.

3.4.8 Inspection

Timber trusses should be inspected at least once each 2 years. More frequent inspections may be directed by the individual military departments for specific facilities, such as commissaries, theaters, gymnasiums, exchanges, dining halls, and places where large crowds assemble. Appendix B contains several suggested formats which may be used as forms to aid in the inspection process. The first is a data sheet which will remain unchanged until alterations are made to the building. Larger elevation views and photos should be used when necessary to monitor serious defects. A checklist will remind the inspector of items to inspect. A simple form may be used for routine annual inspections with minor defects described on the reverse side. Examples of these non-compulsory formats not requiring reporting are included. Visual inspection from the floor, even with the aid of binoculars, is not enough. The following inspection procedure is suggested.

3.4.8.1 *Checking Existing Construction.* If possible, obtain the latest revision of the structural drawings of the truss and verify if the existing structure conforms with the drawings. Significant deviations or alterations should be reported so that the changes can be analyzed structurally and the record drawings updated. No attempt should be made by the inspector to correct apparent construction deficiencies unless structural analysis indicates that correction is advisable or if subsequent inspection reveals movement indicating that the truss is in distress and remedial measures are necessary. The structural detail drawings will indicate the existence of timber connectors (which are normally concealed) as well as the type and size, which will aid in evaluating the seriousness of any splits found in the onsite inspection.

3.4.8.2 *Terminology.* The inspector should familiarize himself with the proper timber terminology and use it in his reports. Timber terms are defined in paragraph 3.4.6.1.

3.4.8.3 *Overall inspection of entire truss.* Examine the truss from the floor to determine if there is:

a. Obvious failure of truss, which would make an inspection from the truss itself unsafe.

b. Lateral bowing of upper or lower chords with respect to truss support points. A truss that is laterally bowed indicates that lateral support is either nonexistent or nonfunctioning. Further examinations must be made of bridging, X-bracing, struts, purlins and deck to determine if slippage is occurring in a connection.

c. Vertical sagging of frame (subsequent study will determine if sagging is normal deflection due to loading, long-term creep, or partial failure of an overloaded member).

3.4.8.4 *Detailed inspection.* Examine the truss at close range from a ladder, lift machine or from the truss itself to determine the following:

a. Rupture of any member.

b. Evident separation of sides of members at joints. Nuts should be snug enough to prevent separation of members without embedment into the wood. Loose or absent nuts are detrimental when they permit the timber members to separate and render the shear connectors less effective. Missing nuts should be replaced and all nuts tightened to snugness without embedment into the wood.

c. Noticeable bowing or warping of any member. Bowing could indicate an overloaded compression member; however harmless warping may occur in an unloaded redundant member.

d. Continued development of checks (nonthrough cracks) toward line of bolts. Progressing checks are indicated by freshly exposed wood surfaces at ends of checks. A check progressing toward a bolt or connector area should be monitored so that corrective action can be taken before it becomes a split.

e. Development of splits through a bolt area or connector area of web joints or chord splices.

f. Evidence of leakage such as waterstains, mold, or decay.

g. Wood crushed by overtightening of bolts.

h. Wood fibers freshly exposed by flaking paint or preservative.

3.4.8.5 *Inspection of Ancillary Member.* Examine other members attached at right angles or providing support to the truss to determine if there has been any movement. These may be:

a. Beams or purlins supported on the top of the top chord. These may be secured by nails "toe-nailed" into the top chord of the truss. Any movement will result in the nails bending at the member interfaces and the members may disengage completely. If purlins had been installed with bolted clip angles on top of the truss or recessed into sides of top chord with steel hangers, such movement would have been almost completely eliminated.

b. Struts installed across tops of bottom chord should be examined in the same manner as purlins.

c. X-bracing members serving as sway bracing or bridging should be examined to determine if connections provide positive support to maintain vertical alignment of truss. The truss designer may be provided lateral bracing by another means but, nevertheless, the absence of X-bracing should be noted in reports.

d. Purlins, beams, and struts should be examined for freshly exposed wood where member extends into expansion joint pocket at firewall.

e. Purlins, beams, and struts abutting walls and chord fastened with clip angles or hangers should be examined for bowing or freshly exposed wood fibers indicating member has been subjected to unusual loads.

f. Masonry unit walls, columns or pilasters supporting trusses and concrete piers supporting timber columns must be examined for deterioration. The presence of cracks in brick or mortar adjacent to the bearing plate must be noted. Recent movement is indicated by vertical edges of bricks being out-of-line, corners of brick or concrete broken, cracked brick, and other exposures of unweathered brick or concrete.

g. Timber columns, knee braces and column capital must be examined for damage created by moving vehicles as well as the other defects discussed above. Special note should be made of any large foreign items installed on columns or any notches or cutouts made to accommodate any type of equipment. Many times such attachments conceal deterioration in the column underneath.

3.4.9 Timber Roof Maintenance.

The following paragraphs describe maintenance procedures which should be followed for timber roof framing.

3.4.9.1 *Bolt Tightening.* It is important that all truss connections receive periodic tightenings until the moisture content of the lumber reaches a state of equilibrium with the atmosphere. It is also important that, during the first year, the connections be tightened at frequent intervals to prevent the connections from becoming excessively loose, resulting in settlement of the trusses, excessive splitting caused by the introduction of abnormal stresses, and, in extreme cases, failures in truss members. There are a number of corrective methods for repairing damaged members. The types of failures, near failures, and other unsatisfactory conditions encountered vary and require a different approach in practically all cases. Bolts should be snug but not overtightened to the extent to cause damage to the timbers. Listed below are typical repair and maintenance operations as performed under the bolt-tightening program.

a. Truss bolts will be tightened as soon as they become excessively loose. Bolts may be considered loose if, after striking the bolthead a sharp blow with a hammer, the nut can be taken up two full turns or more. Actually, this condition would not cause concern when there are a number of members meeting at a connection, if the actual reduction of bearing area on the connectors were the only consideration. However, a looseness of bolts at all connections reduces the rigidity of the truss as a whole. The character of the timber trusses is such that there is a certain eccentricity to the lines of stress, and such looseness would tend to increase that condition.

b. Climatic conditions determine the rate at which shrinkage occurs. In the northeast, for example, the summer season is warm and moist so very little shrinkage is likely to occur. During the winter months when the air is normally less humid and the buildings are heated, the relative moisture content of the atmosphere is greatly reduced. Consequently, it is unlikely that any appreciable shrinkage will occur from May to October in that area. During the remaining period, a closer check should be kept on trusses. Climatic conditions vary in different sections of the country, but require the same general consideration as outlines above.

c. While performing a routine bolt-tightening operation, the bolts should be checked to determine if there is sufficient thread to tighten the nut. Also check the size of washers; if they are so small that the truss members cannot be drawn together without embedding the washer, they should be replaced with larger ones. Where it is impractical to remove the bolt to place a new washer next to the bolthead, a square, slotted washer may be inserted between the existing washer and the wood. Wherever slotted washers are used, a nail should be driven into the timber at the edge of the washer, protruding sufficiently to eliminate the possibility of the washer turning and falling off in the event of further shrinkage of the timber. All washers should be at least ¼ inch in thickness and not less than 2 inches square. When tightening nuts, the bolthead should be struck sharply with a hammer to force the bolt through the truss member and break any adhesion between the bolt and timber resulting from corrosive action.

d. Under those conditions where there is insufficient thread to draw the timber tightly together, a filler washer of some type is required. Usually these bolts extend at least 2 inches beyond the nut. A short compression spring has been used with excellent results as a filler, which, in addition, maintains a tight connection, thus reducing the frequency for future tightenings. These spring washers should, therefore, be considered when preparing for a first tightening of any truss. The bolts should be checked to determine the amount extending beyond the nut after they have been tightened; if the extension is sufficient, the springs should be installed. The springs that have been used are of round edge, $^7/_{16}$-inch by ¼-inch section, and of two to three coils. The pressure exerted when fully compressed is approximately 2,800 pounds and there is a straight-line reduction as it expands. This pressure compares favorably with the allowable compression stresses perpendicular to the grain.

e. In many structures, inspection reveals that bolt tightening is required due to shrinkage alone. As a general rule, bolt tightening should be performed if the average takeup on nuts is more than two turns. This, of course, is quite arbitrary and depends greatly on the size of members and length and size of bolts. The importance of keeping bolts tight cannot be overstated. Design values are predicated upon tight connections. In a bolt-tightening operation, care should be exercised to see that the men have safety belts, if necessary, to work from a hazardous height. Spud wrenches of the proper size are used in order that uniform leverage and takeup may be obtained in all bolt-tightening operations. The use of slotted washers is recommended as fillers. It is important that bolts be tight, but too much leverage on the spud wrench may force the washer into the fiber of the wood, destroying that fiber and cupping the washer. Effective tightening of bolts should be accompanied by tapping on members and boltheads. It is especially important that bolt tightening be performed upon completion of a structure, and that frequent inspection and additional tightening be performed during the year following construction. A few drops of oil placed behind the nut will facilitate tightening of bolts having rusty or dirty threads. It is recommended that each bolt, after tightening, be keel-marked for inspection purposes. It is further recommended that date of tightening be stenciled on one of the trusses of a structure to keep the importance of this maintenance work firmly in the mind of inspectors.

3.4.9.2 *Omission of Ring Connectors and Bolts.* At the time of bolt tightening, it will be noted whether or not the corrective bolts are in the holes drilled for them or whether any bolts have been omitted. In such cases, bolts should be replaced or installed. If timber connectors, such as shown in figure 3-19, have been omitted at any joint or if there is visual evidence of excessive stress at the joint, repairs should be made and the proper bolts and connectors installed while the truss is fully supported at the panel points and clamps are relieving the joint of all stress. The condition of the joint should be recorded and special observations made upon subsequent inspections. Precautions should be taken so that additional loadings, such as hoists and monorails, will not be applied to those panel points.

3.4.9.3 *Roof Settlement.* As roof truss connections become loose, roof settlement occurs. While this settlement might not be of concern to the structural adequacy of the truss itself, problems may develop in other areas requiring remedial action.

a. Roof Drainage Systems. On structures containing parallel chord roof trusses, any settlement will seriously affect the roof drainage. Usually a wood truss is fabricated with several inches of camber, a considerable portion of which remains after the installation of the roof deck, roofing, and other dead loads. The roof slope for proper drainage is predetermined, and the roof purlins are set on shims or blocks to acquire that slope. As the truss connections become loose due to shrinkage of the lumber, the trusses sag and drop below the horizontal. This, of course, removes the possibility of rainwater draining from the roof and so increases the live loads to which trusses are subjected. It has proved to be almost impossible to replace a camber in a truss. Consequently, jacking a truss prior to a bolt-tightening operation will be of little value. Instead, the roof purlins must be raised from the top chord of the truss and shims placed between the purlins and chords. Perform all jacking directly from the truss; otherwise, the removal of the roof loads from the truss will only cause the truss to rise with the roof. In order to jack the purlins, short timbers should be set on the bottom chord of the truss perpendicular to the chord and directly under the purlins to be raised. The purlins should then be jacked cautiously so that there will not be an abrupt rise in the roof to break the roof covering and cause leaks. This work should be performed during the summer season when the roofing is pliable.

b. Binding of Doors. Where roof settlement of a hangar occurs at the door guides, which were originally set with provision for approximately 3 inches of adjustment, a binding of the doors is inevitable. The procedure for adjusting the door guides, of course, depends upon the design of the canopies and guides.

3.4.10 Timber Roof Repair

The following paragraphs illustrate and discuss methods of repair and standards to be used. Typical examples of actual conditions found and repaired are presented.

3.4.10.1 *Shoring.* It is frequently necessary to shore trusses to prevent collapse or to provide security while making repairs. Figure 3-20 indicates proper locations for shoring typical trusses. Shores can be placed at all panel points if desired. The methods shown indicate the minimum number of shores necessary to properly support typical trusses. In shoring Warren-type trusses, it is advisable to place a temporary strut to prevent introducing serious secondary stresses in the truss members. Eight-ton jacks may be used under the shores. Shores themselves may be of steel or of seasoned timber. Sufficient planking should be placed under jacks to distribute load on the floor. Trusses should be raised slowly and carefully, jacking each shore in small increments at any one time. Otherwise, additional failures. may occur, due to secondary stresses and distortion, and damage may be done to the roof membrane of the structure. Both judgment and experience are required for this operation.

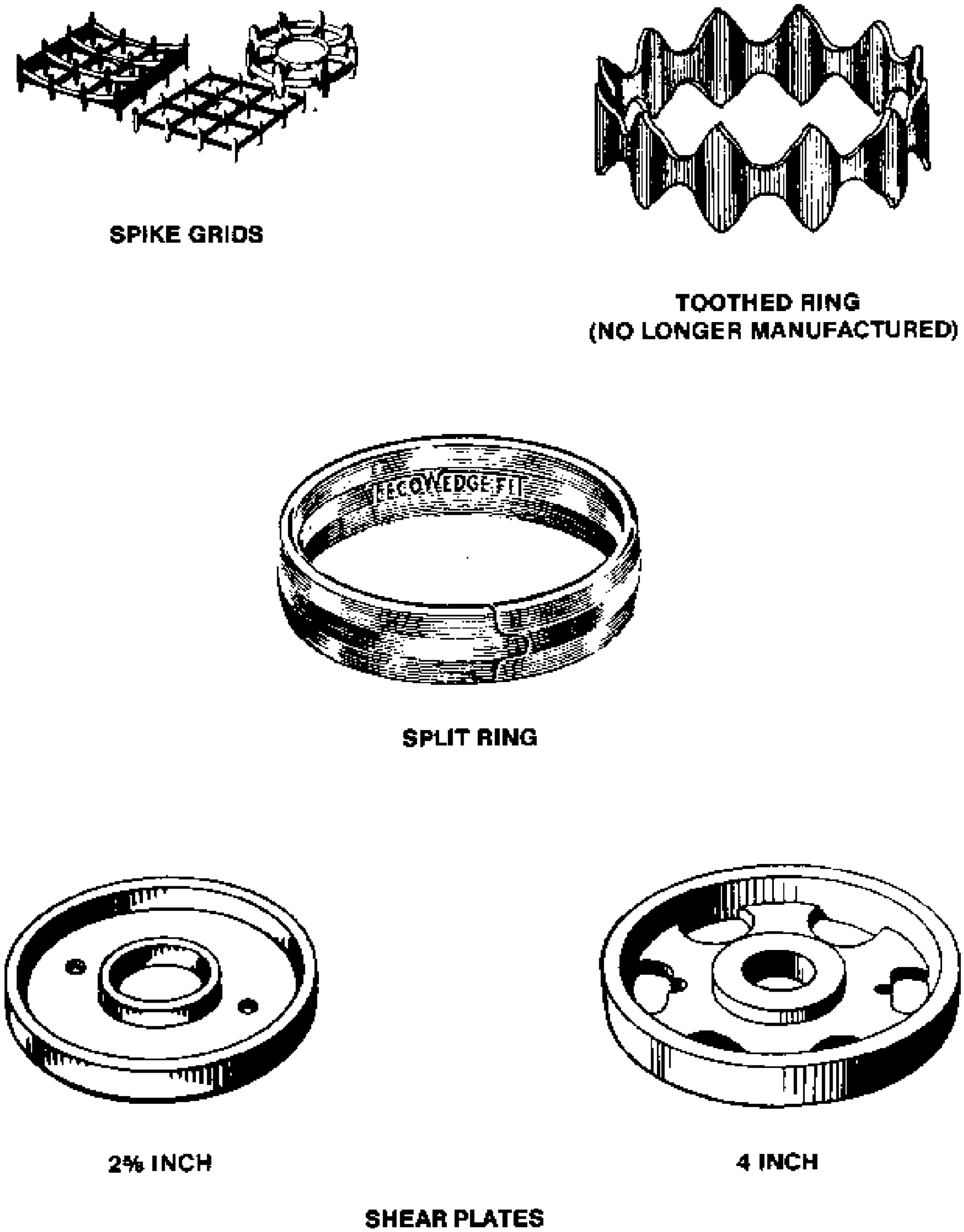


Figure 3-19. TIMBER CONNECTORS.

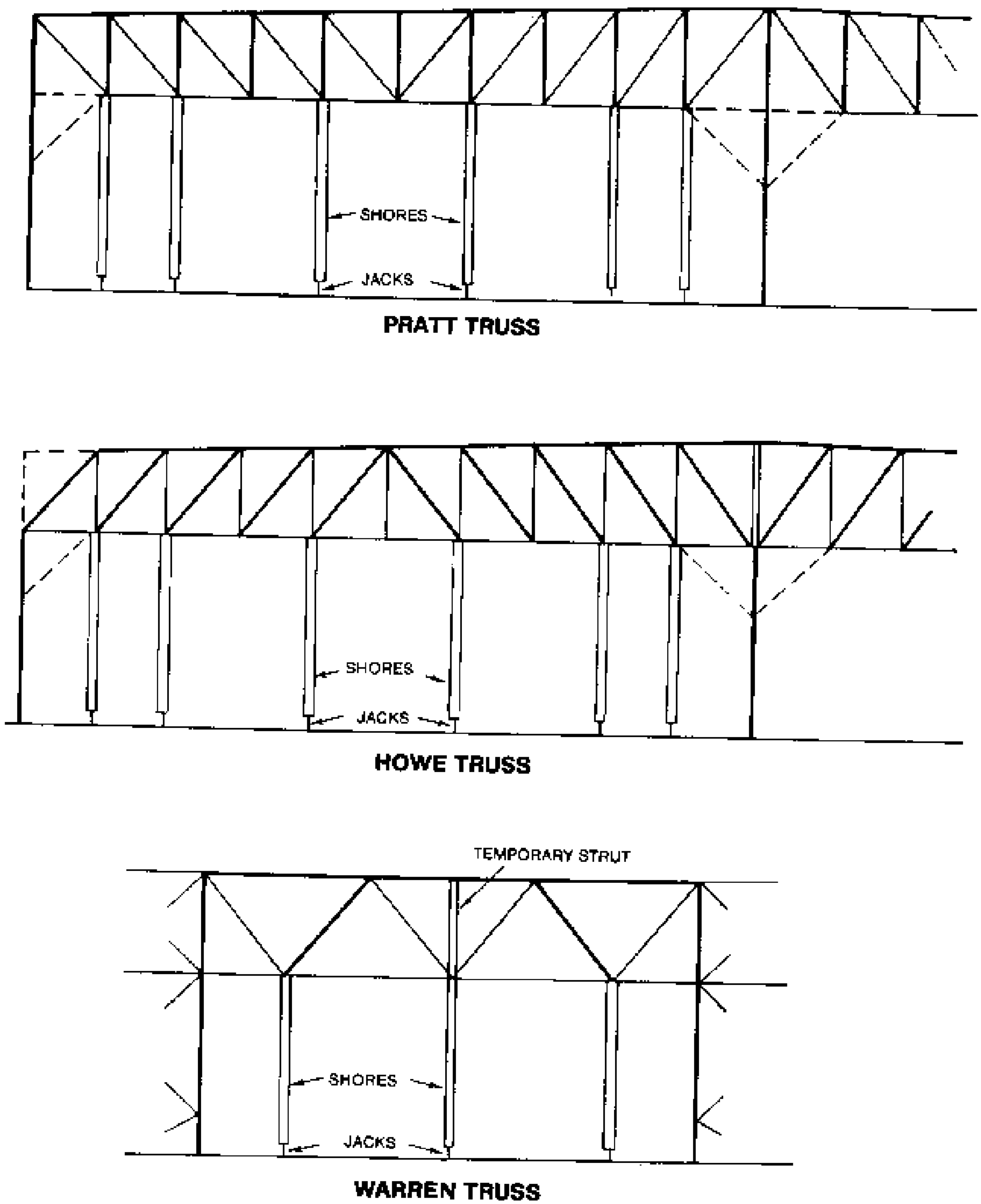


Figure 3-30. SHORING OF TYPICAL TRUSSES.

3.4.10.2 *Split and Checked Members.* As previously stated, the standard practice of using unseasoned lumber for trusses invites checks and splits in the members when unseasoned lumber is used. Checks and splits are normal reactions in most timber as it dries out, and it is more pronounced in certain types of lumber. In those members that have only one row of bolts, any check or split that occurs is normal and is not likely to be serious. However, if the split passes through the boltholes and continues beyond into the member, it requires attention. The recommended remedy for such splitting and checking is the installation of stitch bolts in the ends of each such member that has split. The bolts used for this purpose are ½-inch bolts, threaded on both ends; $^{9}/_{16}$ inch holes are drilled 2 to 4 inches from the end of the split member and perpendicular to the axis of the member. The bolt is then inserted and 2-inch, square-cut washers are place at each end and the nuts are tightened. It is advisable to install the stitch bolts prior to tightening the bolted connection. If the split is serious and continues well into the member, a second stitch bolt should be placed on the opposite side of the connection about 6 to 12 inches from the ring connector. Usually, this operation will not reduce the net area enough to weaken the member. In some cases, when the split passes through the connection but does not pass too far up into the member, it may be stopped by drilling a small hole through the thickness of the member at the end of the split. This hole will relieve any abnormal stresses at that point. Care must be exercised in drilling stitch boltholes so that holes are parallel to the face of the member. Ship auger bits tend to follow the grain and stray from the intended centerline path. Metal-type fluted drill bits with extended shafts are more effective in drilling straight holes.

3.4.10.3 *Damaged Web Members* (Tension). Quite often an inspection of truss members will indicate that certain members may not be of structural grade material because of the slope of grain is excessive, or the members may contain either an excessive number of unsound knots. These conditions will weaken the members, especially those in tension, and in the case of unsound or excessive knots will reduce the net area of the members. In the event that the condition appears critical or an actual failure has occurred, it will be necessary to reinforce or replace the member.

a. Replacing any truss member can be a costly operation. Unless the building is for permanent use, it is recommended that the member be repaired or augmented rather than replaced. The least complicated procedure is merely to shore the truss directly under the damaged member. This procedure should, of course, be followed only if the floor space is not a consideration.

b. When a tension member fails, settlement may occur in the truss, and the ends of the member at the point of failure may become separate. If the member is to be repaired by splicing, the separated ends must be returned to their original position. This requires simultaneous shoring of the truss and axial tension jacking of the member.

c. A second and more satisfactory procedure is to prepare steel rods with a steel plate welded to one end and the two rods connected by a turnbuckle. The plate at the end of each rod is drilled in the field to fit the existing bolts at the connections at either end of the damaged member. Grooves are cut into the outer face of the top and bottom chord for shear plates and the connectors and plates installed. CAUTION: Grooves for shear plates are cut with a tool utilizing the existing bolt holes as alignment guides for the groove cutters. Before bolts are removed for this purpose, adequate shoring and tension jacks must be installed. The turn-buckle can then be taken up until the web member is returned to its original position.

d. In cases where checks and splits have occurred in tension members, with excessive slope of grain, it may be possible to close the split or retard further development of the split by placing stitch bolts or clamps along the member at strategic points. Stitch bolts, however, should be installed only after careful consideration, for the excessive use of stitch bolts between connections is not desirable and may weaken the member if installed indiscriminately.

3.4.10.4 *Damaged Web Members (Compression).* The usual types of failures in compression are either a shear along the fibers when the slope of grain is excessive or a bowing of the member that may or may not result in breaking of the fibers perpendicular to the grain. It is recommended in all cases that the damaged member be repaired by placing a timber of similar width and depth adjacent to the damaged member, connecting them with bolts and split-ring timber connectors. If the failure is close to the panel point, splicing the member may not be practicable. Installing a new member on the same plane would then be advisable, with the chords connecting the new member to the existing bolts with shear plates and steel gusset plates. The new member should then be securely fastened to the damaged member with bolts and split rings.

3.4.10.5 *Damaged Chord Members.* Failures in bottom chord members occur as the result of excessive slope of the grain, knots, or other defects in the material. In most trusses, the chords and most of the web members are made up of at least two timbers. This allows a certain safety factor: if one timber fails, the other will temporarily carry the additional load. It is likely, however, that under that added load the other member would eventually fail unless the failure is discovered at an early date. Periodic inspections will uncover such conditions before failures occur in adjoining members.

a. Checks usually occur parallel with the grain of the timber. Checks and splits may be more pronounced at panel points containing two rows of bolts that restrain the normal shrinkage action and is further aggravated by the fact that the stresses from the web members are transmitted to the chord in directions perpendicular and at a slope to the chord. If the slope of the grain is excessive, the checks are likely to develop into splits by extending to the edge of the member and may result in failures.

b. Splits often occur in the chord member at the splices where the ends of the timbers butt. There are no sloping forces at those points to aggravate the condition, but occasionally the split continues well into the member, possibly passing through boltholes. Wherever such splits have occurred, it is recommended that stitch bolts be inserted through the depth of the chord member at the splice between the bolts and the end of the chord member. In that way, the split will be kept closed and will not have a tendency to increase.

c. Short members, such as splice plates, are especially susceptible to checks and splits. Quite often, a split develops along the center of the timber parallel to the grain; however, that condition should cause no concern, as splice plates are often deigned of two timbers of the same length, but one-half the width. If the split should develop along a row of boltholes, it is recommended that the member be replaced. The splice plates of many trusses are designed so that they contain a row of bolts at either edge and, at each end, one additional bolt which is on the centerline of the member. Under such a condition and when the split occurs along the center of the splice plate, the condition may be corrected by inserting a stitch bolt beyond the last bolt at each end of the splice plate.

d. At panel points when the split in the chord member is very pronounced, even though the split follows a flat grain, it is advisable to install a stitch bolt within 6 to 12 inches of the outer bolt at that connection. A similar bolt may be inserted at the other side of the panel point. However, judgment should be used when installing stitch bolts at such locations, and they should be installed only where splitting is excessive.

e. If an actual failure has occurred in a chord member, that member should be replaced. To do this, the truss should be shored at the panel points along the bottom chord and the damaged member removed. Using the damaged member as a templet, the new member can be fabricated and installed. The replacements should be of the same material as the truss and of the same moisture content, if possible.

f. If only partial failure has occurred, the chord may be repaired by installing timber splices extending well beyond the ends of the failure. In some cases, steel rods and turnbuckles, similar to those recommended for tension web members, have been used to advantage. However, it is normally more desirable to replace the member and, if possible, to limit the use of steel rods and turnbuckles to locations where it is impractical to shore the trusses. Steel plates should always be used in combination with shear-plate timber connectors when used to reinforce wood members.

3.4.11 Heavy Timber Solid Beams and Columns

Periodic inspection and maintenance schedules will not be limited to timber-trussed structures. Many structures of beam and column design have been erected. As these heavier timbers season, severe checking sometimes occurs. In most cases, this checking, although of considerable width and depth, is parallel to the axis of the member and usually requires no attention. An attempt to close such checks with stitch bolts will only aggravate the condition and cause the checks to extend completely through the members. Whenever this checking occurs in cross-grained members, corrective measures must be taken. In extreme cases, the members should be replaced. In some cases, repairs can be effectively made by bolting channel or angle iron parallel to the member and connecting them with bolts and shear plates.

3.4.11.1 *Edge and End Distances and Recommended Spacings.*

a. Bolt Connections. Figures 3-21 and 3-22 indicate recommended minimum spacings and edge and end distances for bolts in repair design. Data are based on the use of a ¾-inch bolt. Three lines of bolts are not always satisfactory and should be used only in large members where spacing can be kept at a maximum. Shrinkage usually occurs at the center of the piece, and a split usually develops along the centerline of bolts.

b. Connector Spacing Figures 3-23 and 3-24 indicate recommended minimum spacing and edge and end distances for 4-inch shear plates or split rings for use in repair design. For connectors used in lumber not properly seasoned, 80 percent of the tabulated allowable connector loads will apply; spacing and edge and end distances should be increased above the minimum. Installation of the 4-inch connector should be carefully and exactly performed. A large number of present failures are directly traceable to careless workmanship at the time of construction. When 4-inch connectors are used in 1 x 6 members, extreme care should be exercised that they be properly grooved, spaced, and located in order to maintain proper edge and end distances. In this connection, consideration will be given to the advisability of substituting larger dimension timber for repair design.

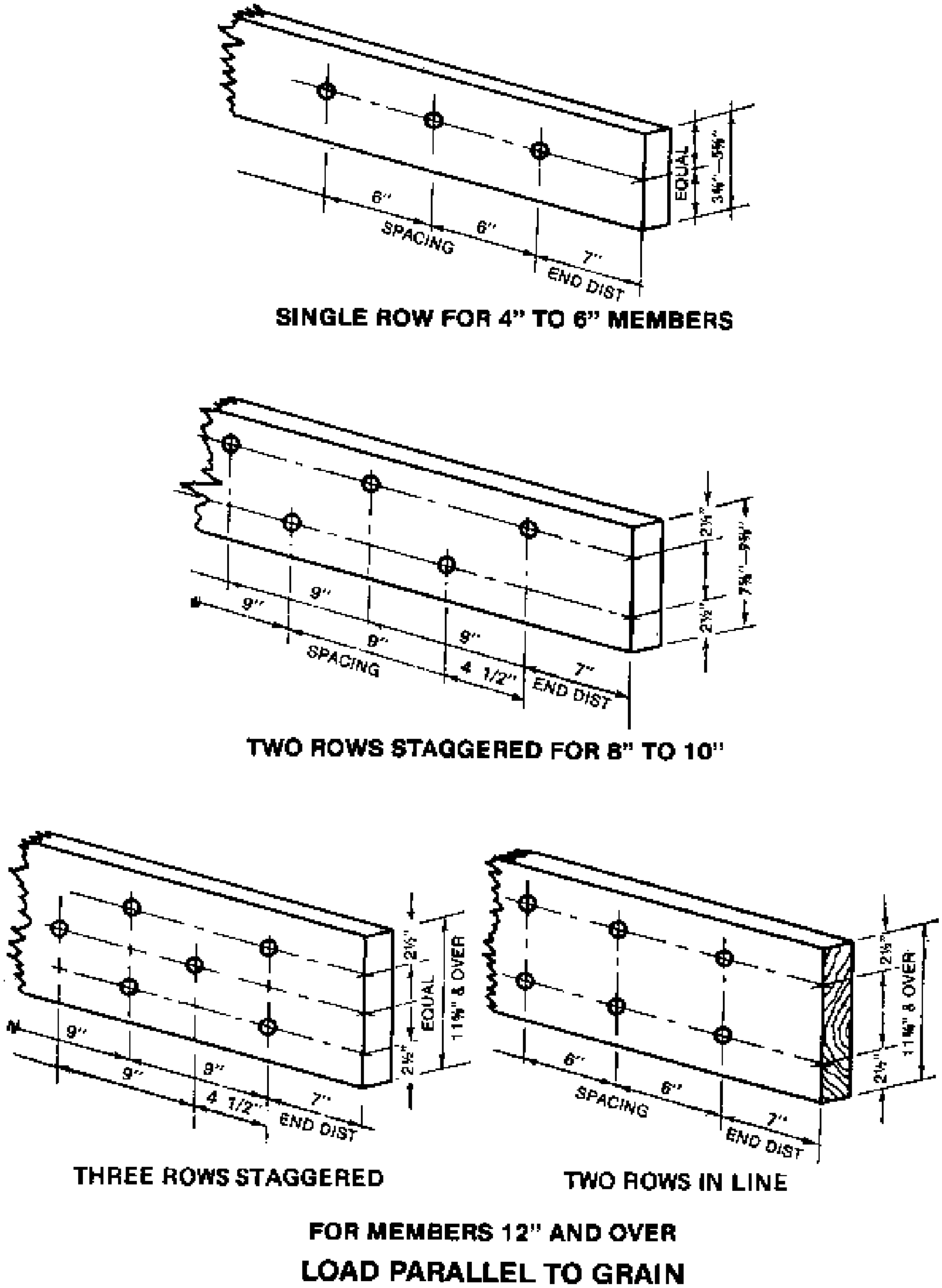


Figure 3-21. BOLT CONNECTIONS (IN USE PRIOR TO 1970).

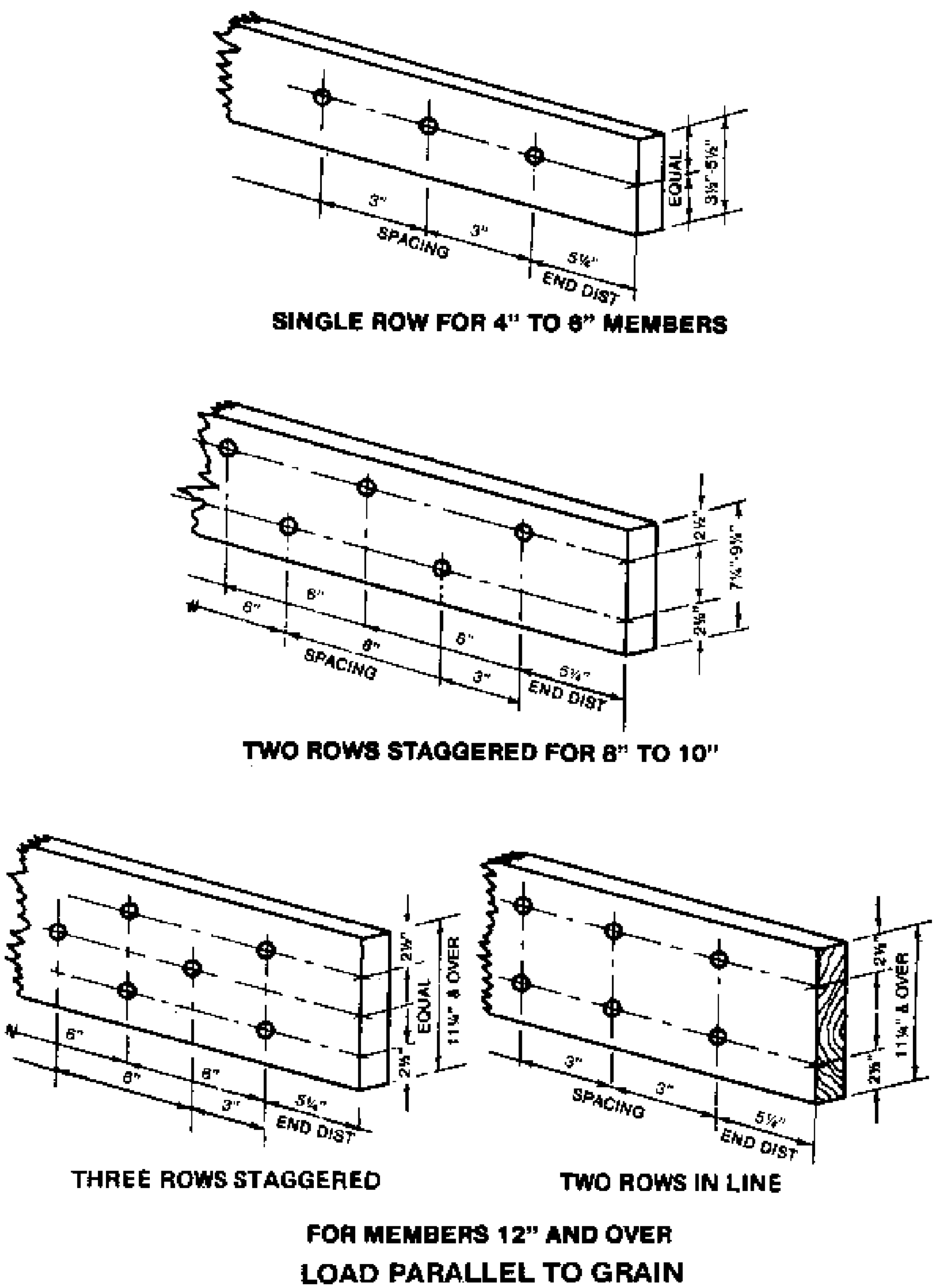


Figure 3-22. BOLT CONNECTIONS (IN USE AFTER 1970).

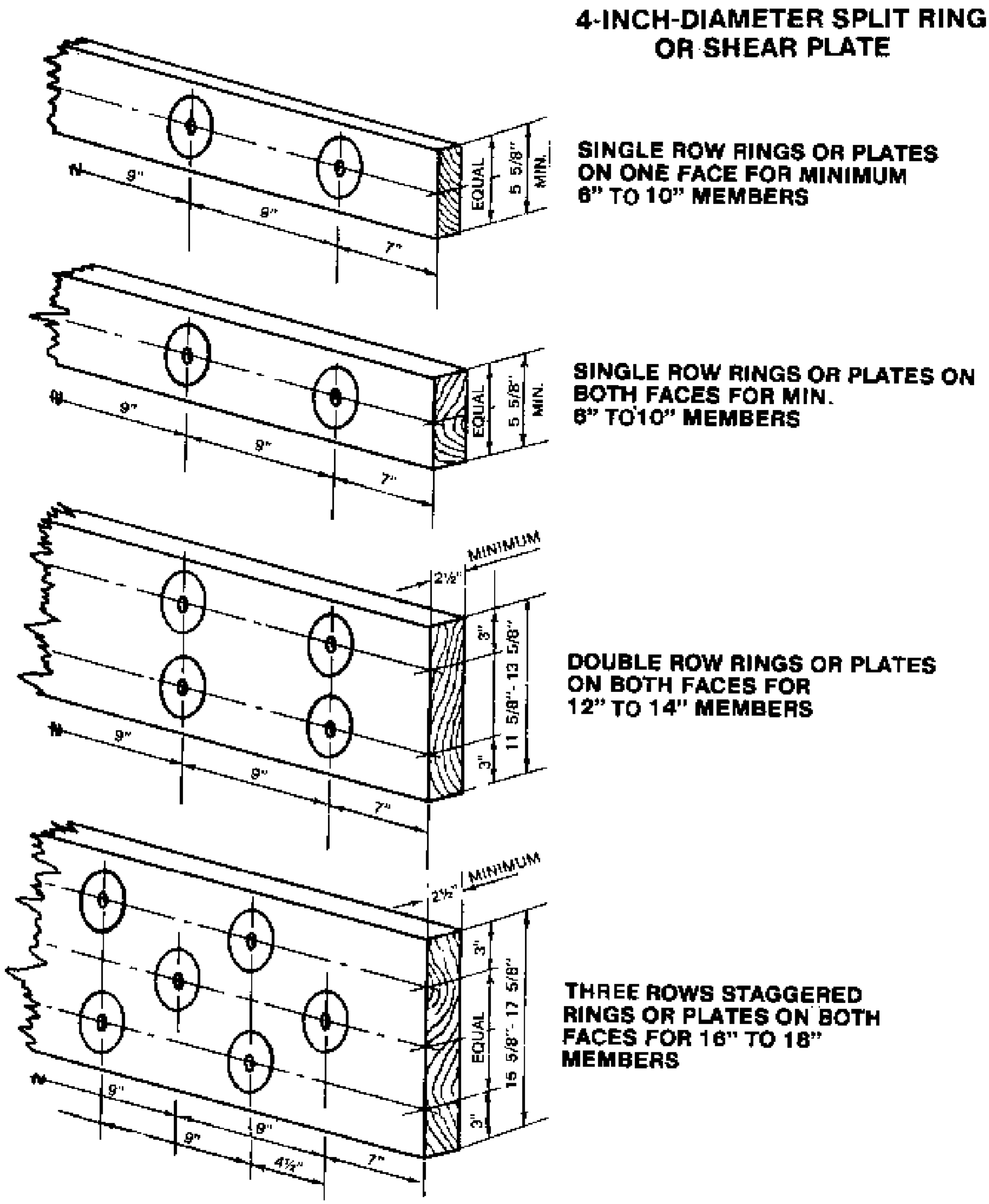


Figure 3-23. CONNECTOR SPACING (IN USE PRIOR TO 1970).

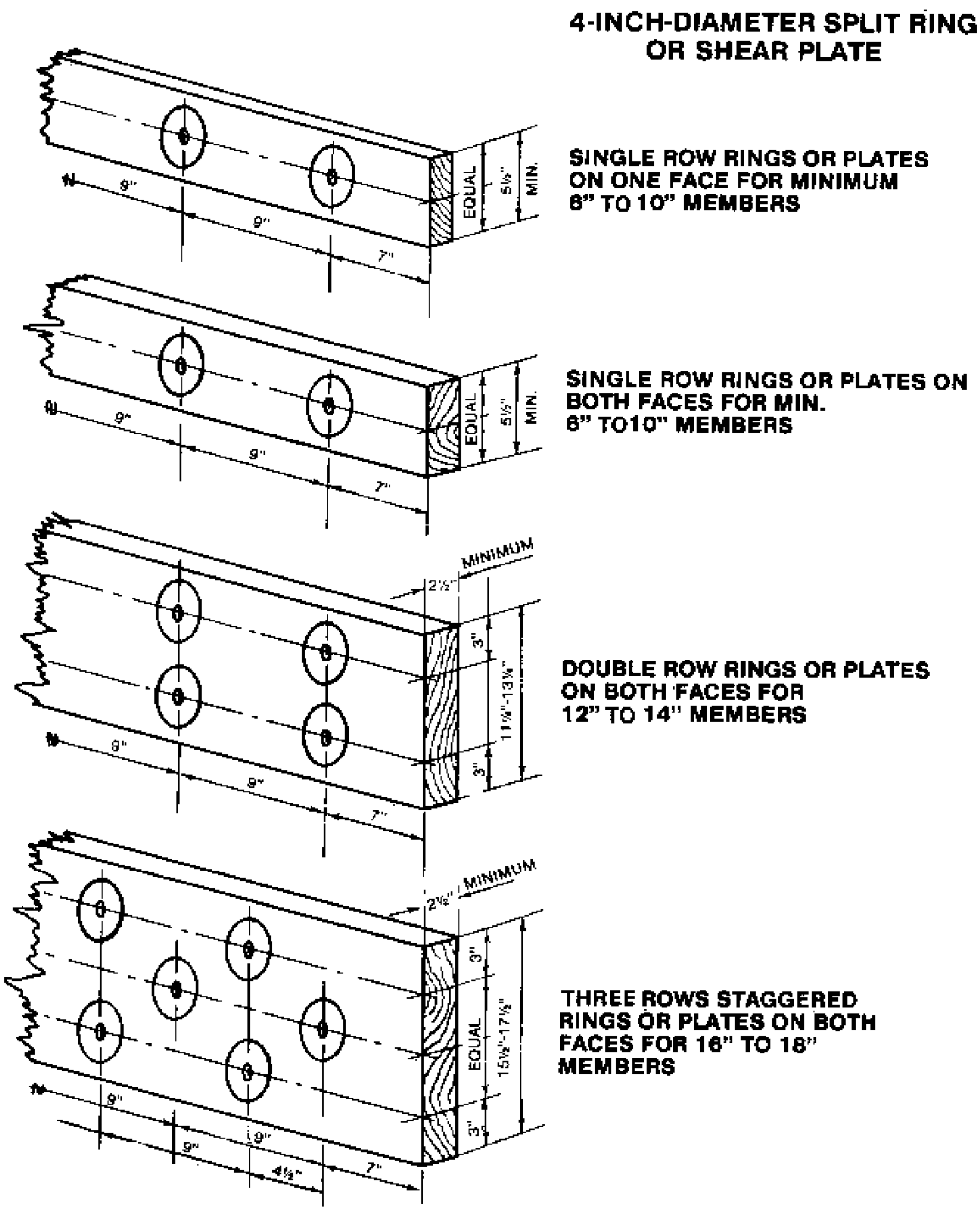


Figure 3-24. CONNECTOR SPACING (IN USE AFTER 1970).

3.4.11.2 *Allowable Loads.*

a. Bolts. For repair purposes, the allowable load in pounds on one bolt loaded at both ends in a three-member connection (double shear) of Douglas fir or southern pine (dense) is given in table 3-1.

Table 3-1. Allowable Loads for One Bolt.

Length of bold in main member (in)	*Diameter of bold (in)*	*Allowable load parallel to grain of well-seasoned lumber (lb)*
2½	¾	2,710
3½	¾	3,280
5½	¾	3,350
2½	1	3,680
3½	1	5,000
5½	1	5,930

When a joint consists of two members (single shear) of equal thickness, one-half of the above tabulated loads for a piece twice the thickness of one of the members will apply.

b. Connectors. For repair purposes, the allowable load in pounds on one connector is provided in table 3-2.

Table 3-2. Allowable Loads for Connectors.

Type of connector	*Diameter of bold (in)*	*Number of faces of member with connectors of same bolt*	*Allowable load parallel to grain (lb)*
Split Ring 2½	¾	2	3,160
Split Ring 4	¾	1	6,020
Split Ring 4	¾	2	6,140
Shear Plate 2 e	¾	2	2,900
Shear Plate 4	¾	2	4,970
Shear Plate 4	f	2	6,720

3.4.12 Timber-Repair Details

3.4.12.1 *Stitch Bolts.* Repair of end splits by stitch bolts is very common and normally is performed when a split opens up at the end greater than ¼ inch. It is particularly important to control the splitting when the end split runs through the line of bolts. It is not advisable to completely close the end split with stitch bolts in the event that such closure will throw excessive stress in the member. Stitch bolting in this case merely prevents further deterioration of the condition. Stitch bolts to be installed in heavy timber members (nominal four inches or larger) should be **d** inch in diameter and long enough to accommodate the nut and a ¼ inch cut washer at each end. Stitch bolts for use in nominal 3 inch lumber should be $^{5}/_{16}$ inch in diameter and those for nominal 2 inch lumber should be 14 inch in diameter. Using larger bolts removes too much wood from the end of the member thus reducing the equivalent end distances. After tightening the existing bolts, install the stitch bolts. See figure 3-25.

3.4.12.2 *Yoke Angles and Clamps.* Figure 3-26 illustrates the repair of a minor split occurring at or near the joint of a chord member. Yoke angles or clamps are preferably used in this case since stitch bolts would reduce the effective area of the chord member. Note the boring of a small hole immediately beyond the termination of a split. This treatment has proved helpful in arresting continued splitting.

3.4.12.3 *Steel Banding.* High strength steel banding such as that used to seal shipping cartons has proved effective in arresting spread of splits. The bands should be of high tensile strength steel 1¼ inch wide and 0.035 inch thick. The strapping should be applied with a Signode Model PH 2 stretcher which has no part remaining under the strapping during tightening to cause slackening on removal of the stretcher. The seals should be No. 34SHOC with fastening accomplished with a model SYC3435. See figure 3-27 for a typical steel banding for arresting splits.

3.4.13 Typical Minor Repairs

3.4.13.1 *Minor Splits by Stitch Bolts.* Figure 3-25 illustrates the use of a stitch bolt in repairing scabs in which end splits have developed. Also shown is a stitch-bolted repair to wood columns in which splitting and deep checking along the grains have occurred. Except in unusual cases, it is not necessary to stitch bolt columns unless the split is developing at an angle of 1 to 14 or greater and if the slope of the grain tends to carry the split to the extreme edge of the column. This type of treatment is effective in solid columns.

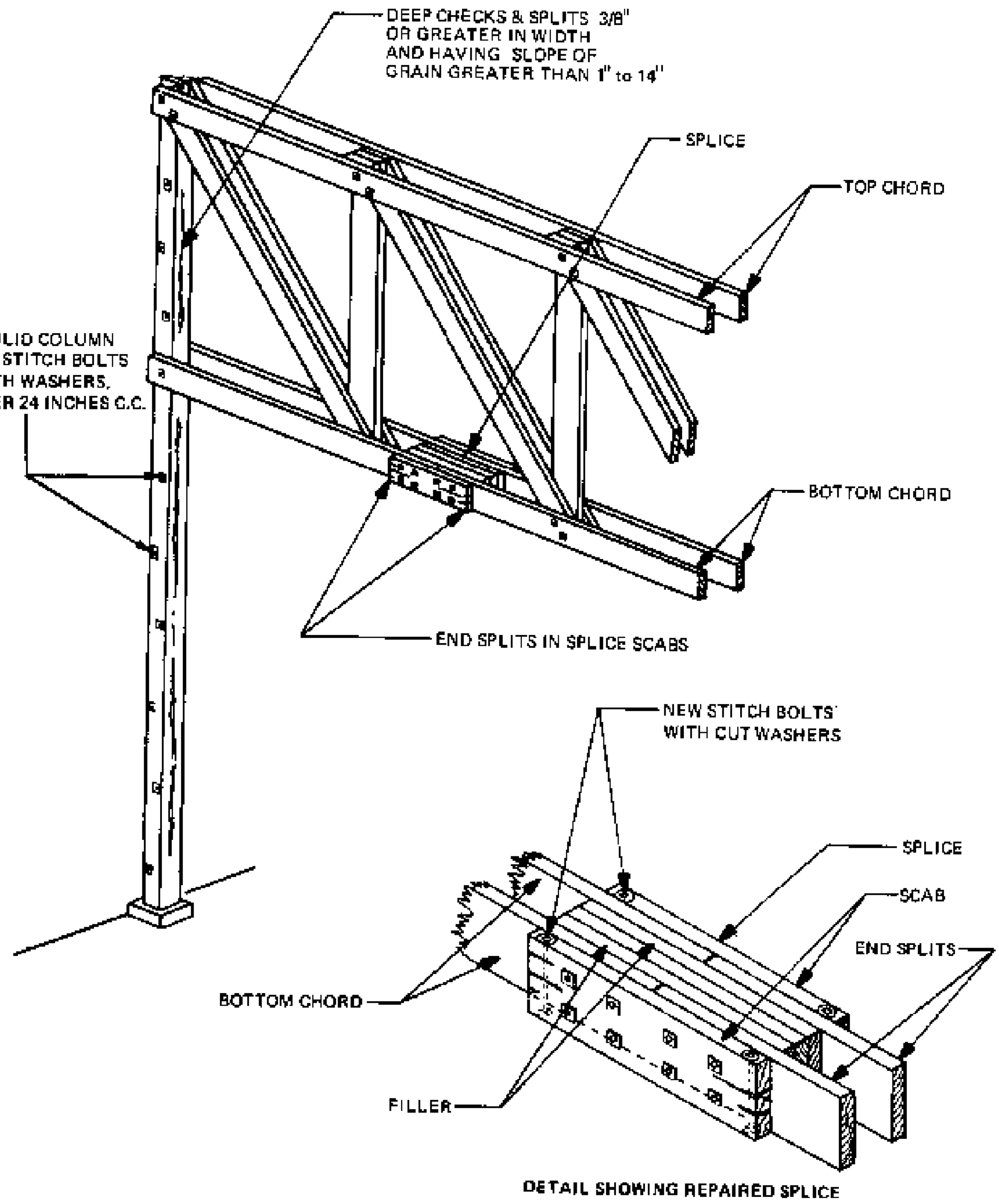


Figure 3-25. MINOR REPAIR OF SPLITS USING STITCH BOLTS.

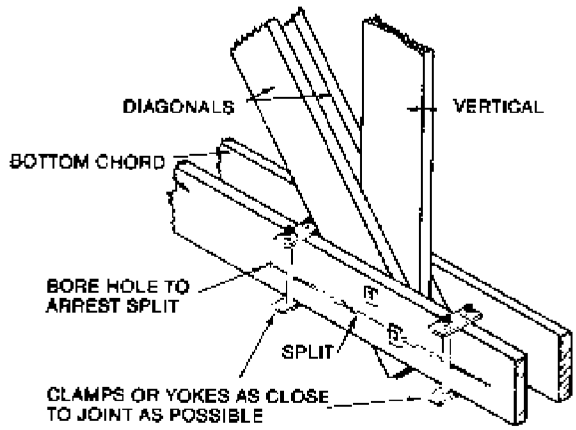


Figure 3-26. TEMPORARY REPAIR WITH YOKE AND CLAMP.

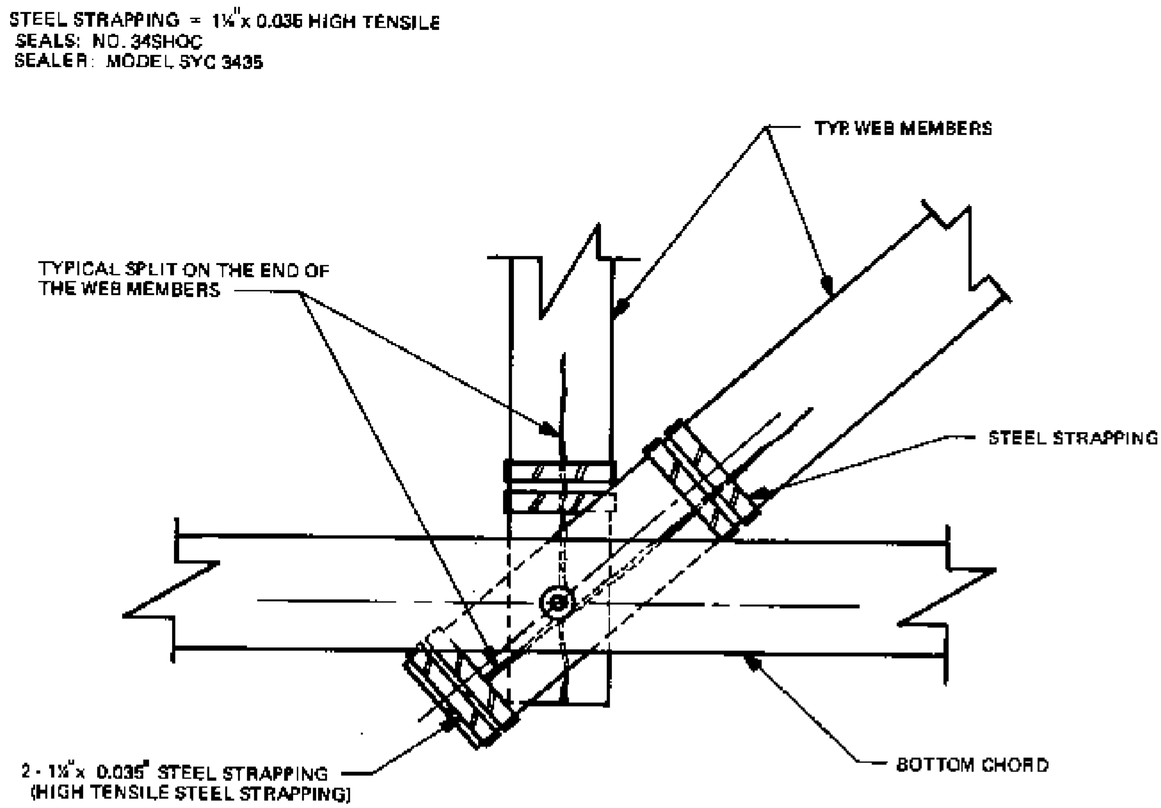


Figure 3-27. TYPICAL STEEL BANDING FOR ARRESTING SPLITS.

3.4.13.2 *Chord Splice Repairs*. Figure 3-28 shows a lower chord splice in which both the splice members and the chord members were badly warped. This condition usually occurs when trusses are constructed of light material generally 2 inches thick with depths 8 to 10 inches or greater. The omission of outside splice plates and an inside filler block between the chord was a contributing factor to the conditions shown. The remedy is to install outside splice plates using split rings and the addition of an inside filler block for stiffness, as shown in figure 3-28.

3.4.13.3 *Split Lower Chord.* Figure 3-29 illustrates the repair of a split in a lower chord. The repair is accomplished by adding two splice plates, one on either side of the lower chord and the outside plate carried through the panel point nearest the fracture. The procedure in carrying this splice plate through the nearest joint is used if there is insufficient room on each side of the fracture to develop the full strength of the member when the splice is bolted in place. Before applying the splice plates, a small hole is drilled ahead of the split to arrest further splitting. Next, a clamp is applied of sufficient size to draw the broken member together. If a member has a thickness greater than 2 inches, a stitch bolt is placed through the member to retain this position. Next, two splice scabs are applied and bolted to the fractured member using sufficient bolts on each side of the break to develop the full strength of the member.

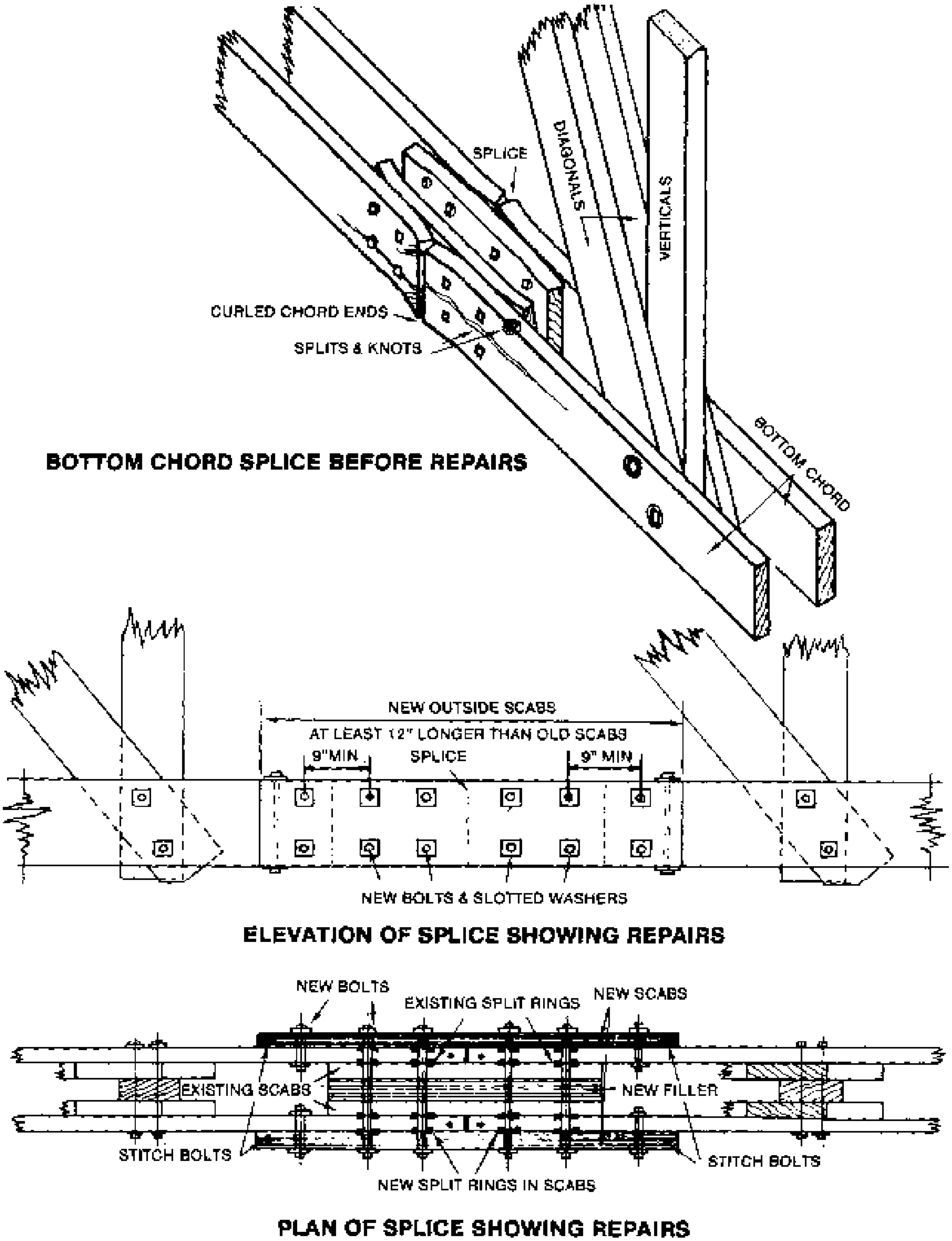


Figure 3-28. TYPICAL CHORD SPLICE REPAIR.

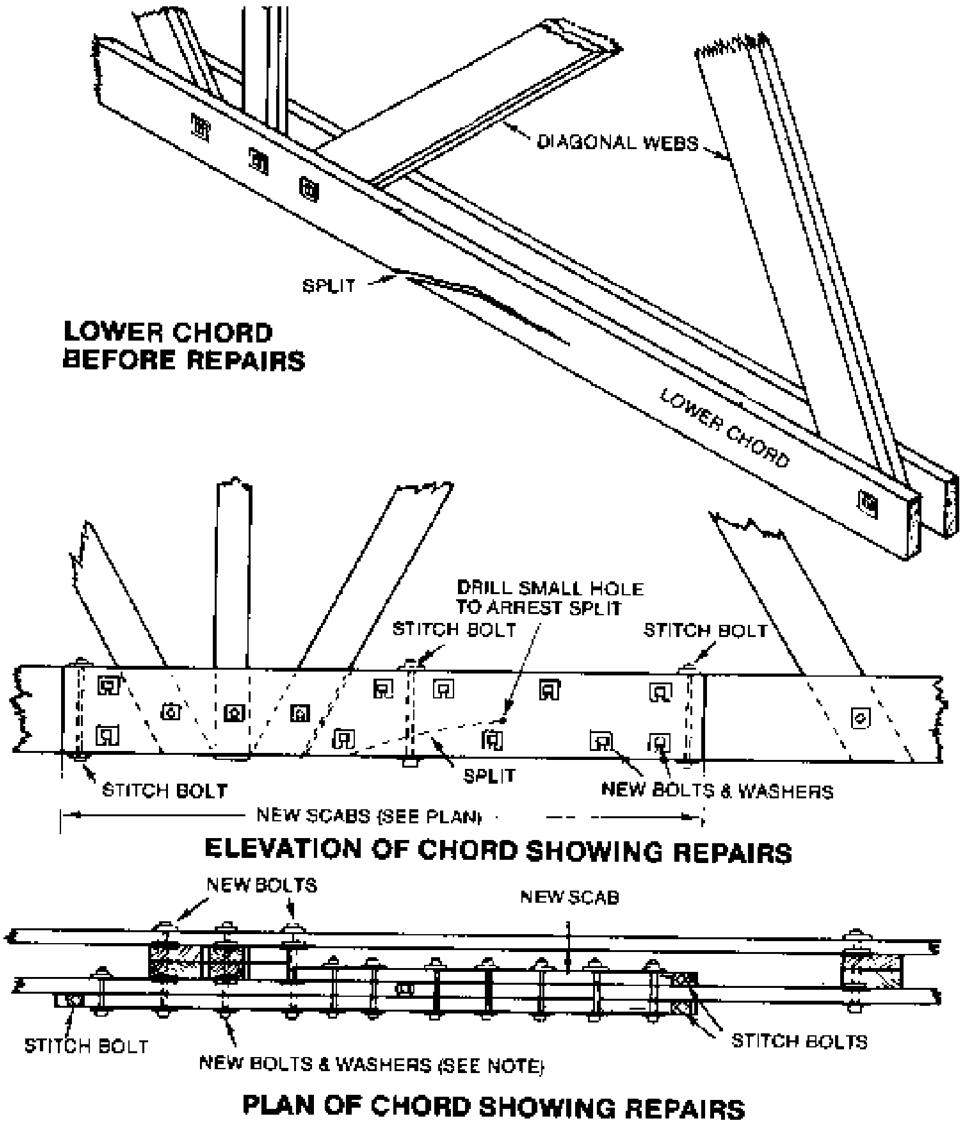


Figure 3-29. REPAIR OF MAJOR SPLIT IN LOWER CHORD.

3.4.14 Repair of Complete Breaks.

3.4.14.1 *Lower Chord Using Split Ring Connectors.* In many cases due to extreme knotty conditions and the use of brash (brittle) timber, it will be necessary to repair lower chords when one or more of the members has completely failed. Figure 3-30 illustrates a typical repair for a failure of this type. Note that split rings have been used, permitting the use of fewer bolts and a shorter plate than would be necessary for a bolted connection. However, experience has shown that when such a break appears near a panel point, it is good practice to carry the splice plates completely through the panel point. The illustration also shows the installation of new filler blocks between the chord members. A break of this type cannot be adequately repaired by adding splice plates to the failed members alone, due to the difficulty in installing split grooves on the inside face of the broken member. Therefore, the splice plate, which would normally be on the inside face of the broken member, is placed on the outside face of the opposite chord member where split rings can be readily installed.

3.4.14.2 *Failed Chords.* Using Bolts Without Connector Rings. Figure 3-31 illustrates an alternate method of repair of the same type of failure as shown. The same principles described in figure 3-32 apply here except that, inasmuch as split ring connectors are not used, the entire repair can be confined to the single broken member. In order to develop the full strength of the failed member, it is necessary by this method to use a considerably larger number of bolts than required by the former method. It also is necessary to use longer pieces of repair timber. This method is not recommended for large fractures and should only be used when split rings and the equipment necessary for their installation are not available.

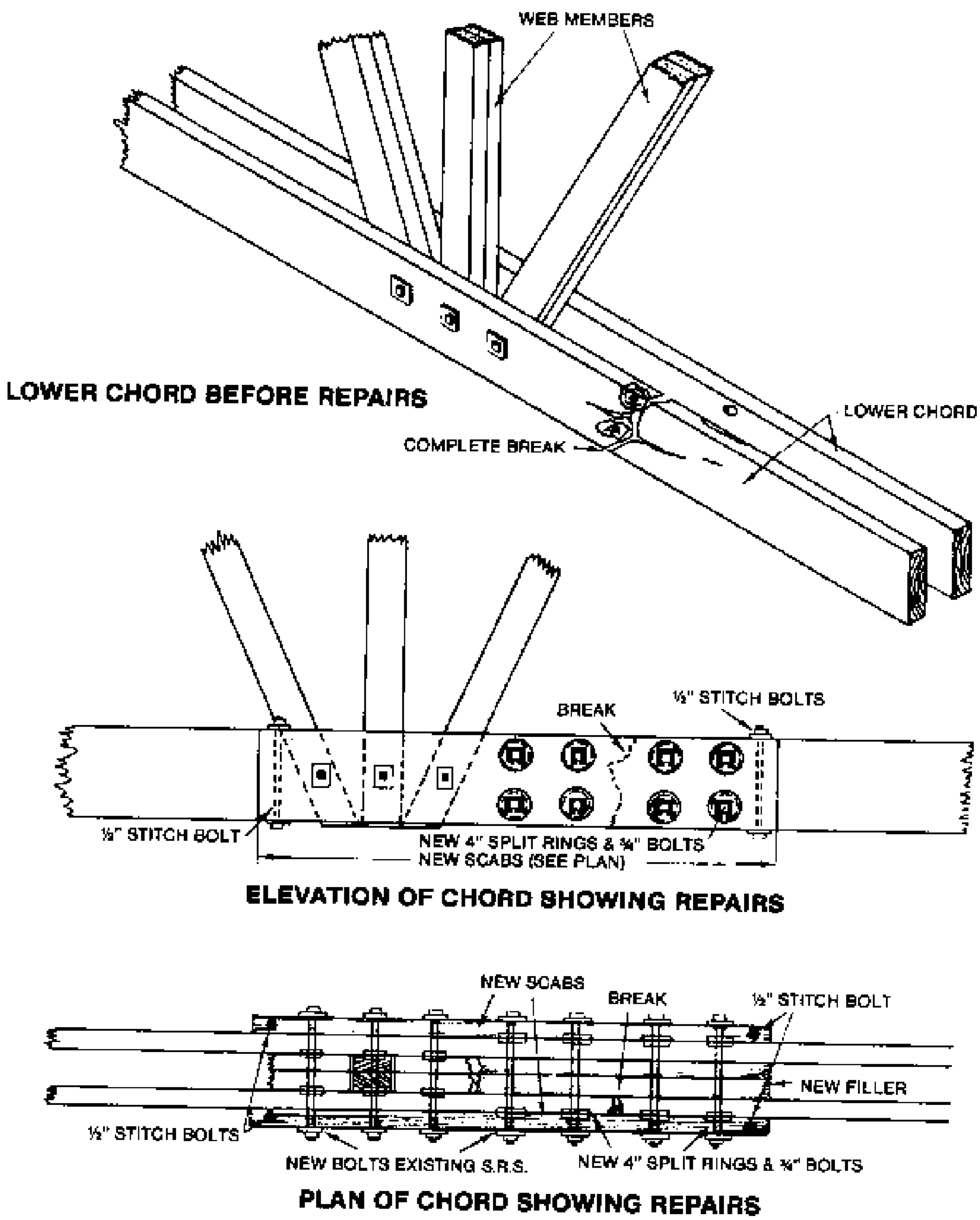


Figure 3-30. REPAIR OF BROKEN CHORD USING SPLIT-RING CONNECTORS.

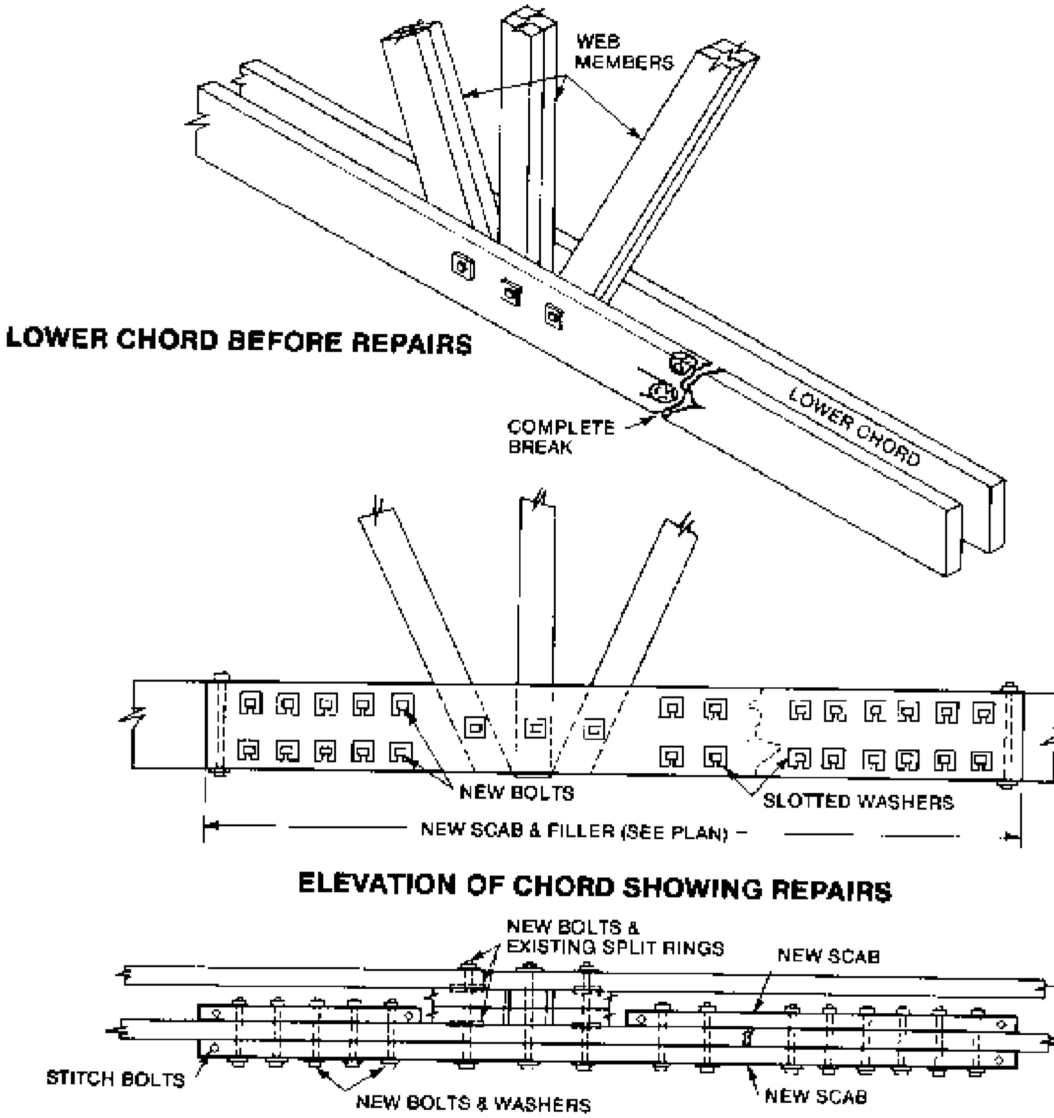
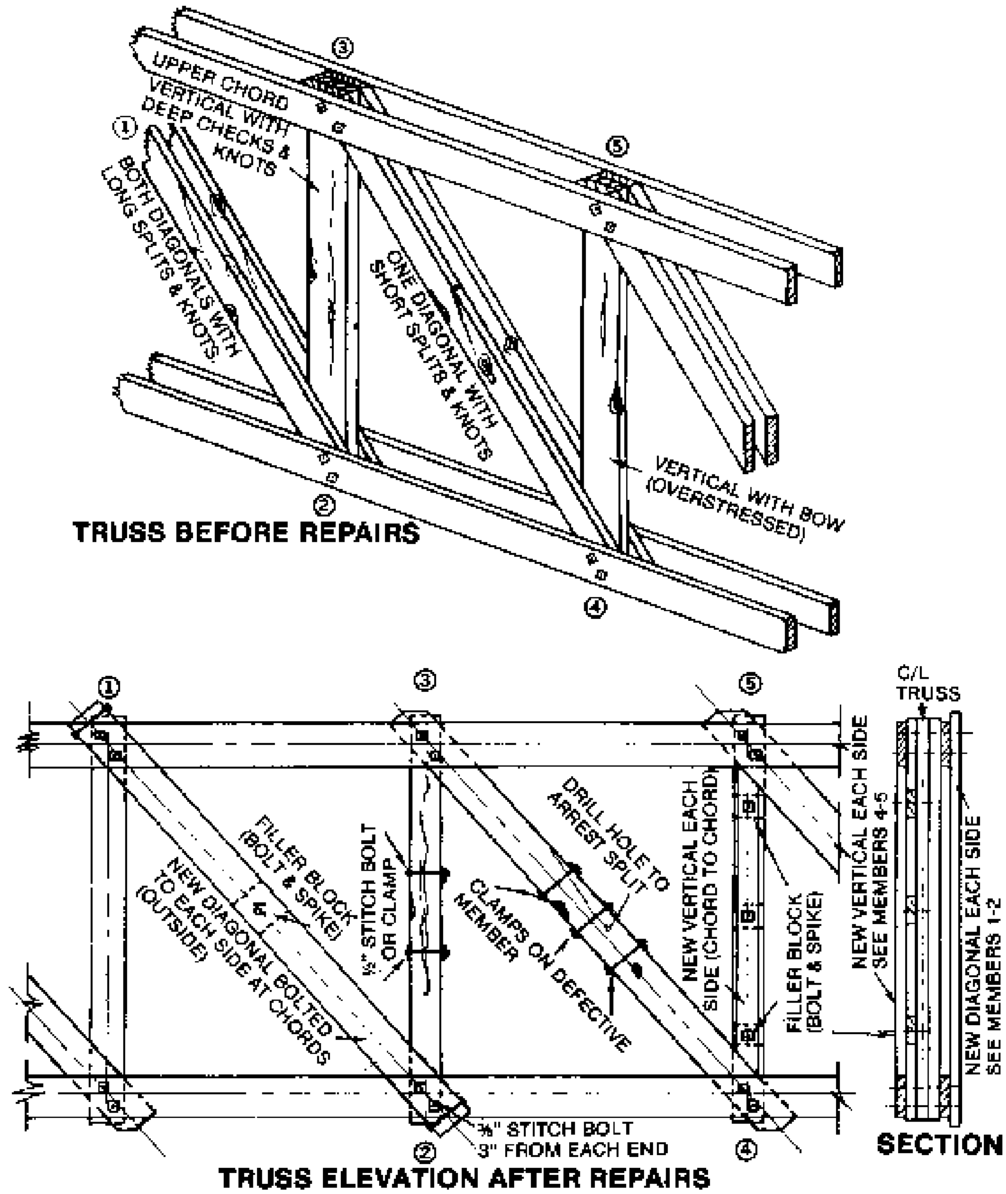


Figure 3-31. LOWER CHORD REPAIR BOLTS.



DIAGONAL 1-2 WITH MAJOR DEFECTS–REINFORCE WITH NEW PIECES
DIAGONAL 3-4 WITH MAJOR DEFECTS–REPAIR WITH CLAMPS
VERTICAL 4-5 WITH BOW & DEFECTS–REINFORCE WITH NEW PIECES
VERTICAL 2-3 WITH MINOR DEFECTS–REPAIRED WITH CLAMPS OR STITCH BOLTS

Figure 3-32. TEMPORARY WEB REPAIR.

3.4.14.3 *Web Members:* Figure 3-32 shows a number of typical breaks and defects found in the web members of timber trusses. In the case of member 1-2, where breaks occur in both diagonal members, it has been good practice to install complete new diagonals bolted to each side of the chords, as illustrated in the lower figure for both tension and compression members. For compression members, either verticals or diagonals, repairs can be carried out as illustrated in members 2-3 and 2-4. Neither of these repairs should be used in the case of tension members, which should only be handled by the method shown in 1-2. It is frequently found that vertical compression web members, due to being overstressed, are considerably bowed, as illustrated by member 4-5. This condition is best remedied, as illustrated in the lower figure, by the application of a new vertical stiffener bolted to each side of the vertical with the necessary filler blocks and through bolts to make a tight connection.

3.4.15 Repairs to a Bowstring Truss

To illustrate mass repairs to a truss, figure 3-33 combines typical separate failures examined in a series of trusses. The upper chord, as is generally the case of a bowstring truss, is in good condition; but the web members show signs of lateral deflection and the lower chord has several serious breaks. The lower chord has been repaired by installing new chord members for the full span, using splices as described in paragraph 3.4.13.2 above and illustrated by figure 3-28. The repair of the web members shown in figure 3-32 is described in paragraphs 3.4.10.3 and 3.4.10.4 above.

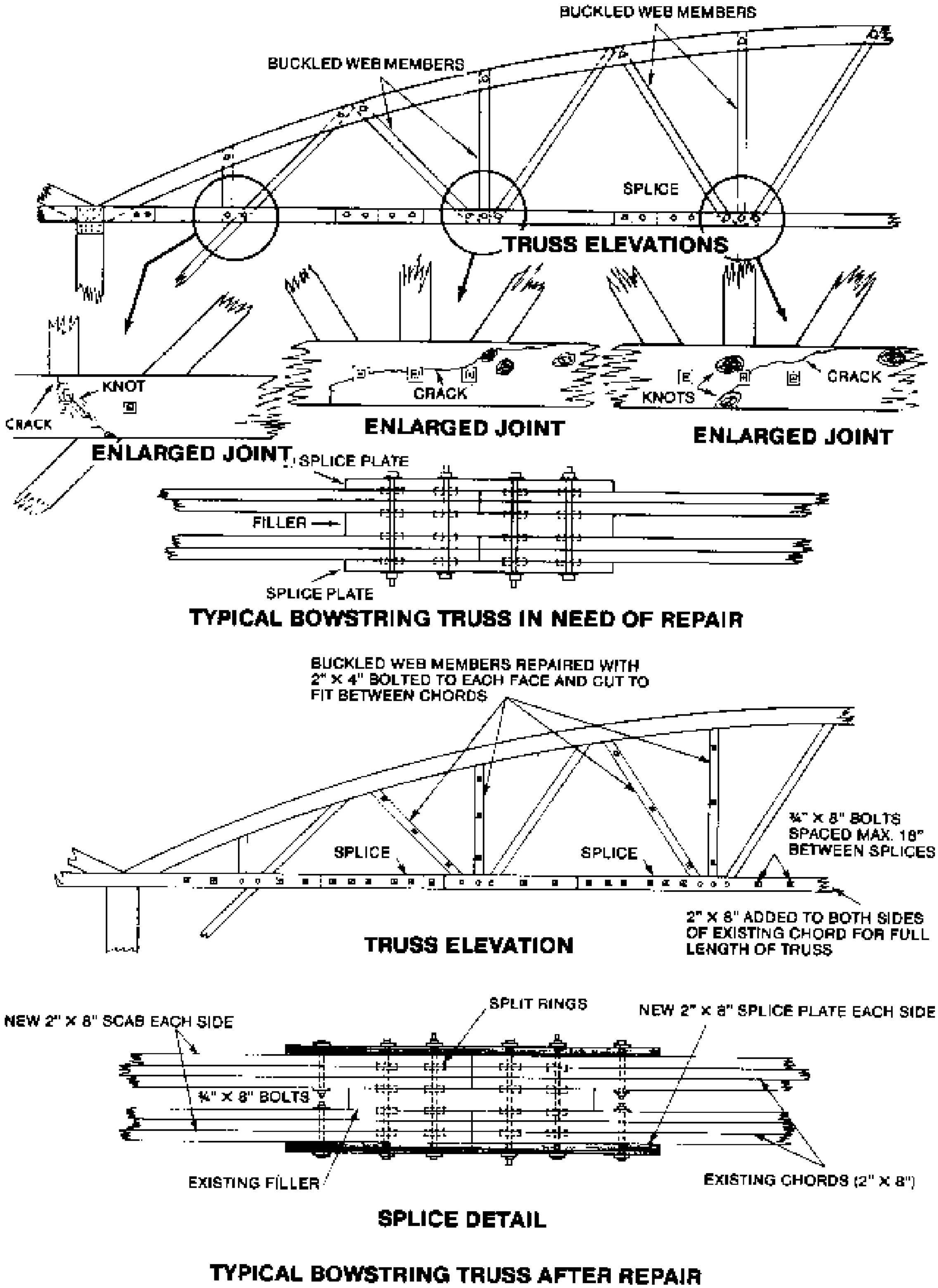


Figure 3-33. TRUSS REPAIR.

3.4.16 Materials Used in Repair

3.4.16.1 *Hardware.*

a. Slotted Washers. This type of washer can be used as a filler in bolt tightening when the bolts run out of takeup thread. The slotted feature makes it unnecessary in most cases to withdraw bolts from members. The center of gravity of the washer is below the bolt center so that the danger of the washer turning and falling off the bolt is minimized. Slotted washers also can be used in backing up thin-cut washers. Many trusses were originally constructed using cut washers of small diameter. When bolts are tightened, they have a tendency to cup and press into the fiber of the wood. When this condition occurs, a slotted washer or other type of plate washer of proper bearing surface should be placed behind the cut washer before tightening.

b. Stitch Bolts. Frequently, it is necessary to prevent cumulative splitting of members. Stitch bolts are effective for this purpose, particularly in counteracting minor end splits in compression members. The stitch bolt consists of a relatively small diameter bolt installed the depth of a member with washers at each end. As stitch bolts require the drilling of a hole the depth of the member, with consequent reduction of cross-sectional area, their use in tension sections must be employed with caution.

c. *Yoke Angles and Clamps.* Yoke angles and clamps may also be used to confine splits and retard cumulative checking and splitting. Details are shown in figure 3-34. Since clamps and yoke angles do not create a reduction in the net section of a member, their use in a tension member is satisfactory. It is particularly important, however, to keep an assembly of this nature constantly tightened.

d. Ring Connectors and Shear Plates. Figure 3-35 details the type of 4-inch split rings and 4-inch shear plates currently in use. The assembly of both the shear plate and the split ring is indicated and represents assembly for new or original work. In many cases, it is desirable to replace wooden scabs with steel plates, necessitating the use of shear plates where split rings were originally used. As the shear plate is of smaller diameter than the split ring, some means of adapting this shear plate to the cutout for the split ring must be used. For this purpose, a shear plate bushing has been developed permitting a flush connection without further dapping of the wood member. Additional dapping is costly and may dangerously reduce the net section of the member. This method is illustrated by A and B of figure 3-35. Split rings and shear plates are only effective when properly fitted to the timber. This can only be accomplished successfully through the use of proper tools. Cutterheads and accessories are available through regular supply sources. This procedure is not applicable to the 2½ inch split ring since the comparable shear plate is 2 e inches.

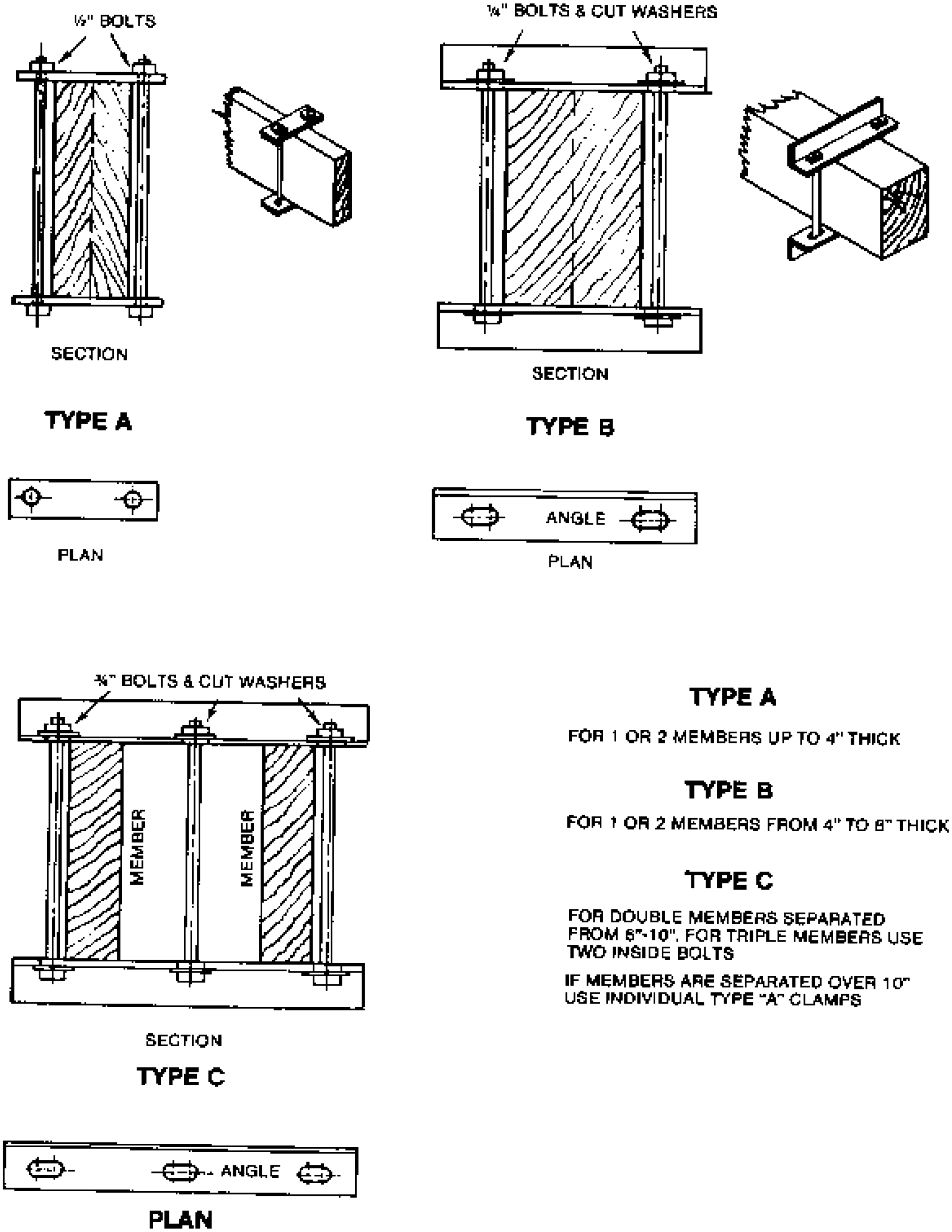


Figure 3-34. TYPICAL YOKE AND CLAMP DETAILS.

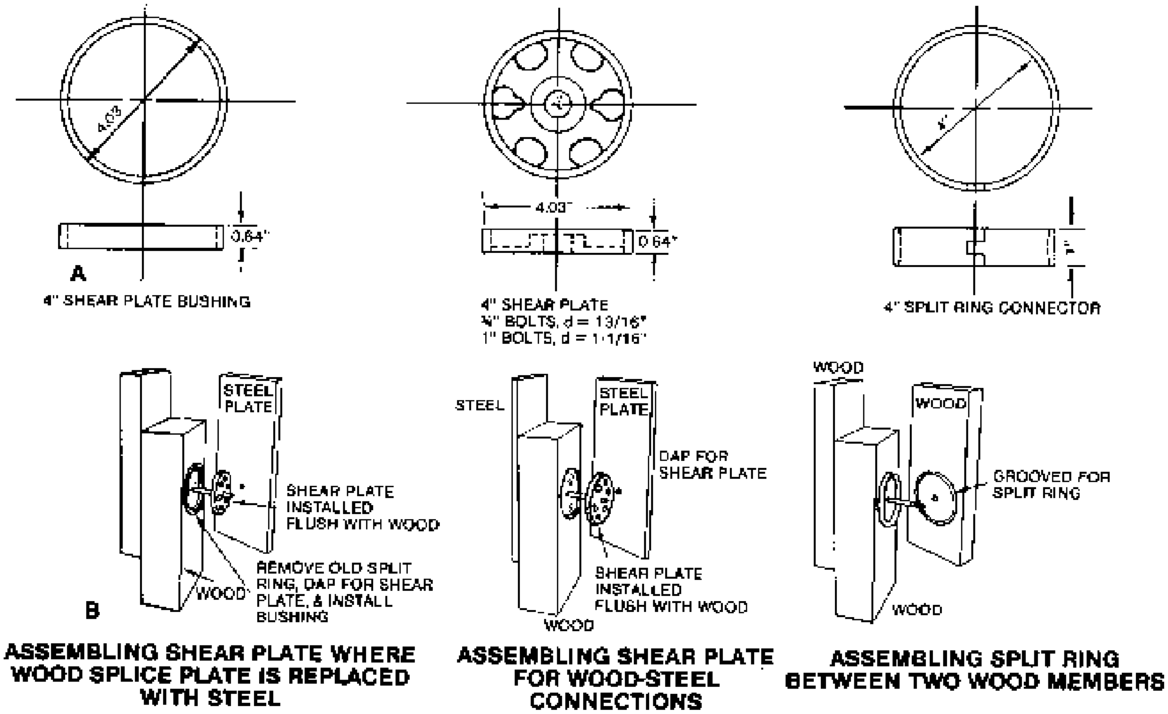


Figure 3-35. CONNECTION DETAILS

3.4.16.2 *Timber for Repair Purposes.*

a. Species of Wood. If inspection reveals that scabbing and reinforcing are necessary, it is of prime importance that mistakes made in original construction are not repeated in repair. Material, design, and workmanship must be carefully considered. Only wood suitable for structural purposes will be used in the repair of timber structures. The most common structural woods are Douglas fir, larch, southern pine.

b. Grades. Stress grades of structural woods are specified for all repairs. Generally, acceptable grades to specify for repair purposes are obtained from the latest edition of the "National Design Specifications for Wood Construction" published by the National Forest Products Association. Record plans and original design analysis should be closely studied to determine the original design assumptions and conditions. In the absence of these data, request guidance from the next highest command supervisory authority.

c. Painting Ends of Members. Wood dries more rapidly at end-grain than at side-grain surfaces. The tendency to check is, therefore, more pronounced in the end grain. A moisture-resistant end costing is recommended to protect such surfaces from checking during air seasoning. End coatings will be applied as soon as possible to the freshly cut end surface, for end checks, once started, tend to go deeper into the wood as drying progresses. End coatings may be divided into two classes: those that are liquid at ordinary temperatures and can be applied without being heated, and those that are solid at ordinary temperatures and must be applied hot. Two cold coatings being tested at the Forest Products Laboratory, U.S. Department of Agriculture (Technical Note No.186) are phenolic-resin varnish, pigmented with aluminum paste or powder, and filled hardened gloss oil. Both are tough and easily applied. Hot coating materials include pitch, asphalt, resin, and paraffin. The Forest Products Laboratory maintains a list of vendors of these materials.

3.4.17 Repair of Rafters, Purlins, and Bracing

Examine rafters, purlins, and bracing periodically for damage primarily due to roof leaking. If rafters or purlins sag from overload, they are repaired by splicing additional member or members to the existing ones.

3.4.18 Truss Bracing

A common fault of many trusses is the lack of adequate bracing. Trusses require bracing to keep top and bottom chords from bowing from a straight line and to prevent them from tipping from a vertical plane. The primary element for truss bracing is the roof itself; therefore, purlins and joists should be securely fastened to trusses. See figure 3-36. Trusses can be stiffened by adding bracing and it is possible to minimize other repairs through the provision of adequate bracing. The most common types of bracing include the following:

3.4.18.1 *Top Lateral Bracing* Top diagonal bracing is used in the plane of the upper chords. The purlins act as struts. Usually two pairs of crossing diagonals are used in each outside bay on each side of the roof. These diagonals brace the trusses together in pairs. The purpose of this bracing is to stiffen the structure, as the diagonals have no calculated stress. See figure 3-38.

3.4.18.2 *Bottom Lateral Bracing* Bottom lateral bracing, together with the horizontal struts or runners, are attached to the bottom chords of trusses and serve to tie the trusses together. Usually, bottom lateral bracing is not provided for big trusses unless vibration due to heavy equipment or machinery is anticipated. See figure 3-37.

3.4.18.3 *Vertical Sway Bracing.* Vertical sway bracing is usually in a vertical or incline plane, along the centerline, along a sloping plane, or between columns. It is used in connecting the top of one truss to the bottom of the other. It is very useful during erection, and it resists wind pressure on the ends of the building. See figure 3-38.

3.4.18.4 *Knee Bracing* Knee bracing is often used in large structures, and it is used in connecting columns to the trusses. This kind of bracing is used more for rigidity than strength. It is always designed as a compression member, while all other bracings are preferably designed as tension members. See figure 3-39.

3.4.19 Epoxy Repair of Trusses

Repair of trusses using pressure-injected epoxy compounds has been economically and successfully applied in recent years by comparison to conventional repair methods such as replacement, scabbing, and stitch bolting. This method is particularly useful when disruption of work activities below the repair is of concern. The procedure consists of three steps: preparation, placement of injection ports, and epoxy seal injection.

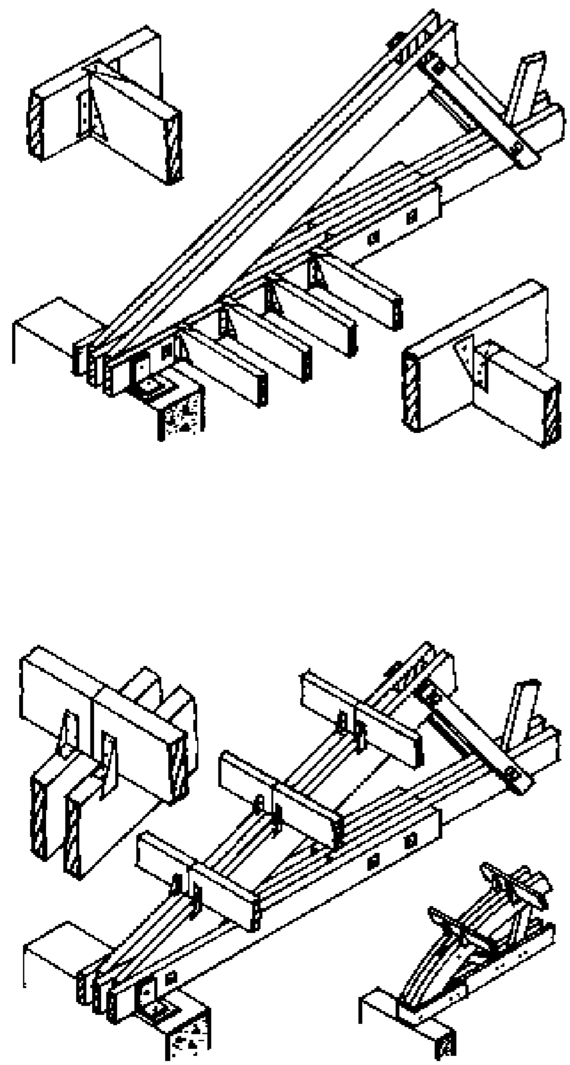


Figure 3-30. JOISTS FASTENED TO TRUSSES.

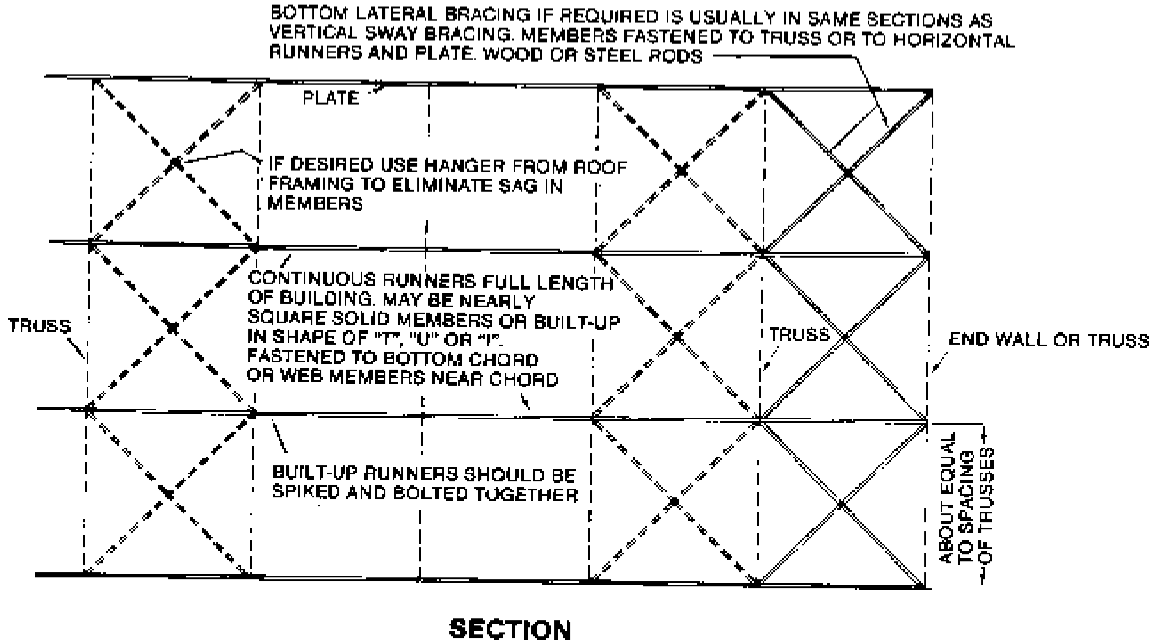


Figure 3-37. BOTTOM LATERAL BRACING.

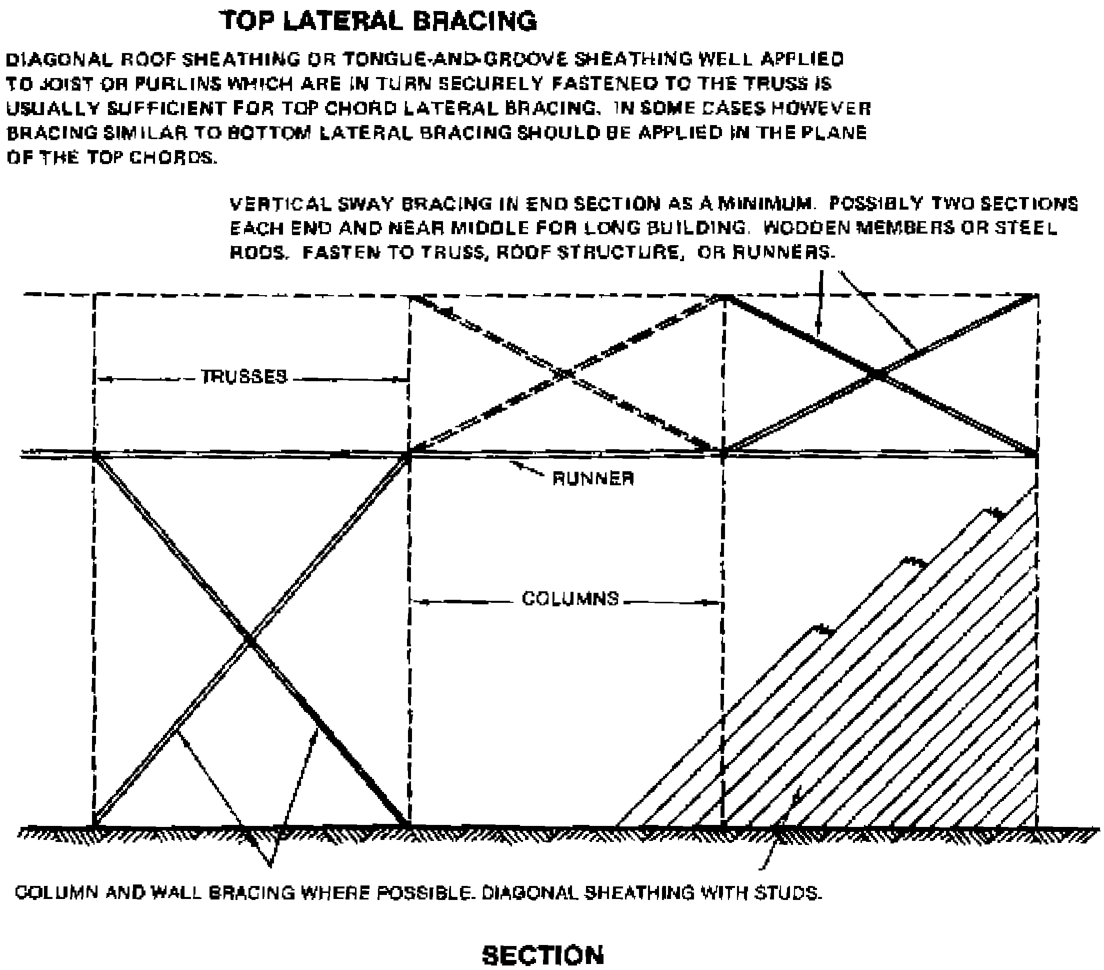


Figure 3-38. TOP LATERAL AND VERTICAL SWAY BRACING.

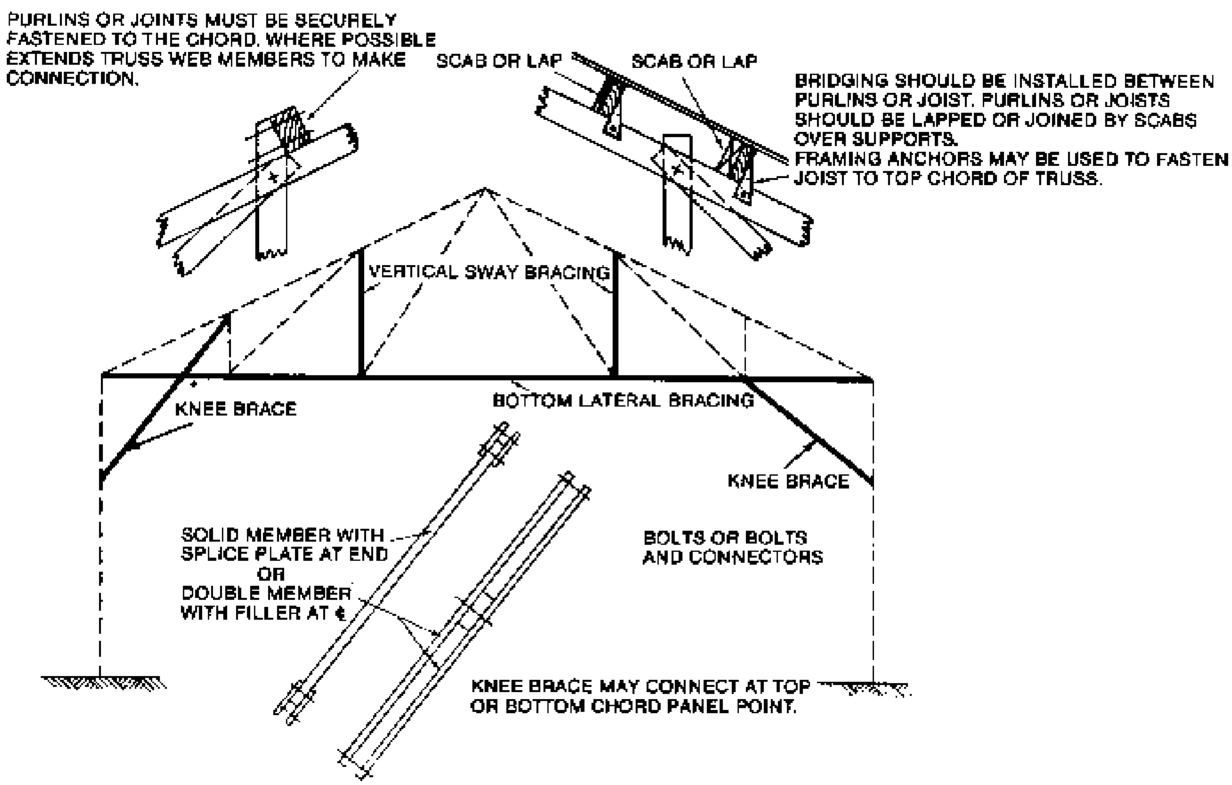


Figure 3-39. KNEE BRACING.

3.4.19.1 *Advantages and Limitations.* There are several advantages to using epoxy repair when repair conditions are favorable. Properly applied, the repaired joint is actually stronger than the original joint before it was damaged. However, this is not true with other repair methods. The second advantage is that epoxy repair requires little shoring. The third advantage is that it is cheaper (as much as 50 percent) than conventional replacement methods. The fourth advantage over other methods is that the epoxy repair can reach inside of the damaged joint. There are two major advantages in the use of epoxy repair. First, temperature can be critical and must be considered before starting repair. When the air temperature is high (125°F or 51.7°C and above), epoxy repair should not be attempted. Second, a determination of whether the entire outside of the joint can be reached for sealing must be made; all cracks and openings must be sealed before injection or the joint will leak and may lose its strength.

3.4.19.2 *Structural and Nonstructural Repair.* Epoxy repair can be divided into two broad types: structural and nonstructural. Nonstructural applications include waterproofing, crack sealing, and cosmetic repairs. Repairs of the nonstructural type are usually quite simple because the goal is to provide a seal. The work effort is successful if the repair prevents leaks. Structural repair can be difficult. Often the total damage is not visible. Cracks may be very small or as large as 1 inch or more. Sealing before injection can be difficult and, for a successful repair, it must be complete. Epoxy must be injected into all voids for the repair to be successful. More care and attention to detail are required than for nonstructural repairs.

3.4.20 Types of Epoxy Repair:

3.4.20.1 *Type A-1.* Epoxy injection of cracked or split members at truss joints.

3.4.20.2 *Type A-2.* Epoxy injection and reinforcement of decayed wood.

3.4.20.3 *Type A-3.* Splicing and epoxy injection of broken members.

3.4.20.4 *Type B-1.* Epoxy injection of longitudinal cracks and splits away from joints.

3.4.20.5 *Type B-2.* Repair of bearing surfaces using epoxy gel.

3.4.21 Strength of Epoxy Repairs.

Among the many factors affecting repair are the many joint types that require repair. Figure 3-40 shows a group of truss joints. As can be seen in the illustration, the number of members, lap area, grain orientation, and number of mechanical connectors will vary. Other important factors are thickness of members, age of wood, and crack width between lapped surfaces. Planning a repair effort should consider the following:

3.4.21.1 *Degree of Damage.* Because epoxy repair is used to provide the shear resistance in lapped members, the degree of damage is usually not important. As long as there are adequate lapped surfaces for bonding, the strength of the joint can be completely restored. The major exception is decay. Repairing a decayed member is difficult and requires special expertise.

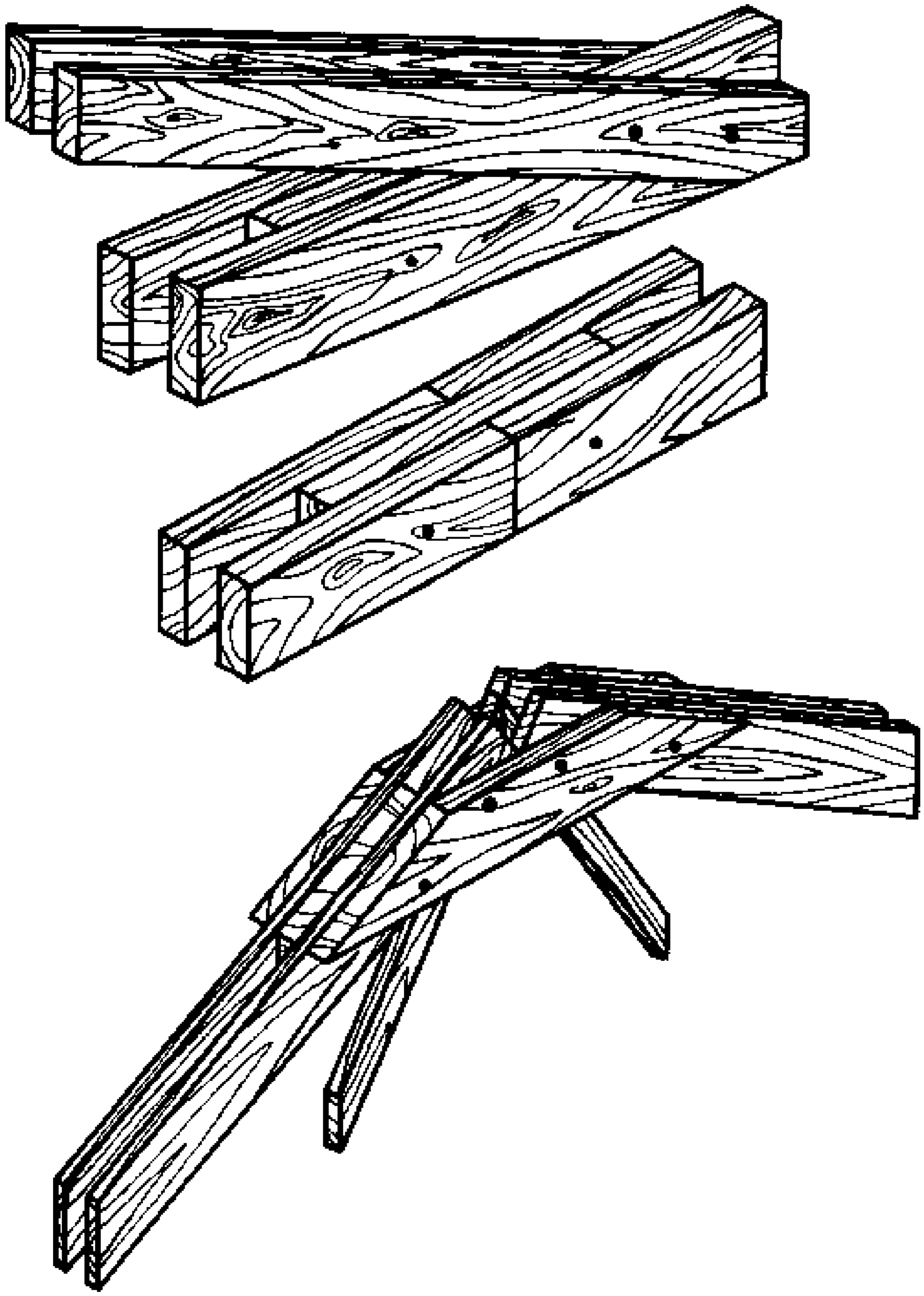


Figure 3-40. TYPICAL JOINTS IN TIMBER TRUSSES.

3.4.21.2 *Effect of Mechanical Connectors.* All joints in wooden trusses must have some sort of connector. In older trusses mechanical connectors such as bolts, split rings, and toothplates have been used. Often it is found that some connectors have been omitted or, if the joint is badly damaged, the connectors may have fallen out. After epoxy repair the strength of the joint is not affected by a missing connector. A glue line must fail (or deform badly) before the load can be transferred to the connectors. The load required to fail the glue line is usually greater than the connector's ability to carry the load. When the glue line fails, the connector will fail in most cases.

3.4.21.3 *Width of Overlap.* Tests have established that the failure stress of a bonded lap joint is not affected by the width of the overlap.

3.4.21.4 *Length of Overlap.* Bonded double lap-joint strength is directly related to the length of the lap in relation to the thickness of the middle member. Thickness of the lap does not add to the strength of the repair.

3.4.21.5 *Effect of Grain Orientation.* Tests indicate a load-capacity loss of a repaired joint as the grain angle changes from 0° to 90°.

3.4.21.6 *Effect of Glue-Line Thickness.* The effect of the glue-line thickness on joint strength is so small that it can be discounted.

3.4.22 Characteristics of Epoxy Compounds

3.4.22.1 *Chemical Grouts.* Chemical grouts consist of two or more chemicals which react to form either a gel or solid. This is in contrast to cement grouts which consist of solid particles suspended in a liquid.

3.4.22.2 *Epoxy Resins.* These resins are two-component systems made of a resin base and a hardener (catalyst). Flexibilizers are sometimes added to prevent cracking of the set glue due to movement of the joint. Epoxy resins are available that cure in high moisture areas. They have the following characteristics:

a. Ability to resist acids, alkalies, and organic chemicals.

b. Ability to cure without volatile byproducts.

c. Ability to cure without external heat.

d. Ability to accept various thickening agents.

Once hardened epoxy resins will not liquify when heated (thermosetting) but will soften. The required characteristics of epoxy resins to be used in wood structural repair are shown in table 3-3.

Table 3-3. Mechanical Properties for Resins Used in Repair of Wood Structures

Characteristics	*Low viscosity injection material*	*High viscosity sealing gel*
Pot Life (min)	10-60	10-60
Initial cure (hr)	1-8	1-8
Final Cure (day)	2-5	2-5
Viscosity (c/s)	200-500	Nonsagging
Hardness (shore D)	80-100	80-100
Modulus of Elasticity (k/in^2)	0.4-0.6	0.4-0.6
Tensile Stress (k/in^2)	5-8	5-8
Compressive Stress (k/in^2)	5-10	5-10

3.4.23 Steps in Epoxy Repair

There are four basic steps in the epoxy repair procedure. Each step is described in the following paragraphs:

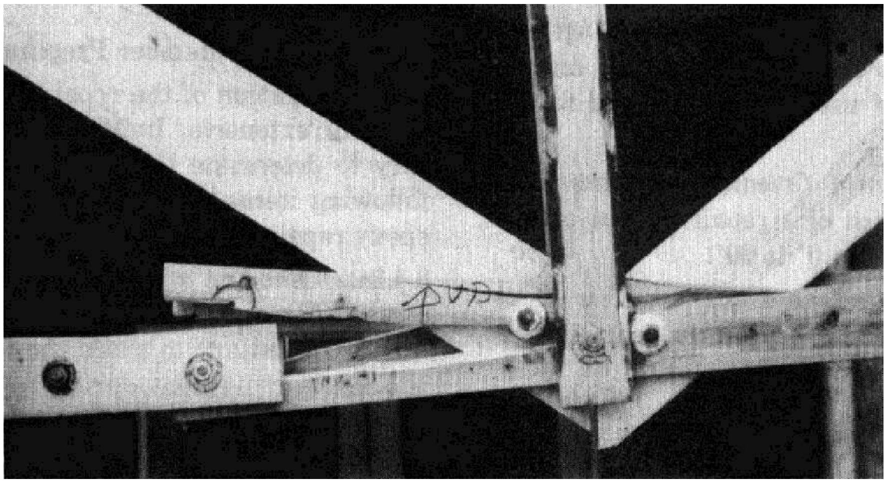
3.4.24 Special Member Preparations

The preparation of the repair area can range from little to extensive. Individual judgment is necessary to determine the preparations required. The following items should be considered prior to any epoxy repair:

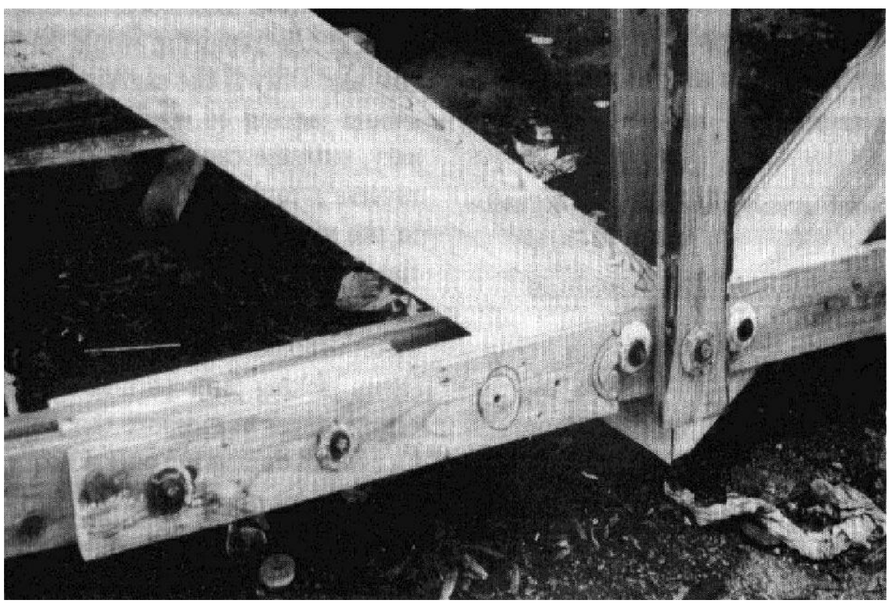
3.4.24.1 *Shoring and Jacking.* In cases where excessive damage or deterioration has occurred, it may be necessary to shore the member to prevent additional movement during repair or to jack the member back to a more normal position. Based on field observations of damaged buildings, jacking has been required only in isolated instances. Three reasons for considering jacking are: (1) to remove excessive sag, (2) to relieve stresses, and (3) to close large cracks. Jacking to relieve stresses is not recommended. Experimental studies have shown that it is difficult to close cracks by jacking and that the size of the crack is unimportant in the epoxy repair process. Therefore, the only reason to jack a truss before repairing would be to remove excessive sag. Only if the sag/span ratio exceeds 1/240, should jacking be considered. If jacking is necessary, extreme caution should be exercised. Stress reversals could cause member failures, especially in the vicinity of the jacking points. The differential movement may also damage attachments such as roofing. In general a structural analysis of the system should be conducted to determine the maximum jacking force permissable. If jacking is necessary, gages to measure the jacking forces should be utilized during the operation.

3.4.24.2 *Addition of Splice Plates.* Some repairs may require the addition of splice plates, e.g., a broken member. The epoxy repair technique is most effective for lapped joints in which the epoxy is injected between the lapped surfaces to provide shear resistance. For broken members, splices are tacked on both sides of the broken member (as shown in figure 3-41) to be later injected with epoxy. Since most failures occur at joints already consisting of lapped members, additional splice plates are generally not necessary.

3.4.24.3 *Removal of Moisture Source.* For moist or decayed sections, the moisture source must be eliminated to protect the member from further deterioration. Although most epoxy formulations adhere in moist environments, the moisture may cause the decay to continue in encapsulated or adjacent areas, and resulting in further deterioration. If the moisture content exceeds 20 percent, the member should be dried out before repair and the source of the high moisture eliminated. For trusses, the roof should be repaired so that continued leaking will not contaminate the repaired member.



(A) DAMAGED TRUSS JOINT



(B) OLD SPLICE PLATE REMOVED AND LONGER SPLICE PLATE ADDED

Figure 3-41. PREPARTION OF MEMBERS BY ADDING SPLICE PLATES.

3.4.24.4 *Reinforcement.* For severely decayed members, reinforcing elements may be necessary. Holes are drilled and fiberglass reinforcing rods inserted to form either a strong connector pattern between sound and unsound wood, or a stiffening internal truss or frame for increasing load carrying capacity. See figure 3-42 Epoxy injection will bond the reinforcing members to the surrounding wood to provide increased strength. Since little experimental evidence is available, this procedure should not be used without careful engineering analysis.

3.4.24.5 *Cleaning*. The area to be repaired should be thoroughly cleaned, with all dust and debris cleared to provide a good bonding surface. An air jet from a compressed air source has been found to be very effective for this purpose.

3.4.25 *Joint Sealing.*

The area to be repaired must be completely sealed on the exposed surfaces except for injection and bleeding ports. The success of the repair largely depends on the effectiveness of the sealing. The sealant used should be a high viscosity epoxy with a puttylike consistency (referred to as a gel). The usual steps in the sealing process are as follows:

3.4.25.1 *Port Setting.* The placing of the ports serves three purposes. First, a means is provided for injecting epoxy into the interior of the damaged area; second, a means is provided for venting the air which is displaced by the epoxy during the injection process; and third, a means is provided for determining the penetration of the epoxy into the damaged area.

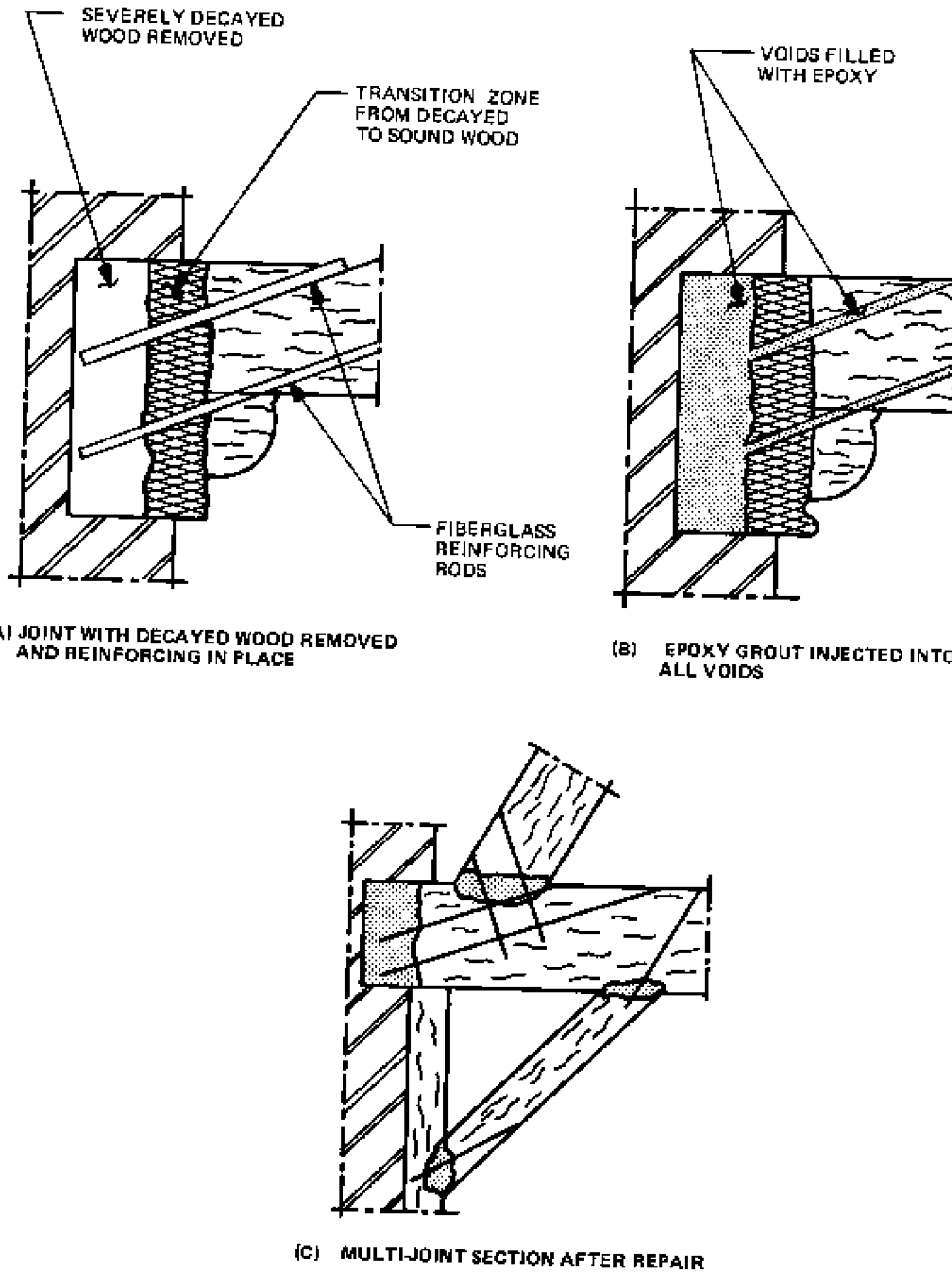


Figure 3-42. REINFORCED EPOXY REPAIR.

a. Materials. One of the most common materials used for ports is ¼-inch-diameter copper tubing. Also frequently used is small diameter (¼ to d inch) standard pipe. Plastic tubing has also been successfully used. The primary requirements for port materials are that the part should be bondable with the epoxy gel, and that it can be sealed or closed during the injection itself.

b. Placement of Ports. Ports are placed by drilling holes with a diameter identical to the outside diameter of the port. The port is inserted into the hole and sealing gel is applied around the port. The depth of the hole depends on its location and type. Recalling that the key to a successful epoxy repair is insuring penetration into all lapped surfaces, the ports should be placed to maximize penetration. Alternative placement methods are shown in figure 3-43. One method is to place the port at the juncture of the lapped surfaces as illustrated by port type A in figure 3-43. The hole is drilled at an angle to the surface while insuring that the hole includes the lap area. The depth of the hole should be approximately ½ inch. The second method is to drill holes perpendicular to the lapped surfaces as illustrated by port type B in figure 3-43. This method allows easier installation and allows the penetration of multiple lap planes by drilling the hole deeper. The hole should be drilled deep enough to penetrate the lapped surfaces desired. For either method the port should only be inserted approximately ¼ inch into the hole. After placement, the port should be sealed with gel. The gel should be built up around the port as shown in figure 3-44. It is important to build up the gel to prevent leaking during injection and capping.

c. *Location and Number of Ports.* The minimum number of ports for single lapped surface is three. Two ports are usually placed at the top and one at the bottom as shown in figure 3-43, however, placement may vary depending on the shape of the lapped surfaces. For members oriented at an angle-to-grain, three ports per lapped surface are usually sufficient. Hence, the total number of ports would be three times the number of lapped surfaces at a joint. However, for parallel-to-grain members such as splices, the lap area may be long enough to justify additional ports. It is recommended that two ports per lapped surface be provided (one top and one bottom) for every 2-foot length of spliced members. Figure 3-45 shows installed ports inplace for typical joints. Another location for ports would be the cracks and splits. It is recommended that single ports be placed at the extreme ends of all longitudinal splits with additional ports placed at 3-foot increments.

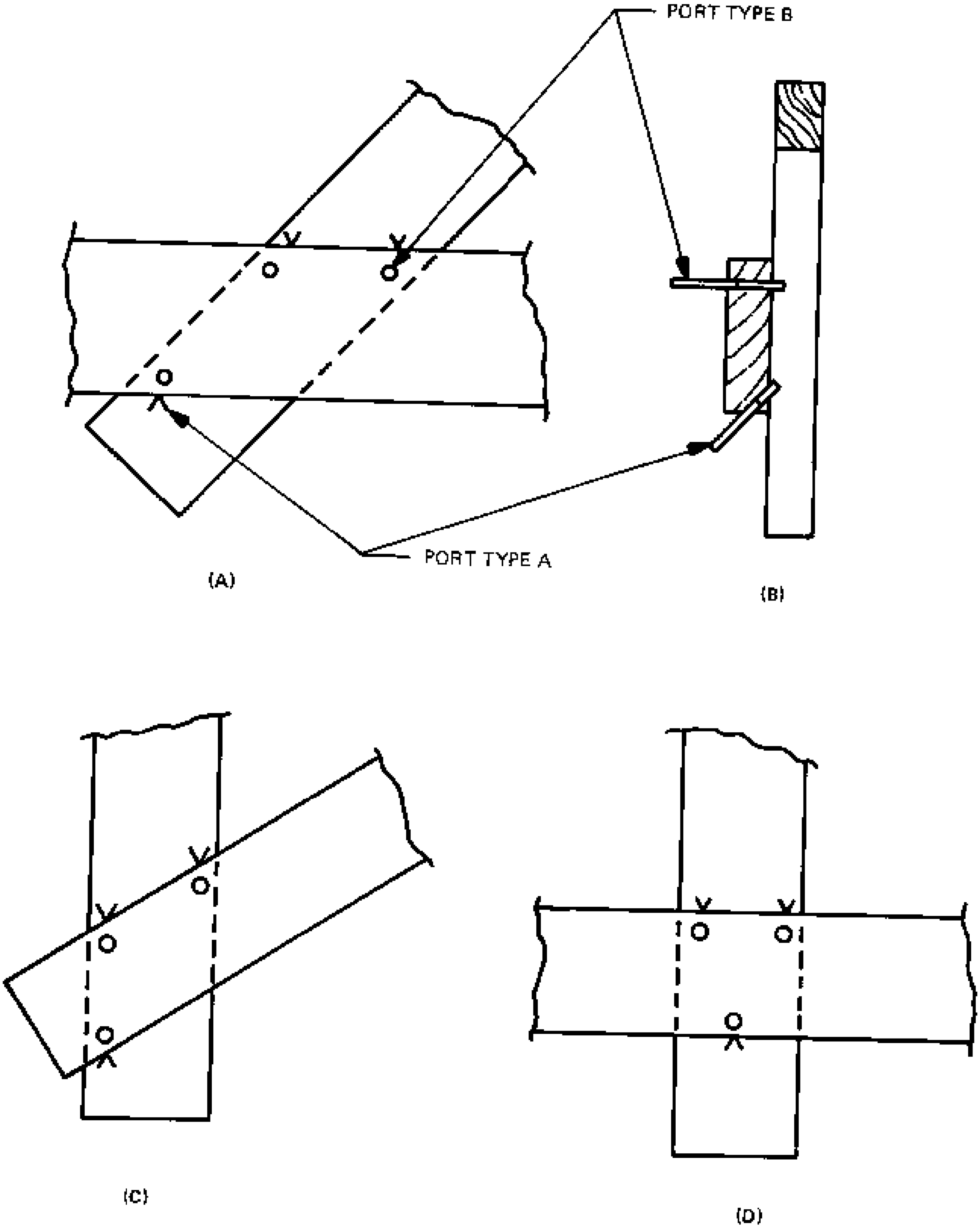


Figure 3-43. ALTERNATE METHODS OF SETTING INJECTION PORTS.

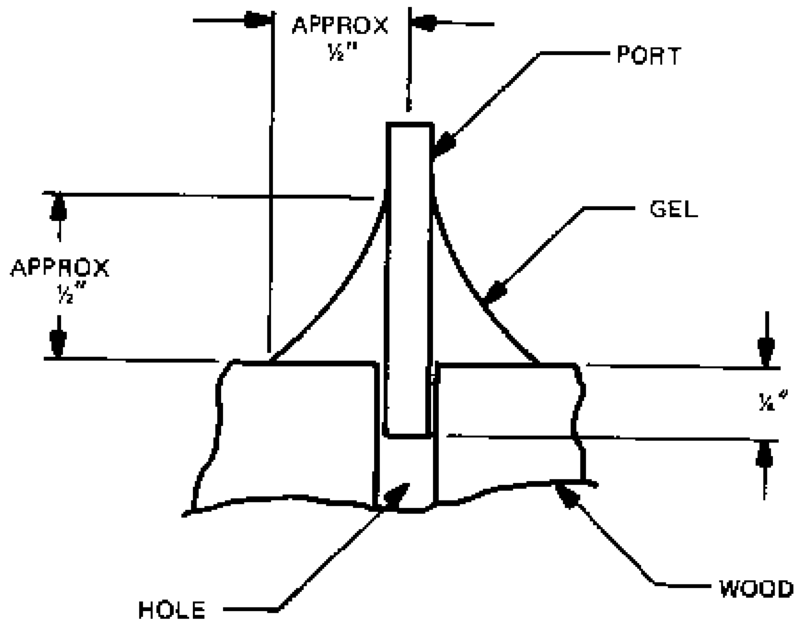


Figure 3-44. CROSS SECTION SHOWING GEL BUILD-UP AROUND PORT.

Figure 3-45. INSTALLED PORTS IN PLACE.

3.4.25.2 *Lap Joint and Crack Sealing.* All cracks, lap joints, bolts, holes, and defects must be completely sealed with gel. This sealing is usually performed by hand using putty knives and trowels. The gel must be thick enough to span the openings and withstand pressures of 40 to 80 lb/in^2. A cross section of a crack covered with gel is shown in figure 3-46. The thickness of the gel at the crack, h, should be approximately equal to the crack thickness, t. The gel is usually spread ¼ inch on either side of the crack. For cracks wider than **d** inch, a fiberglass cloth can be placed over the crack and gelled over. This procedure prevents the gel from penetrating too deeply into the crack and provides a stiffening effect once the gel has hardened. Care should be taken to apply the gel to the surface only. Forcing gel deeply into cracks may obstruct the injection epoxy and could prevent the injection epoxy from filling the voids. The gel is significantly weaker than the injection epoxy and should not be counted on for strengthening the repaired joint. Special care should be taken in sealing the following since experience has shown that leaks often occur at these points.

a. at sharp corners.

b. at openings greater than ¼ inch.

c. around bolts and washers.

d. around ports.

The entire joint or damaged area must be completely sealed. The injection epoxy has a viscosity similar to thin paint and will seek the path of least resistance when injected. Any small opening will leak enough that the injection cannot continue without sealing the leak. Typical sealed joints are shown in figure 3-47 and typical sealed splices are shown in figure 3-48.

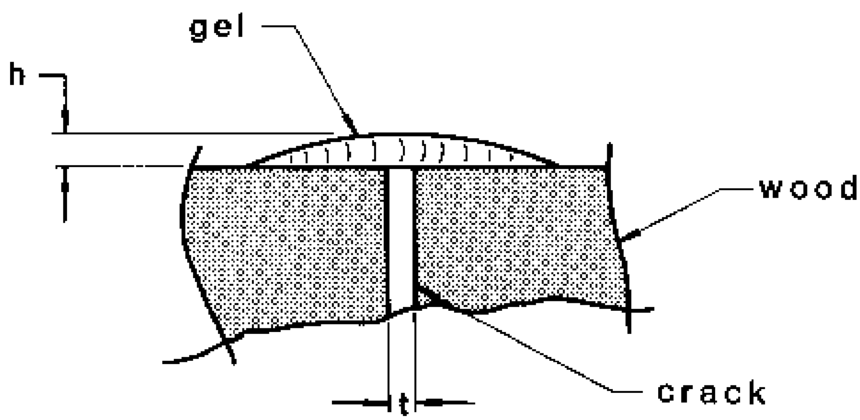


Figure 3-46. GEL APPLIED OVER LONGITUDINAL SPLIT.

3.4.25.3 *Leak Testing.* It is recommended that joints be leak tested before injection. A suitable procedure is to use compressed air. All ports except one venting port and injection port should be temporarily capped. Compressed air (at 25 lb/in^2 pressure) is then forced into the joint. The joint is then coated with a soap film and observed for bubbles. All leaks are marked and repaired after the film has dried. While leak testing may seem tedious, experience has shown that the time spent in leak testing is more than compensated for by expedited injection. In addition, the joint has a higher repaired strength when leaking is minimized.

3.4.25.4 *Hairline Cracks.* In some cases the deterioration has resulted in a number of hairline cracks which are difficult to visually detect. Should leak testing reveal a large number of such cracks, it is recommended that the entire damaged area be painted with a thick epoxy paint. This application fills hairline cracks and small holes not generally visible.

3.4.26 Epoxy Injection.

The next step is to pressure inject a low viscosity two-component epoxy into the sealed joint through the injection ports (figure 3-49). This can usually be done by attaching the nozzle of the injection gun to a single port (usually the lowest) and letting the other ports serve as vents. As epoxy fills the joint, the venting ports leak epoxy and are sealed off. After all ports are sealed, epoxy injection should be continued to insure penetration into the fibers. Care should be taken not to inject with too much pressure or the seal might break. A maximum bozzle pressure of 40 lb/in^2 is recommended.

When possible, the entire joint should be injected from a single port.

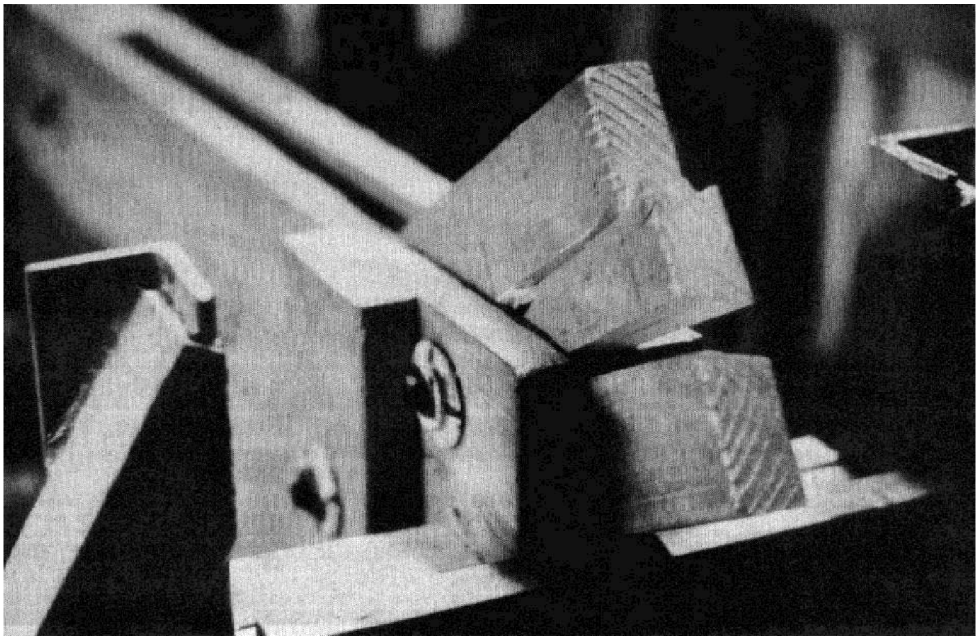
3.4.26.1 *Port Capping.* Various methods can be used to seal off ports during injection. One method is to lightly tap wooden golf tees into the port. Copper tubing can be bent or squeezed closed with pliers. Wooden dowels can also be inserted. The primary caution is that the seals should not be broken in the process.

3.4.26.2 *Leaking During Injection.* Should a leak develop during the injection, a quick-drying patching cement can be applied. Since it is essential to finish the injection before the epoxy initially sets, a patching cement with a 2- to 3-minute pot life is needed. Hydraulic cements which can be mixed with water work well. Hot-melt glues have also been used successfully. Because of the porous nature of wood, leaking will occur on occasion. No injection should be attempted without a supply of patching compound on hand.

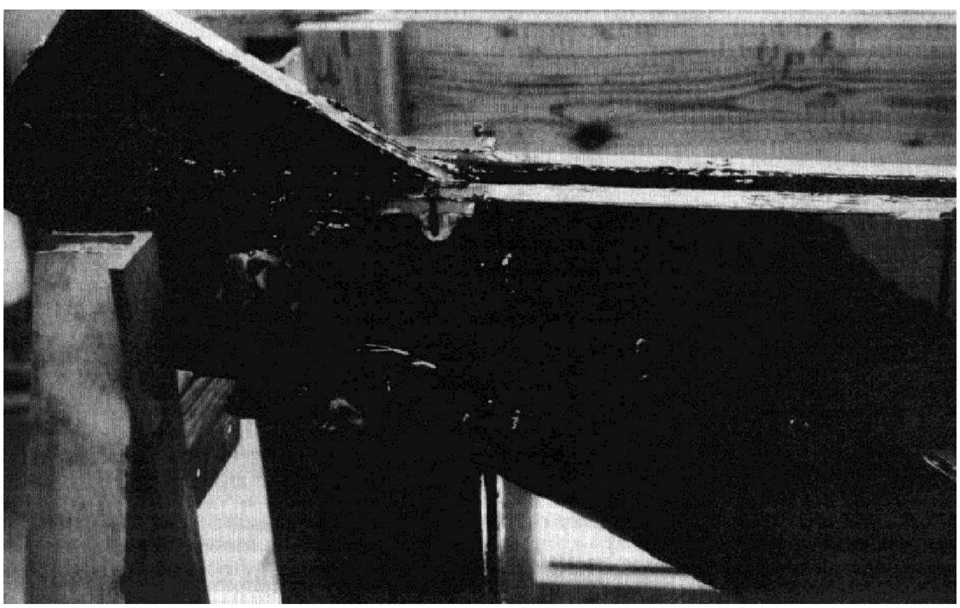
3.4.26.3 *Injection Equipment* .Injection is usually accomplished with automatic equipment, although hand equipment can be used. Typically, two positive displacement pumps geared to the specified mix ratio feed the separate components into a nozzle. Mixing is accomplished by forcing the epoxy through static-mixing brushes in the nozzle. As long as the flow is not interrupted for more than a few minutes, injection can progress for hours without damage to the nozzle.

3.4.27 Finishing

The initial cure time for many epoxies is 2 to 5 hours. Final cure is usually accomplished in several days. After final curing, any temporary supports may be removed. If esthetics are important, the injection ports are removed and sealing gel sanded smooth so paint can be applied to finish the repair.



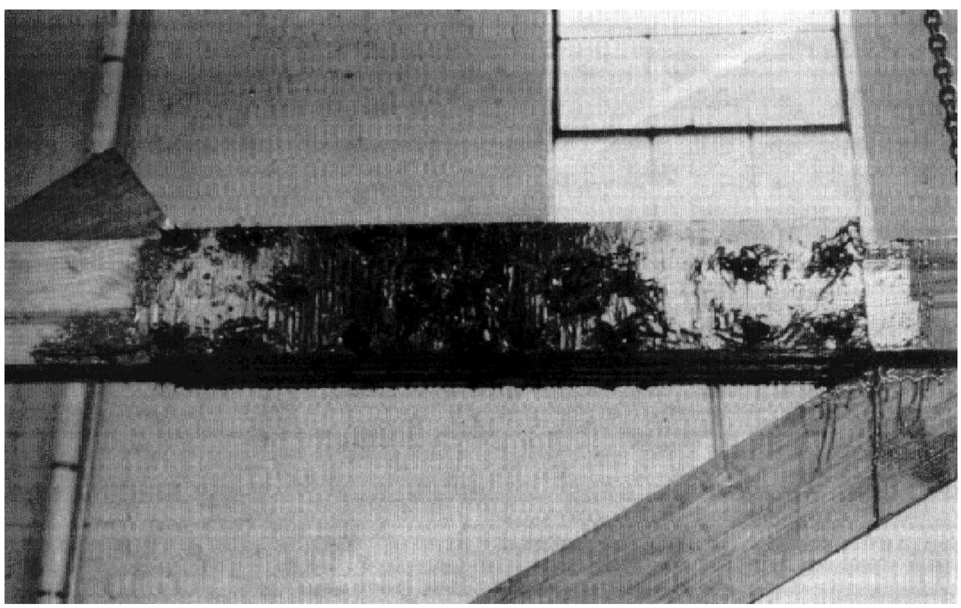
(A) INITIAL JOINT FAILURE



(B) SEALED JOINT

Figure 3-47. TYPICAL SEALED JOINT.

(A) INITIAL SPLICE FAILURE



(B) SEALED SPLICE

Figure 3-48. TYPICAL SEALED SPLICE.

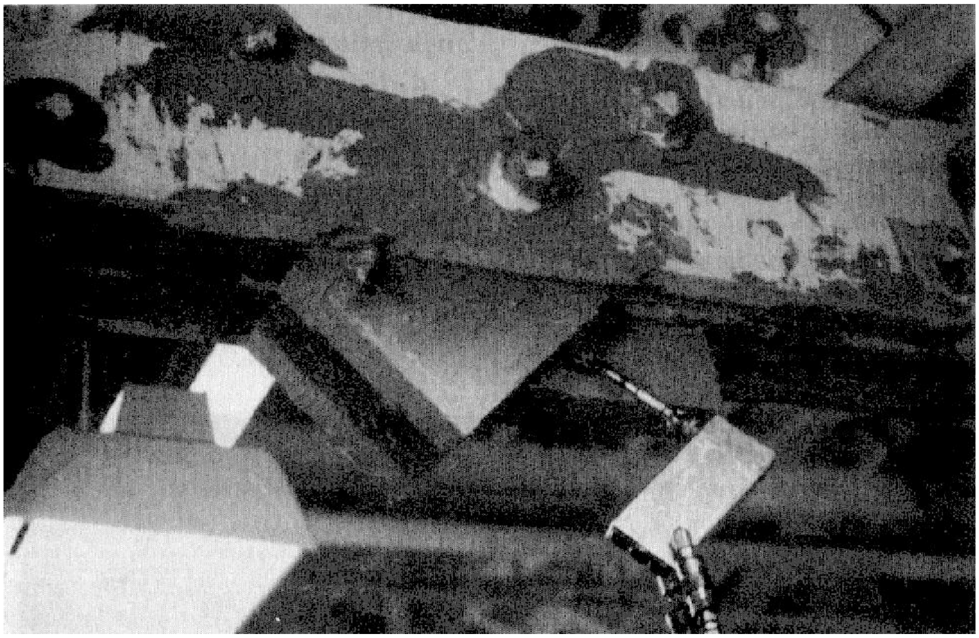


Figure 3-49. EPOXY INJECTION IN PROGRESS.

3.4.28 Injection Equipment

Although hand injection equipment can he used the utilization of automatic equipment is recommended. Typical equipment is described in the fol lowing sections.

3.4.28.1 *Pumping Equipment.* A typical pumping unit is shown in figure 3-50. The specific parts are numbered and described as follows:

a. Tanks—marked for ease of identification.

b. Pumps—positive displacement.

c. Chain drive—geared to provide the correct mix ratio of the two components.

d. Motor—driving mechanism for pumps.

e. Feedlines—transfer epoxy components to mixing head.

f. Check valves—prevents mixed epoxy from penetrating feedline.

g. Pressure gages—monitor injection flow.

h. Quick disconnect couplings—attach to mixing head.

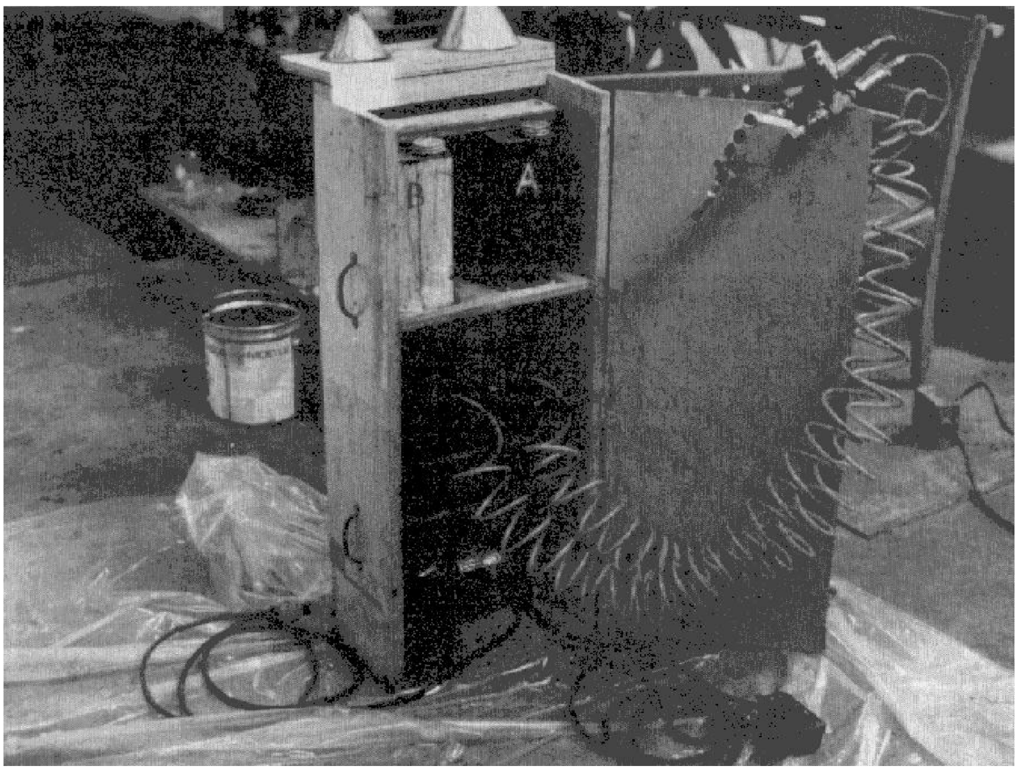


Figure 3-50. EPOXY INJECTION PUMPING UNIT.

3.4.28.2 *Mixing Head.* The mixing head is shown in figure 3-51 with the specific parts numbered. The parts are described as follows:

a. Feedline inlets—feed epoxy components into mixing head.

b. Mixing chamber—components mixed.

c. Mixing brushes—epoxy is forced around brushes for mixing.

d. Brass petcock—on-off valve for mixed epoxy.

e. Nozzles.

(1) Insertion type.

(2) Ferrule and fitting for positive connection to port.

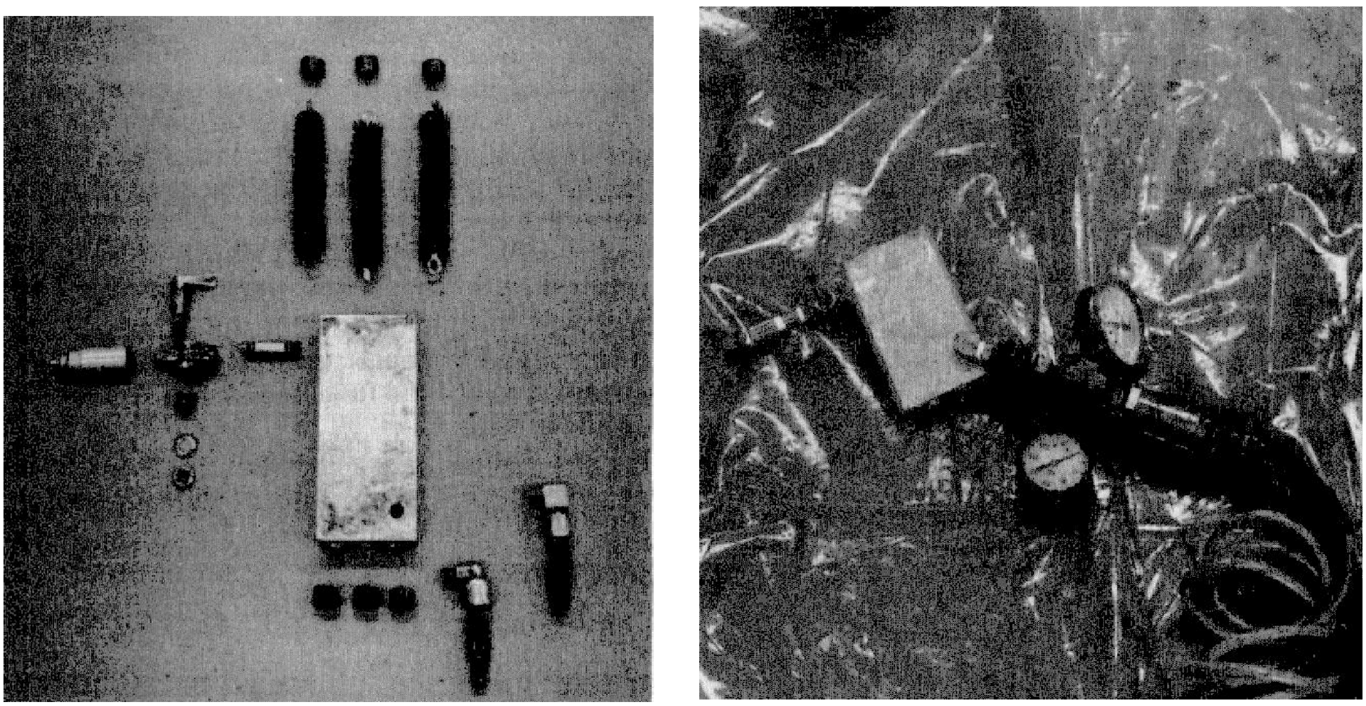
f. Hex head sealing plug—remove for cleaning.

3.4.29 Quality Control

One of the major difficulties associated with the epoxy repair procedure is quality control. Engineering inspection is one measure. However, it may prove difficult to verify whether epoxy has completely penetrated the damaged area. This concern is often emphasized by the fact that workmen may have relatively little experience with wood as opposed to concrete repairs. The following procedures are recommended for insuring a satisfactory epoxy repair.

3.4.29.1 *Epoxy Samples.* In many cases laboratory testing is not possible for wood repair in contrast to concrete repair where test cylinders can be taken. This lack of quality control can result in serious problems for epoxy repaired members. Many epoxies are very sensitive to mix proportions. The standard injection equipment consists of two positive displacement pumps driven by a single motor geared to obtain the proper mix. The two epoxy components are mixed at the nozzle, thus a fairly continuous flow prevents hardening of the epoxy in the nozzle. However, crimped lines, malfunctioning pumps, or line blockages can sometimes occur. In severe cases the problem may result in soft spots within joints. Frequent collecting of small samples in containers will determine if the epoxy is hardening as expected; this should be routinely done. It is recommended that a sample be taken before the injection of each joint with a notation as to the specific point being repaired. Should the epoxy not harden properly, the joint should be repaired by an alternative method.

3.4.29.2 *Shear Block Specimens.* The detection of weak but hardened materials is much more difficult. One method is to inject shear block specimens at the beginning of operations and after the repair of every fifth member. A shear specimen is cut into four shear blocks after curing and each is tested in single shear. The failure stress level should be approximately equal to the ultimate strength of the wood (approximately 600 to 800 lb/in^2 for southern pine). This level of shearing strength indicates a high-quality bond.



(A) UNASSEMBLED HEAD **(B) ASSEMBLED HEAD**

Figure 3-51. MIXING HEAD OF EPOXY INJECTION UNIT.

3.4.29.3 *Coring.* Another quality control problem is determining epoxy penetration into voids. Coring techniques have been developed, but none have proved completely satisfactorvy. The coring devices are either time consuming, thus allowing for only spot checks, or they destroy the sample making it difficult to detect the epoxy.

SECTION V—GLUED-LAMINATED WOOD FRAMES

3.5.1 General

An improvement in the heavy timber construction field is the development of glued-laminated (Glu-Lam) members. Large members are made up from smaller standard dimension pieces of lumber and formed into a variety of shapes and sizes. Glued-laminated members have higher allowable unit stresses than solid timber due to the dispersion of defects, such as knots, and the kiln-drying of the lumber prior to lamination. One of the most popular types for buildings is the glued-laminated arch. See figure 3-52.

3.5.2 Glued-Laminated Wood Beams

Beams built up of smaller pieces can also be shaped to fit architectural and structural require-ments in great variety. Some of these are illustrated in figure 3-52.

3.5.2.1 *Deflection and Camber*

For a given span, deflection is more pronounced in timber members than in steel or concrete. Much more often deflection will be the governing factor in design of timber beams and girders. Designers usually have a camber placed in timber beams and girders, based upon a full dead load and half of a live load. This means that the member will appear to arch upwards at midspan, when the roof has no superimposed load, and flatten out level when it supports a moderate snow load. Under an extreme snow load, usually occurring once every generation, the beam will appear to sag as far downward as it arched upward with no snow. In observing this situation bear in mind that either the top or the bottom of the beam could have been shaped in fabrication to produce a haunch or some other nonconformity. The camber or deflection may be measured from a tight string line held at the same glued surface line from one support to another. However, since members may be shaped after glueing, the only sure way is to consult design drawings where a camber sketch is shown.

3.5.2.2. *Decay*. Designers were originally lead to believe that glue-lam members were water resistant. Consequently, many structures were built with exposed beams and girders. Glue-lam arches were anchored in exposed metal shoes which filled with rain water. These areas are decaying badly and need to be repaired by replacement including full protection from rainwater provided to the new glue-lam members by complete covers.

3.5.3 Repair of Glued-Laminated Members

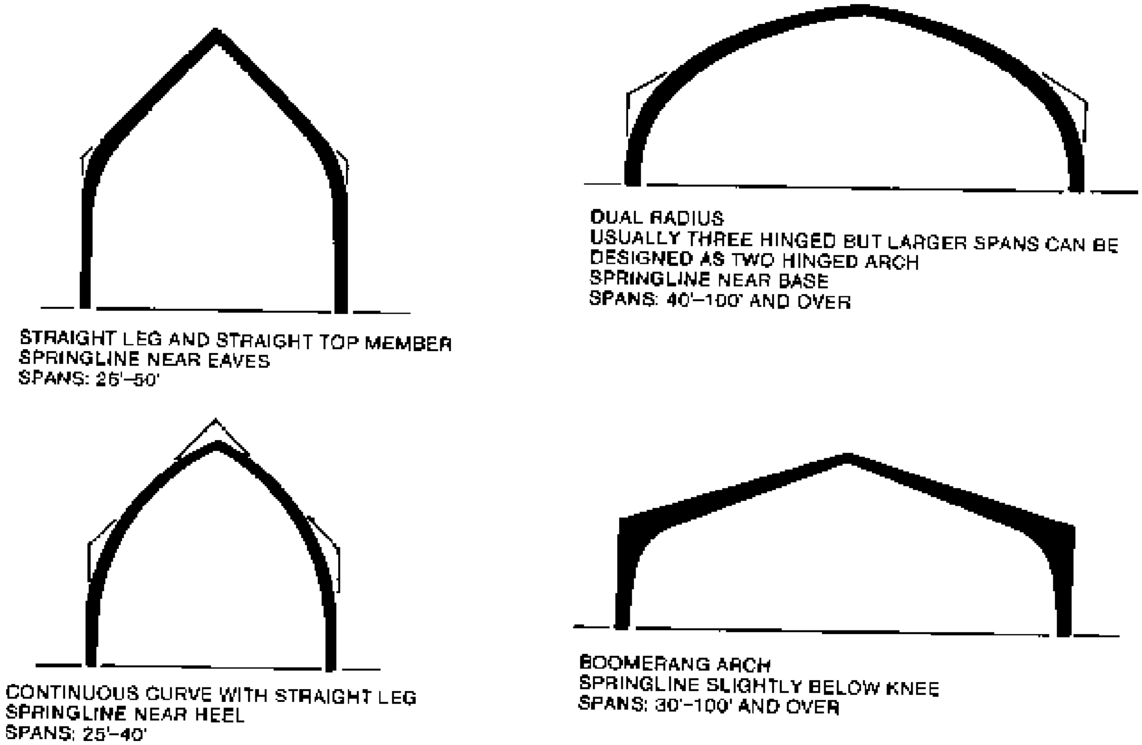
Glued-laminated members, having been kiln-dried before gluing and being of smaller selected pieces, do not ordinarily have the same defects as solid wood members. In arches, periodic inspections should be made to detect any delamination or separating of one piece in the member from another. Minute cracks should be carefully examined; and, if larger than $^{1}/_{16}$ inch, they should be examined by a competent structural engineer. Arches should be examined for alignment and settling.

3.5.4 Corrective Measures

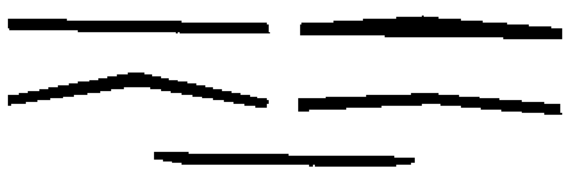
3.5.4.1 *Arches*. Adjustment of tie rods should be made only as directed by a competent structural engineer. Bolts and fasteners at the peak joint should be tightened; however, since the material has been dried, this should not be required as frequently as connections in solid timbers. At the direction of an engineer, steel plates, stitch bolts and spikes may be used to repair arches that have separated or delaminated.

3.5.4.2 *Beams*. Beams may be required in the same way, and lines for detecting sag or deflection should be used.

3.5.4.3 *Purlins and Joists*. Purlins or joists are usually fastened to these members with hangers. Shimming of the purlins in the hangers can be accomplished with small wood wedges or shims.



GLUED LAMINATED ARCH SHAPES



GLUED LAMINATED BEAM SHAPES

Figure 3-53. GLUE LAMINATED SHAPES.