CHAPTER 4

PILE INSTALLATION OPERATIONS

Section I. PREPARATION OF PILES FOR DRIVING

4-1. Preparation of timber piles.

Timber piles selected for a structure should be long enough so that the butts are 2 or 3 feet higher than the finished elevation after the piles are driven to the desired penetration. (Methods of predetermining pile lengths are described in chapter 5.) Timber piles require little preparation or special handling; however, they are susceptible to damage during driving, particularly under hard driving conditions. To protect the pile against damage, the following precautions should be taken.

a. Fresh heading. When hard driving is expected, the pile should be fresh headed by removing 2 to 6 inches of the butt. Removing a short end section allows the hammer to transmit energy more readily to the lower sections of the piles. Butts of piles that have been fresh headed should be field treated with creosote and coal tar pitch (chapter 8), after the pile has been driven to the desired penetration.

b. Fitting. Proper fit between the butt of the pile and the driving cap of the hammer is the most important factor in protecting the pile from damage during hard driving. The butt of the pile must be square cut, shaped to fit the contour of the driving cap, and a little larger than the dimensions of the cap so the wood will be compressed into the driving cap. Under most driving conditions the tip of a timber pile should be left square without pointing. The following points should be kept in mind when fitting timber piles.

- Pointing timber piles does little to increase the rate of penetration.
- Piles with square tips are more easily kept in line during driving and provide better end bearing.
- For very hard driving, steel shoes protect the tips of piles (figure 4-1, 1). Steel plates nailed to blunt tips (figure 4-1, 2) offer excellent protection.

c. Wrapping. If a driving cap is not used, or if crushing or splitting of the pile occurs, the top end of the pile should be wrapped tightly with 12-gage steel wire to forma 4-inch band. The steel wire should be stapled firmly in

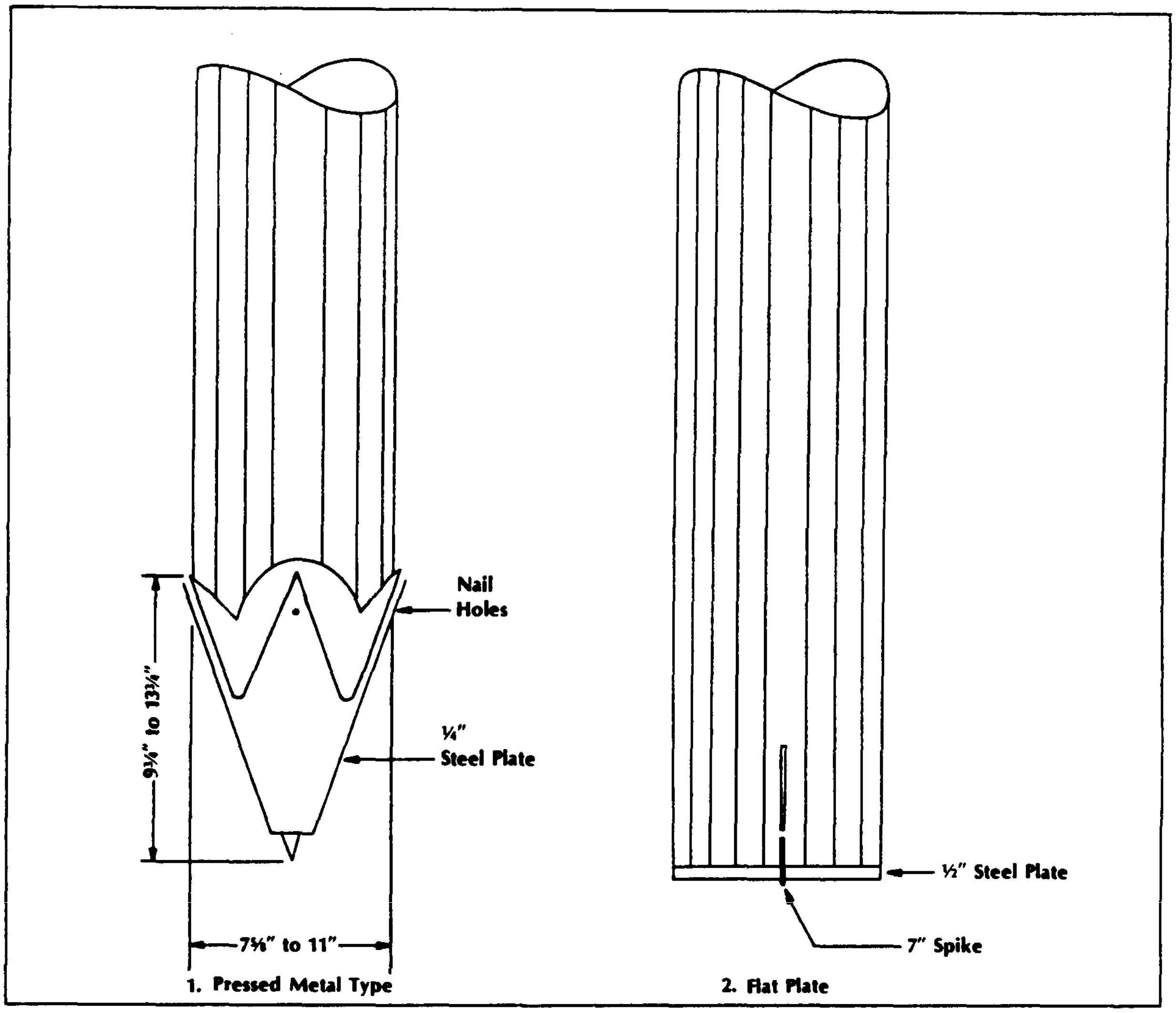

Figure 4-1 Steel shoes for timber piles

place. This is a simple method of protecting pile butte during hard driving. Steel strapping about 1¼ inches wide will also provide adequate protection. Strapping should encircle the pile twice, be tensioned as tightly as possible, and be located approximately two feet from the butt.

d. Splicing. Piles can be spliced if single sections of the required length are not available or if long sections cannot be handled by available pile drivers. Generally, decreasing pile spacing or increasing the number of piles is preferable to splicing. Except in very soft soils or in water, the diameter of the complete splice should not be greater than the diameter of the pile (figure 4-2). The ends of the piles must be squared, and the diameter trimmed to fit snugly in the 8-inch or 10-inch steel pipe. Steel splice plates are also used (figure 4-2).

e. Lagging. Lagging a friction pile with steel or timber plates, planks, or rope wrapping

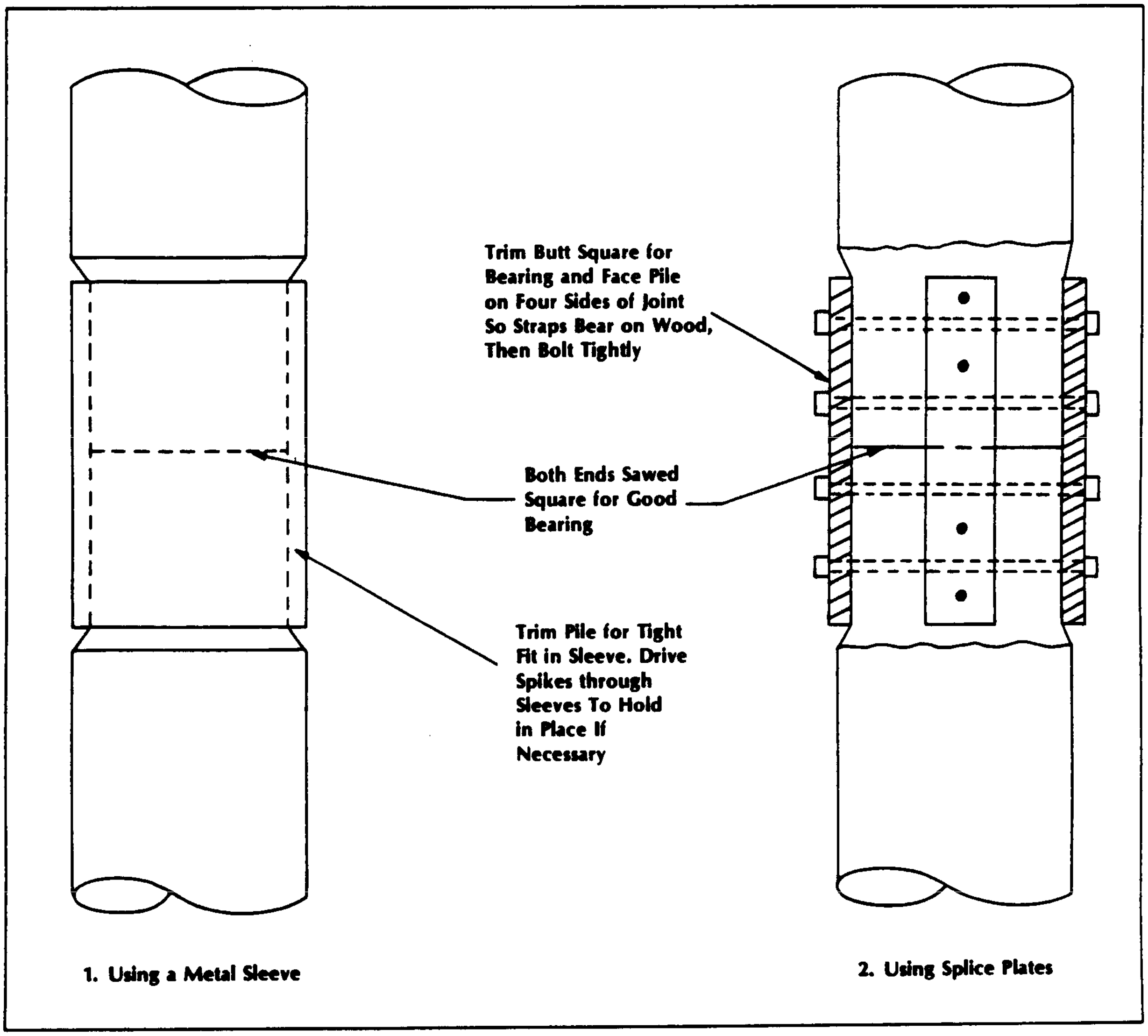

Figure 4-2 Methods of splicing timber piles

can be used to increase the pile's load-carrying capabilities.

4-2. Preparation of steel piles.

a. Reinforcing. Point reinforcement is seldom needed for H-piles; however, if driving is hard and the overburden contains obstructions, boulders, or coarse gravels, the flanges are likely to be damaged and the piles may twist or bend. In such cases H-piles (figure 4-3) and pipe piles (figure 4-4) should be reinforced.

b. Cleaning. Pipe piles driven open-ended, must be cleaned out before they are filled with concrete. Ordinarily they are closed at the lower end, usually with a flat plate (figure 4-4). In a few soils, such as stiff plastic clays, the overhang of the plate should be

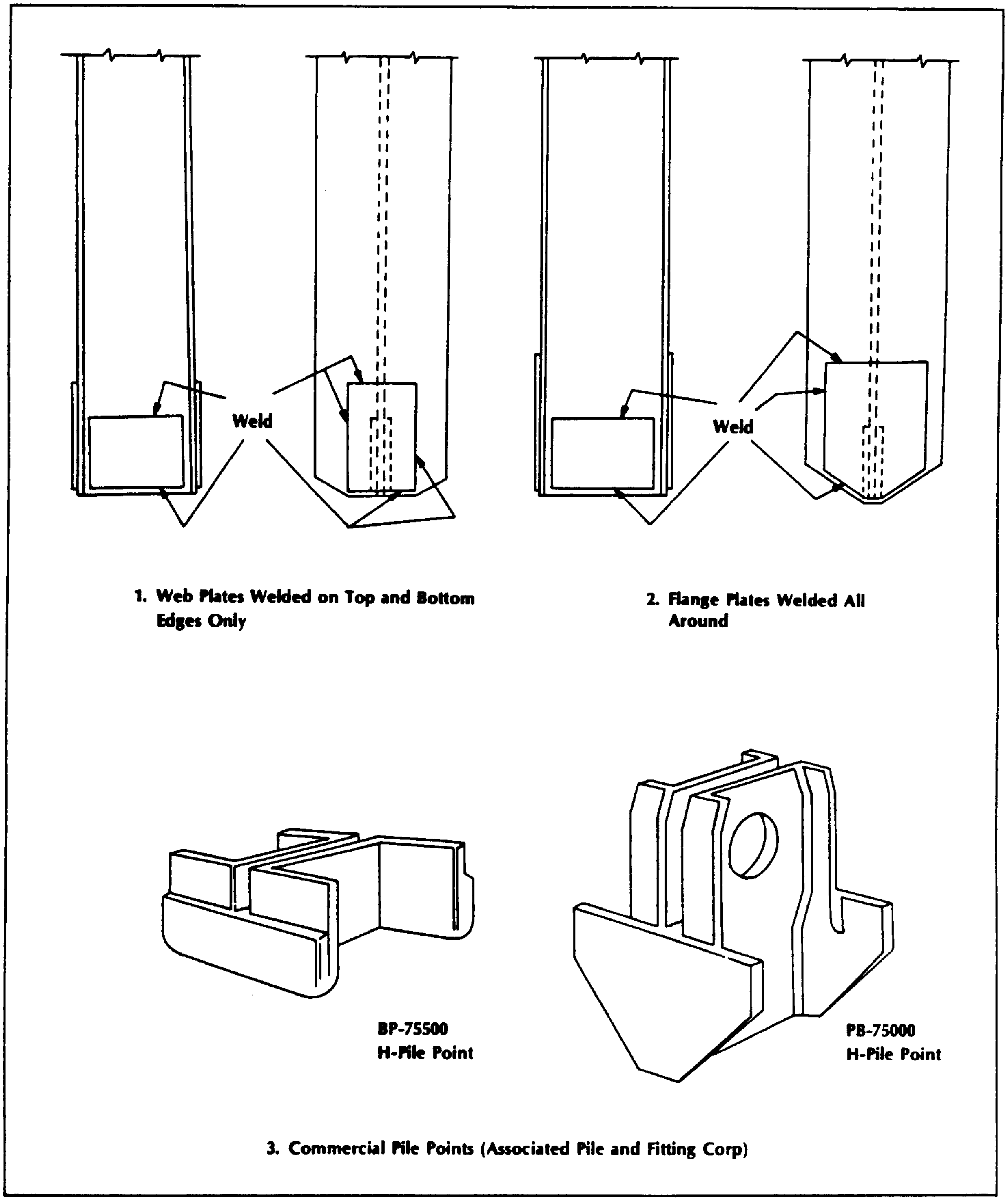

Figure 4-3 Driving points for H-piles

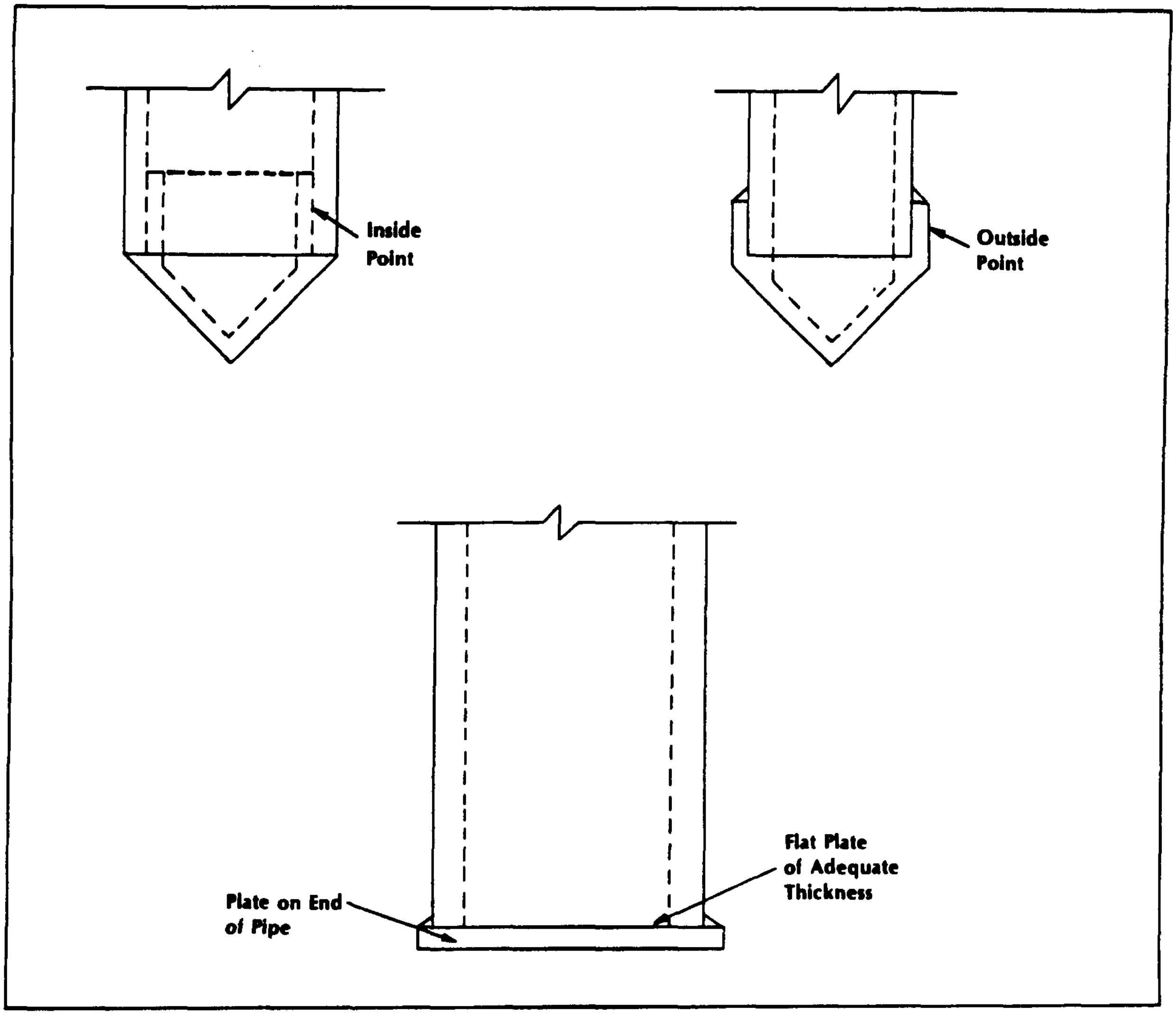

Figure 4-4 Driving points for pipe piles

eliminated. Such pipe piles can be inspected after driving. Damaged piles should be identified and rejected if not repairable.

c. Splicing. H-piles can be spliced and designed to develop the full strength of the pile both in bearing and bending. This is done most economically with butt-welded splices (figure 4-5). This method requires that the pile be turned over several times during the welding operation. Various types of plate and sleeve splices can be used (figure 4-6). Splicing is often performed before the piles are placed in the leads so pile-driving operations are not delayed.

d. Lagging. Lagging is of questionable value and if attached near the bottom of the pile, will actually reduce the capacity of the pile.

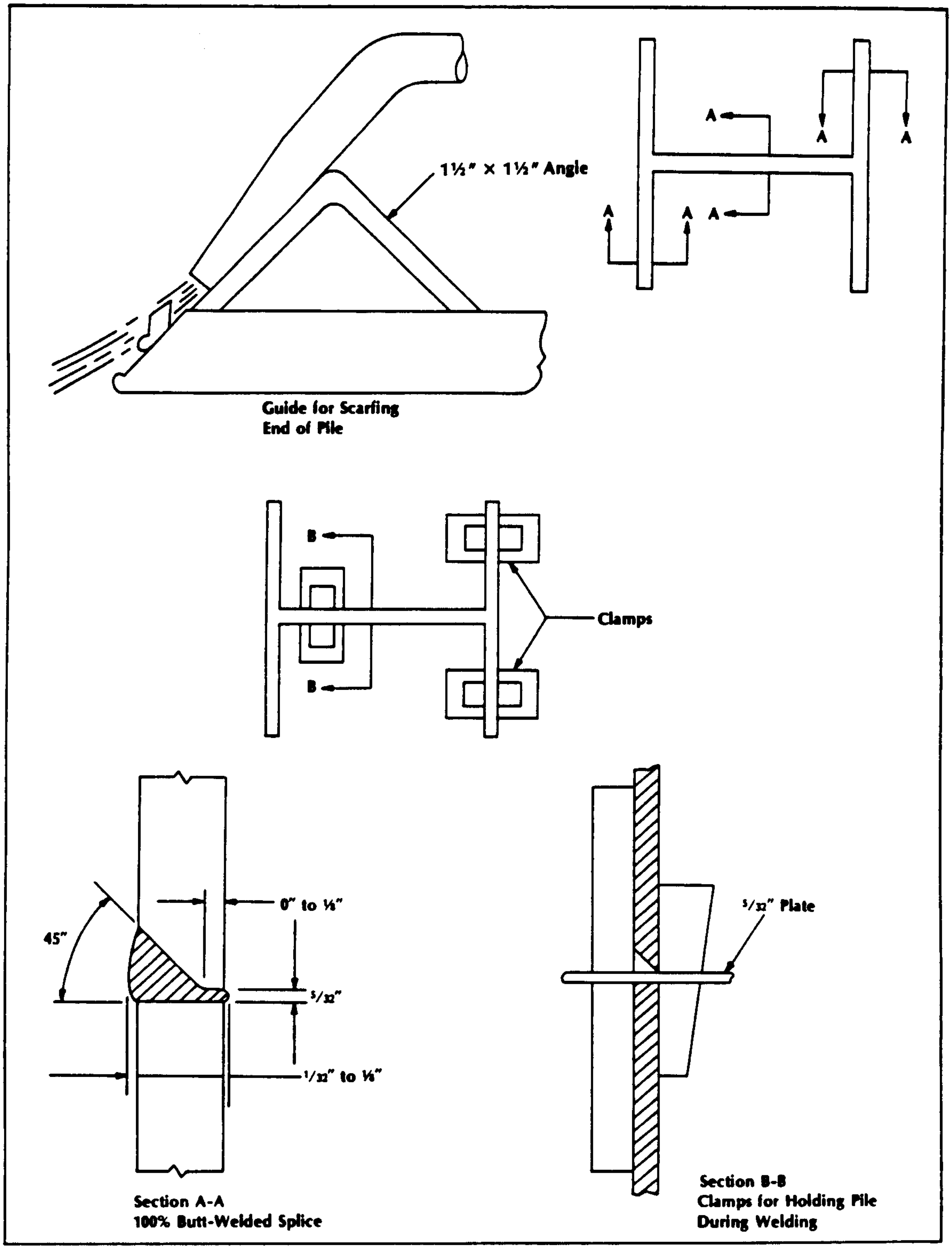

Figure 4-5 Butt-welded splice, welding clamps, and guide for scarfing

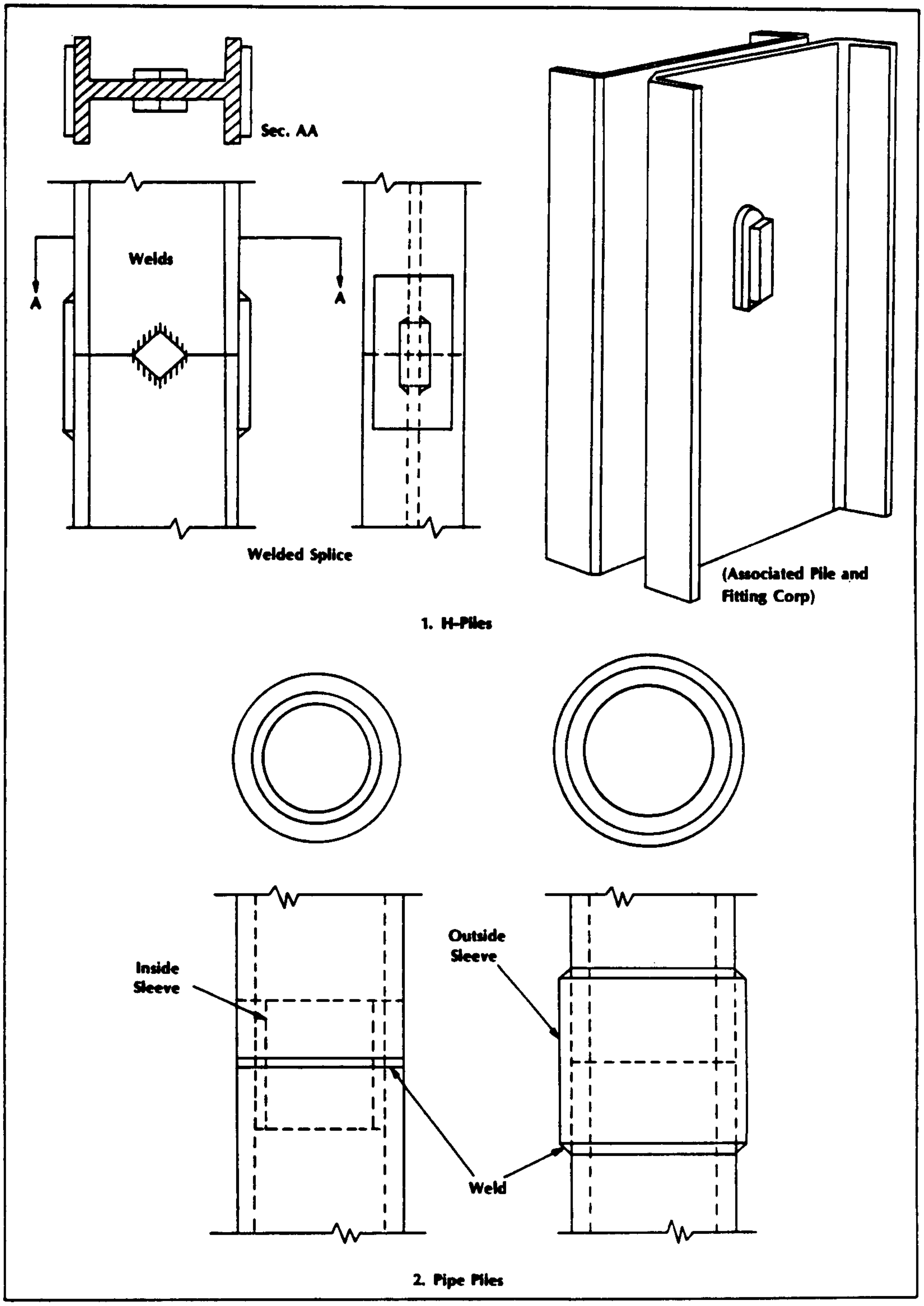

Figure 4-6 Splices of H-piles and pipe piles

4-3. Preparation of concrete piles.

Precast concrete piles should be straight and not cambered by uneven prestress or poor concrete placement during casting.

a. Reinforcing. Reinforcing of precast concrete piles is done in the manufacturing. The top of the pile must be square or perpendicular to the longitudinal axis of the pile. The ends of prestressing or reinforcing steel should be cut flush with the end of the pile head to prevent direct loading by the ram stroke. Poured concrete piles may be re-inforced with steel reinforcing rods.

b. Splicing or cutting. Precast concrete piles are seldom, if ever, spliced. If the driving length has been underestimated, the pile can be extended only with considerable difficulty. The piles are expensive to cut if the length has been over estimated. Poured concrete piles should not require splicing as length is predetermined in the planning stages.

Section II. CONSTRUCTION PROCEDURES

4-4. Positioning piles.

When piles are driven on land, for example a building foundation, the position of each pile must be carefully established, using available surveying equipment. A simple template can be constructed to insure proper positioning of the piles. Piles generally should not be driven more than three inches from their design location. Greater tolerances are allowed for piles driven in water and for batter piles.

4-6. General driving procedures.

Piles are set and driven in four basic steps (figure 4-7).

a. Positioning. The pile driver is brought into position with the hammer and cap at the top of the leads (figure 4-7, 1).

b. Lashing. Generally, the pile line is lashed about one third of the distance from the top of the pile, the pile is swung into the helmet, and the tip is positioned into the leads (figure 4-7, 2). A member of the handling crew can climb the leads and, using a tugline, help align the pile in the leads.

c. Centering. The pile is centered under the pile cap, and the pile cap and hammer are lowered to the top of the pile. If a drop hammer is used, the cap is unhooked from the hammer (figure 4-7, 3).

d. Driving. The hammer is raised and dropped to drive the pile (figure4-7, 4). Driving should be started slowly, raising the hammer only a few inches until the pile is firmly set. The height of fall is increased gradually to a maximum of 6 feet. Blows should be applied as rapidly as possible to keep the pile moving. Repeated long drops should be avoided since they tend to damage the top of the pile.

4-6. Driving requirements.

Careful watch must be kept during driving to avoid damage to the pile, pile hammer, or both. Precautions and danger signs include the following

a. Support. The pile driver must be securely supported, guyed, or otherwise fastened to prevent movement during driving.

b. Refusal. Refusal is reached when the energy of the hammer blow no longer causes penetration. At this point, the pile has reached rock or its required embedment in the bearing stratum. It is not always necessary to drive piles to refusal. Friction piles frequently must be driven only far enough to develop the desired load bearing capacity. In certain types of soils, such as a very soft organic soil or deep marsh deposit, a considerable length of pile may be necessary to develop adequate load capacity. Driving in such soils is frequently easy as piles may penetrate several

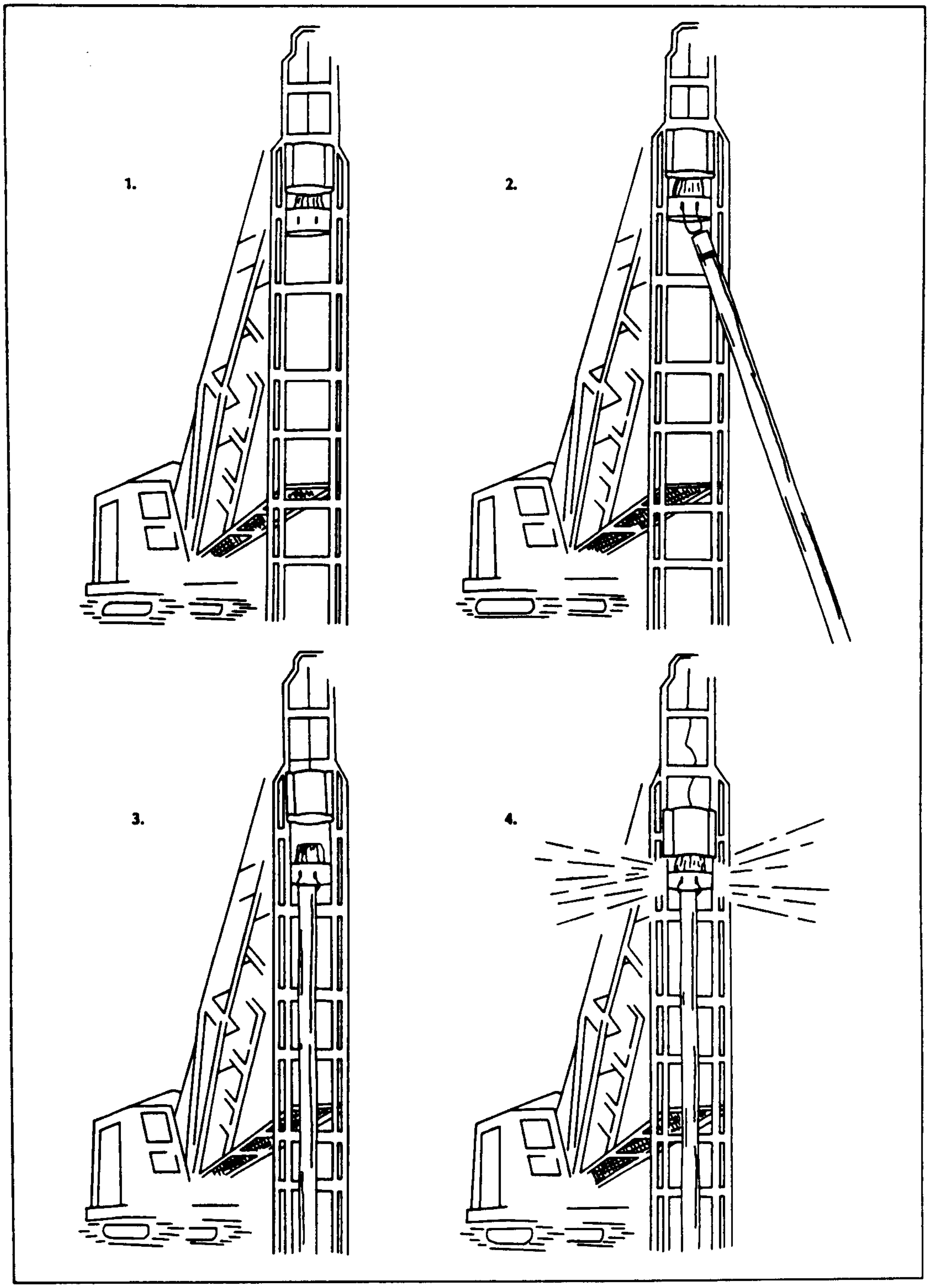

Figure 4-7 Basic steps in setting and driving piles

feet under a single hammer blow. It is important that driving be a continuous procedure. An interruption of even several minutes can cause a condition of temporary refusal in some types of soils, thus requiring many blows to get the pile moving again.

c. Timber piles. Timber piles are frequently overdriven when they are driven to end bearing on rock (figure 4-3). If the pile hits a firm stratum, depth may be checked by driving other piles nearby. If the piles stop at the same elevation, indications are that a firm stratum has been reached. Following are items to be watched for when driving timber piles.

(1) *Breaking or splitting below ground.* If the driving suddenly becomes easier, or if the pile suddenly changes direction, the pile has probably broken or split. Further driving is useless as bearing capacity is unreliable. Anew pile must be driven close to the broken one, or the broken one pulled and a new one driven in its place.

(2) Pile spring or hammer bounce. The pile may spring or the hammer may bounce when the hammer is too light. This usually occurs when the butt of the pile has been crushed or broomed, when the pile has met an obstruction, or when it has penetrated to a solid footing.

(3) *Double-acting hammer bounce.* When a double-acting hammer is being used, too much steam or air pressure may cause bouncing. When using a closed-ended diesel hammer, lifting of the hammer on the upstroke of the ram piston can cause bouncing. This is caused by too high a throttle setting or too small a hammer. Throttle controls should be backed off just enough to avoid this lifting action.

(4) *Crushed or broomed butt.* If the butt of a timber pile has been crushed or broomed for approximately 1 inch, it should be cut back to sound wood before driving is continued. There should be no more than three or four final blows per inch for timber piles driven with a diesel, steam, or air hammer. Further driving may fracture the pile or cause brooming.

d. Steel piles. In driving steel piles, particular care must be taken to see that the hammer strikes the top of the pile squarely, with the center of the hammer directly over the center of the pile. Watch for the following.

(1) *Slack lines.* A hammer suspended from a slack line may buckle the top section and require the pile be trimmed with a torch before driving can proceed. Driving caps (previously described) will prevent this type of damage to H-piles.

(2) *Alignment.* When a steel pile is driven with a flying hammer (free-swing hammer), the pile should be aligned with guys (figure 4-9). Hooks, shackles, or cable slings can be used to attach guy lines. A pile should be considered driven to refusal when five blows of an adequate hammer are required to produce a total penetration of ¼ inch or less.

e. Concrete piles. Required driving resistances for prestressed concrete piles are essentially the same as for steel piles. Driving stresses should be reduced to prevent pile damage. The ram velocity or stroke should be reduced during initial driving when soil resistance is low. Particular attention should be paid to the following.

(1) *Cap or helmet.* The pile-driving cap or helmet should fit loosely around the pile top so the pile may rotate slightly without binding within the driving head.

(2) *Cushioning.* An adequate cushioning material must be provided between the helmet or driving cap and the pile head.

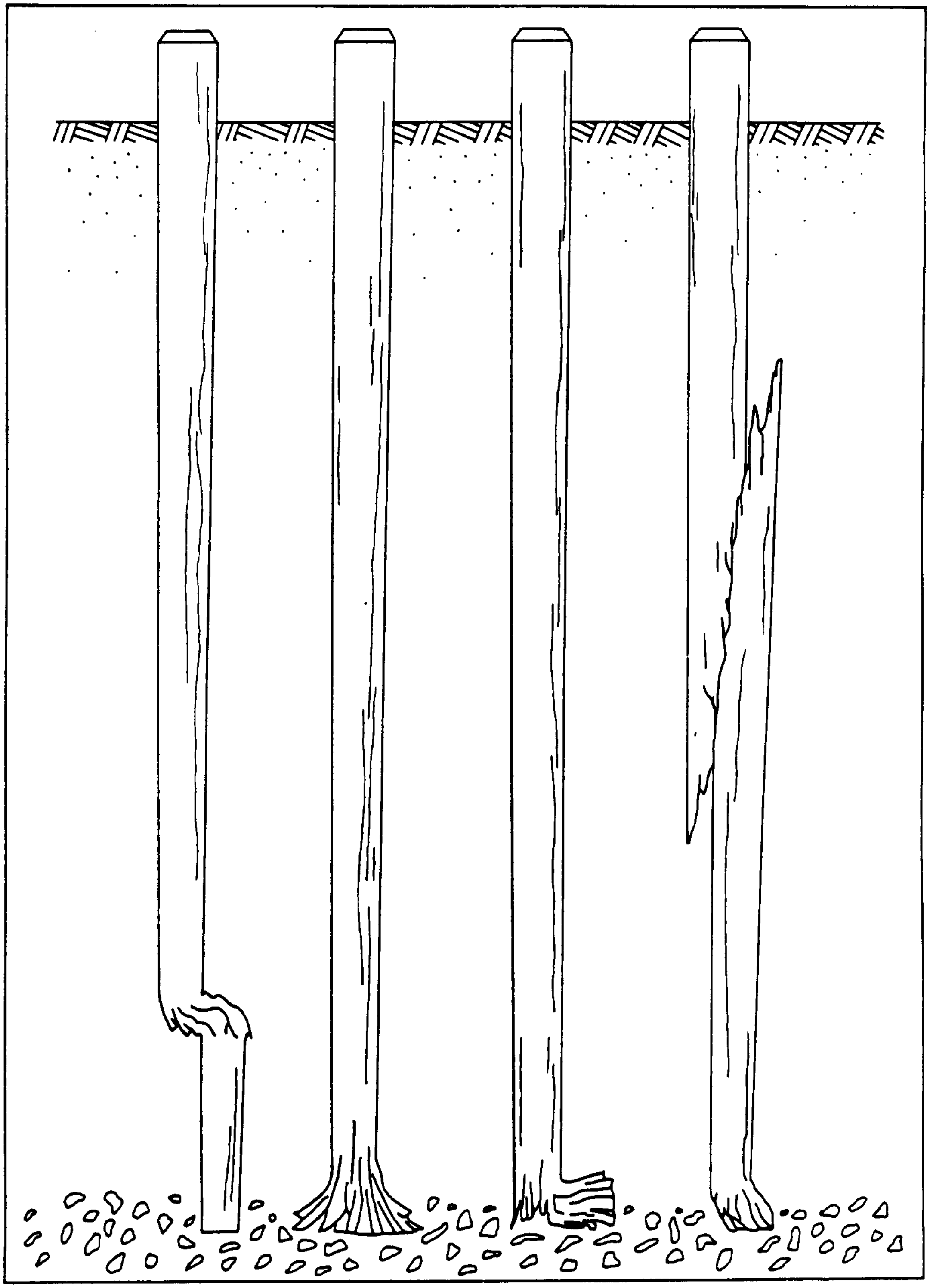

Figure 4-8 Types of damage to timber piles from overdriving

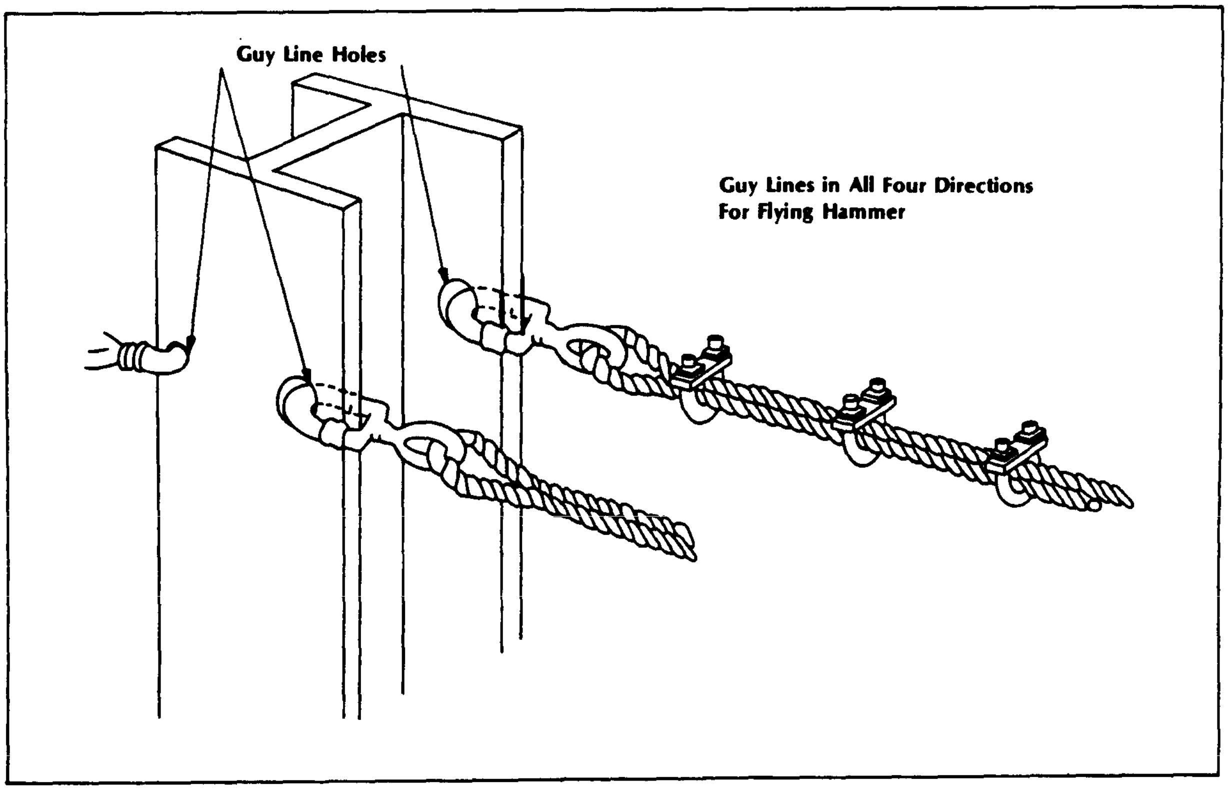

Figure 4-9 Method of guying steel piles

Three or four inches of wood cushioning material (green oak, gum, pine, or fir plywood) are adequate for piles less than 50 feet in length in a reasonably good bearing stratum. Cushions 6 inches thick or more may be required when driving longer piles in very soft soil. The cushion should be placed with the grain parallel to the end of the pile. When the cushion becomes highly compressed, charred, or burned, it should be replaced. If driving is hard, the cushion may have to be replaced several times during the driving of a single pile.

f. Special problems. Special problems may arise when driving various types of piles. A list of potential problems, with possible methods of treatment, is shown in table 4-1.

4-7. Aligning piles.

Piles should be straightened as soon as any misalignment is noticed during the driving. When vertical piles are driven using fixed leads, plumbing is not a matter of concern since the leads will hold the pile and correct the alignment. Vertical piles normally should not vary more than 2 percent from the plumb position.

a. Checking misalignment. Along mason's level is useful in plumbing the leads. For batter piles (figure 4-10) a plywood template can be used with the level. Exact positioning is easier if the driver is provided with a spotter or moon beam.

TABLE 4-1. TREATMENT OF FIELD PROBLEMS ENCOUNTERED DURING PILE DRIVING

Description of Problem	Procedures to Be Applied
Category:	
Obstructions: Old foundations, boulders, rubble, fill, cemented lenses.	Excavate or break up shallow obstruction if practical. For deeper obstructions use spudding, jetting, or temporary casings, or use drive shoes and reinforced tips when the pile is strong enough to be driven through obstructions.
General Problems:	
Vibration: Loose granular materials may compact and cause existing structures near piles to settle. Effect most pronounced in driving displacement piles.	Select pile type with minimum displacement and/or precore or jet with temporary casing or substitute jacking for pile driving.
Damage to Thin Shells: Driven shells may have been crimped, buckled, or torn. They may be leaking at joints as the result of driving difficulties or presence of obstructions.	Each pile is inspected with light beam. If diameter at any location varies more than 15% from original diameter or if other damage to shell cannot be repaired, pile is abandoned, filled with sand and a replacement is driven. Concrete shall be placed in dry shell only.
Inappropriate Use of Pile Driving Formula: Piles driven to a penetration determined solely by driving resistance may be bearing on a compressible stratum. This may occur in thick strata of silty fine sand, varved silts and clays, or medium stiff cohesive soils.	Unsuitable bearing strata should be determined by exploration program. Piles should not be permitted to stop in these strata, regardless of driving resistance. To determine bearing in stiff and brittle cohesive soils and in soft rock, load tests are particularly important.
Difficulties at Pile Tip:	
Fracturing of Bearing Materials: Fracturing of material immediately below tips of piles driven to required resistance as a result from driving adjacent piles. Brittle weathered rock, clay-shale, shale, siltstone, and sandstone are vulnerable materials. Swelling of stiff fissured clays of shales at pile tip may complicate this problem.	For piles bearing in these materials specify driving resistance test on selected piles after completion of driving adjacent piles. If damage to the bearing stratum is evidenced, require redriving until specified resistance is met.
Steeply Sloping Rock Surface: Tips of high capacity end bearing piles may slide or move laterally on a steeply sloping surface of sound hard rock which has little or no overlying weathered material.	Provide special shoes or pointed tips or use one end pipe pile socketed into sound rock.
Loss of Ground: Ground loss may occur during installation of open end pipe piles. Materials vulnerable to piping, particularly fine sands or silts, may flow into pipe under the influence of an outside differential head, causing settlement in surrounding areas or loss of ground beneath tips of adjacent piles.	Avoid cleaning in advance of pile cutting edge and/or retain sufficient material within pipe to prevent inflow of soil from below.
Movement of Piles Subsequent to Driving:	
Heave: Completed piles rise vertically as the result of driving adjacent piles. This is particularly common for displacement piles in soft clays and medium compact granular soils. Heave becomes serious in soft clays when volume displaced by piles exceeds 2½% of volume of soil enclosed within the limits of the pile foundation.	For piles of solid cross sections (timber, steel, precast concrete), survey top elevations during driving of adjacent piles to determine possible heave. For piles that have risen more than 0.005 foot redrive to at least the former tip elevation, and beyond that as necessary to reach required driving resistance. Heave is minimized by driving temporary open-end casing, precoring, or jetting so that total volume displaced by pile driving is less than 2 or 3% of total volume enclosed within limits of pile foundation.
Lateral Movement: Completed piles move horizontally as the result of driving adjacent piles.	Survey horizontal positions of completed piles while driving adjacent piles. Movement is controlled by procedures used to minimize heave.

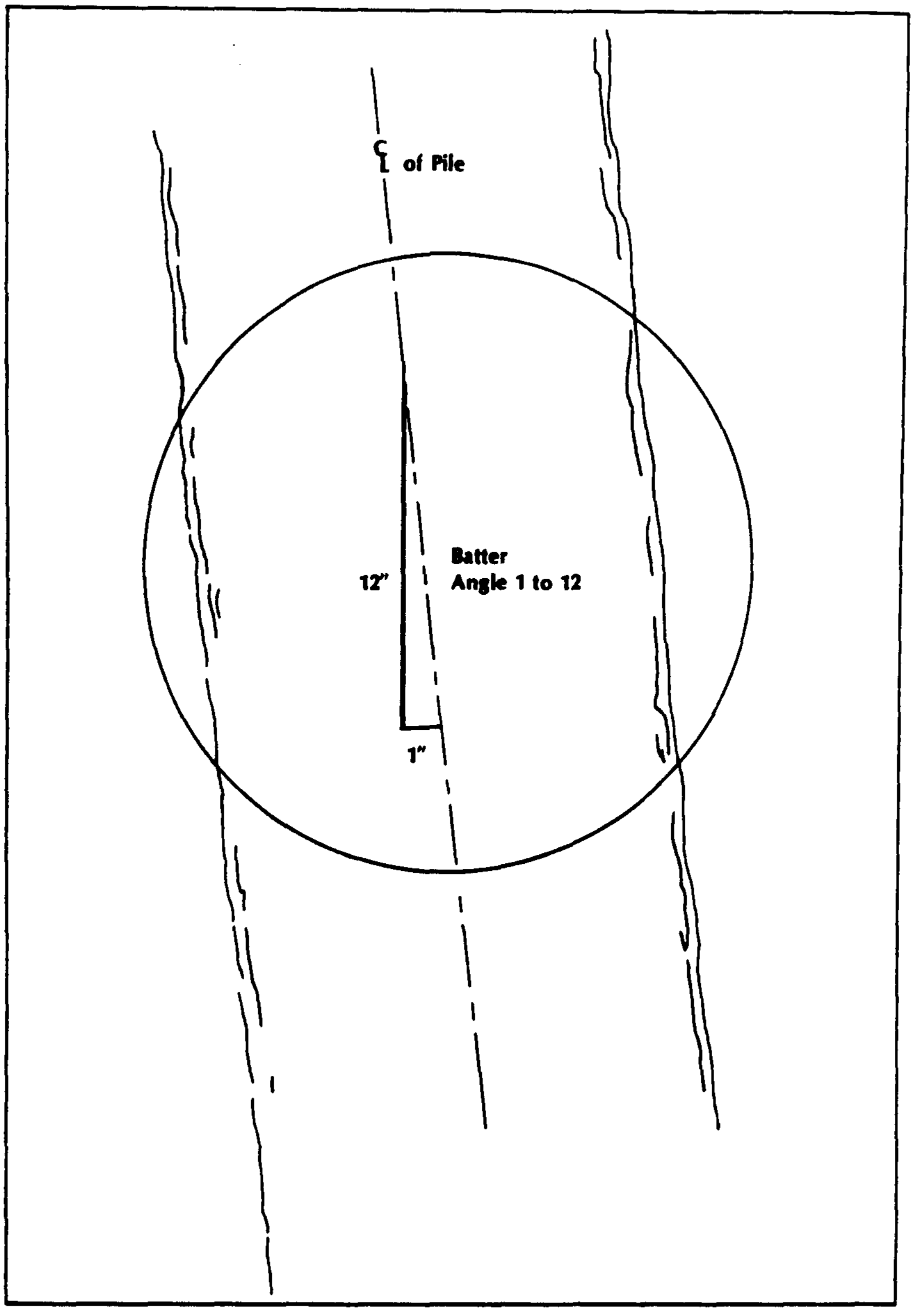

Figure 4-10 Batter of a pile

b. Checking misalignment by cap removal. If the pile is more than a few inches out of plumb during driving, an effort should be made to restore the pile to its proper alignment. The alignment can be checked by lifting the cap from the pile butt. The pile will rebound laterally if not properly aligned with the leads and hammer.

c. Aligning with block and tackle. During driving, a pile may be brought into proper alignment by using block and tackle (figure 4-11). The impact of the hammer will tend to jar the pile back into line. In the case of steel H-piles, this procedure may induce undesirable twisting and should be avoided if possible. Jetting either alone or with the preceding method, may be used.

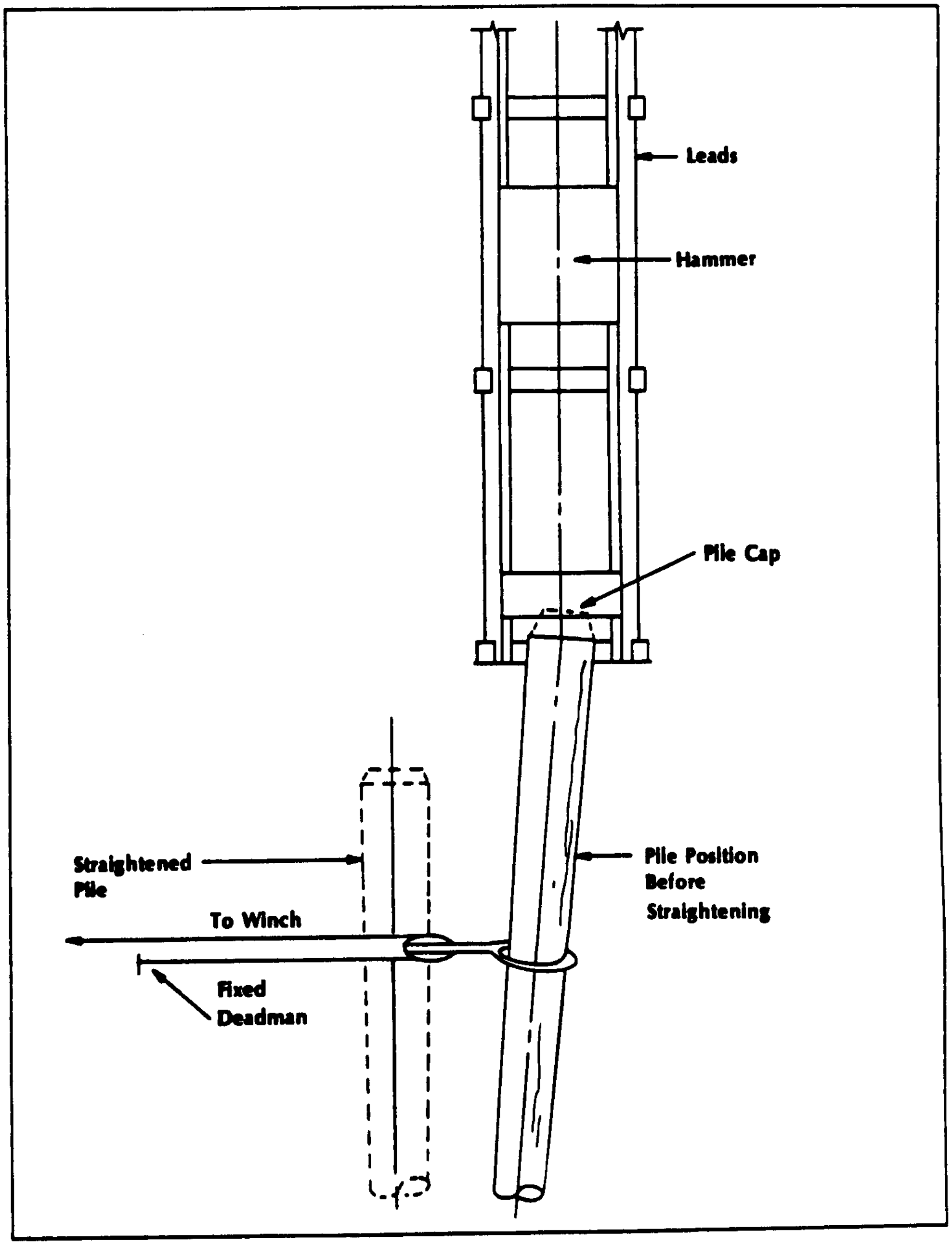

Figure 4-11 Use of block and tackle to realign pile

4-8. Obstructions.

Obstructions below the ground surface are often encountered during pile-driving operations. Obstructions may result from filling operations in the area or from old stumps or tree trunks buried by later deposits. Obstructions are frequently encountered when piles are driven in industrial and commercial areas of older cities or along waterfronts. They are a matter of concern since they can prevent a pile from penetrating enough to provide adequate load-carrying capacity. Piles are frequently forced out of line by obstructions and may be badly damaged by continued driving in an effort to break through the obstruction.

a. Driving. When an obstruction such as a rotten log or timber is encountered, 10 or 15 extra blows of the hammer may cause the pile to breakthrough (figure 4-12, 1). With steel or precast concrete bearing piles, extra blows of the hammer may break or dislodge a boulder (figure 4-12, 2); however, care must be taken that blows do not damage the pile. Pile alignment should be watched carefully during this operation to insure that the lower portion of the pile is not being deflected out of line.

b. Using explosives. If the obstruction cannot be breached by driving, the pile should be withdrawn and an explosive charge lowered to the bottom of the hole to blast the obstruction out of the way (figure 4-12, 3). If using explosives is not practical, the pile can be left in place, and the foundation plan can be changed to use other piles.

c. Jetting. Jetting is particularly valuable in soils which will settle firmly around the pile. Sands, silty sands, and some gravels provide conditions suitable for jetting as driving through these materials in a dense state results in pile damage. Displacement piles in cohesionless soils are frequently placed by jetting.

(1) Hose and pipe jetting. Jetting is performed by inserting the jet pipe to the desired depth, forcing water through the pile to loosen the soil, then dropping the pile into the jetted hole and driving the pile to its resistance. If the pile freezes before final embedment, jetting can be resumed. Jetting should not be deeper than 4 or 5 feet above final grade.

(2) *Attached jetting pipes and hoses.* Jetting for timber, steel, or standard precast concrete piles is usually done by an arrangement of jetting pipes and hoses. The jet pipe is connected with a flexible hose and hung from the boom or the pile driver leads. When possible, two jet pipes are lashed to opposite sides of the pile. Usually the pile is placed into position with the hammer resting on it to give increased weight, and the jet is operated so that the soil is loosened and displaced evenly from under the tip of the pile (figure 4-13). A single jet, however, is not worked up and down along the side of the pile, as the pile will drift in that direction. Proper use of jet pipes is shown in figure 4-14.

(3) *Special precast concrete jetting.* To facilitate jetting, jet pipes can be embedded into precast concrete piles, Jetting arrangements for precast concrete piles are shown in figure 4-15.

(4) *Precautions.* Where piles must be driven to great depths, the double water jets may be insufficient. Additional compressed air can be effective. For combined water and air jetting, the simplest method is to tack-weld a small air pipe to the outside of the water-jet pipe. In any jetting operation, the alignment of the pile is critical. Jetting is a useful method to correct the alignment of timber piles in a pile bent (figure 4-16). Jetting around a pile while it is being driven is undesirable as the pile will drift off line and location. Pile tips must be well

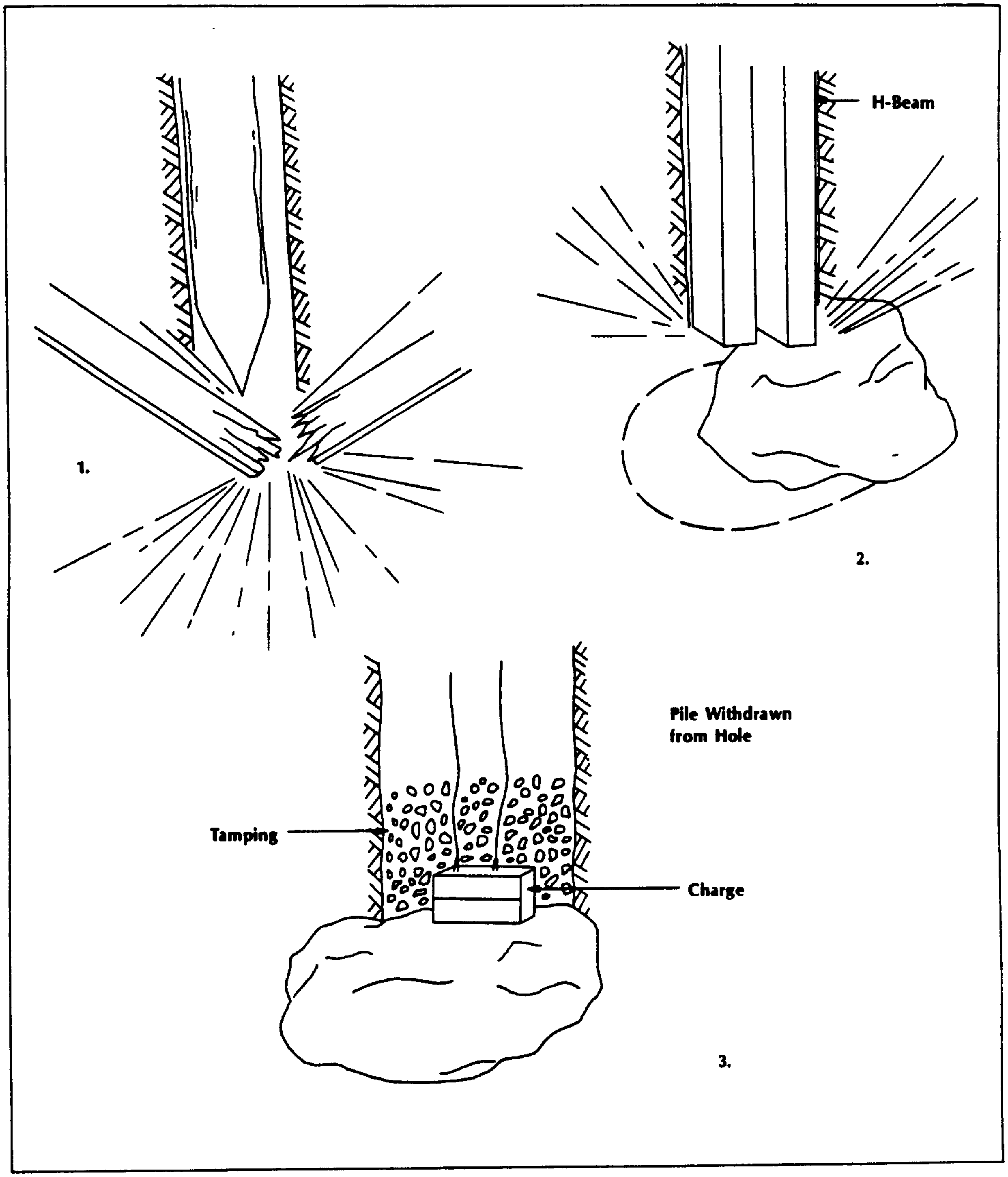

Figure 4-12 Breaching obstructions

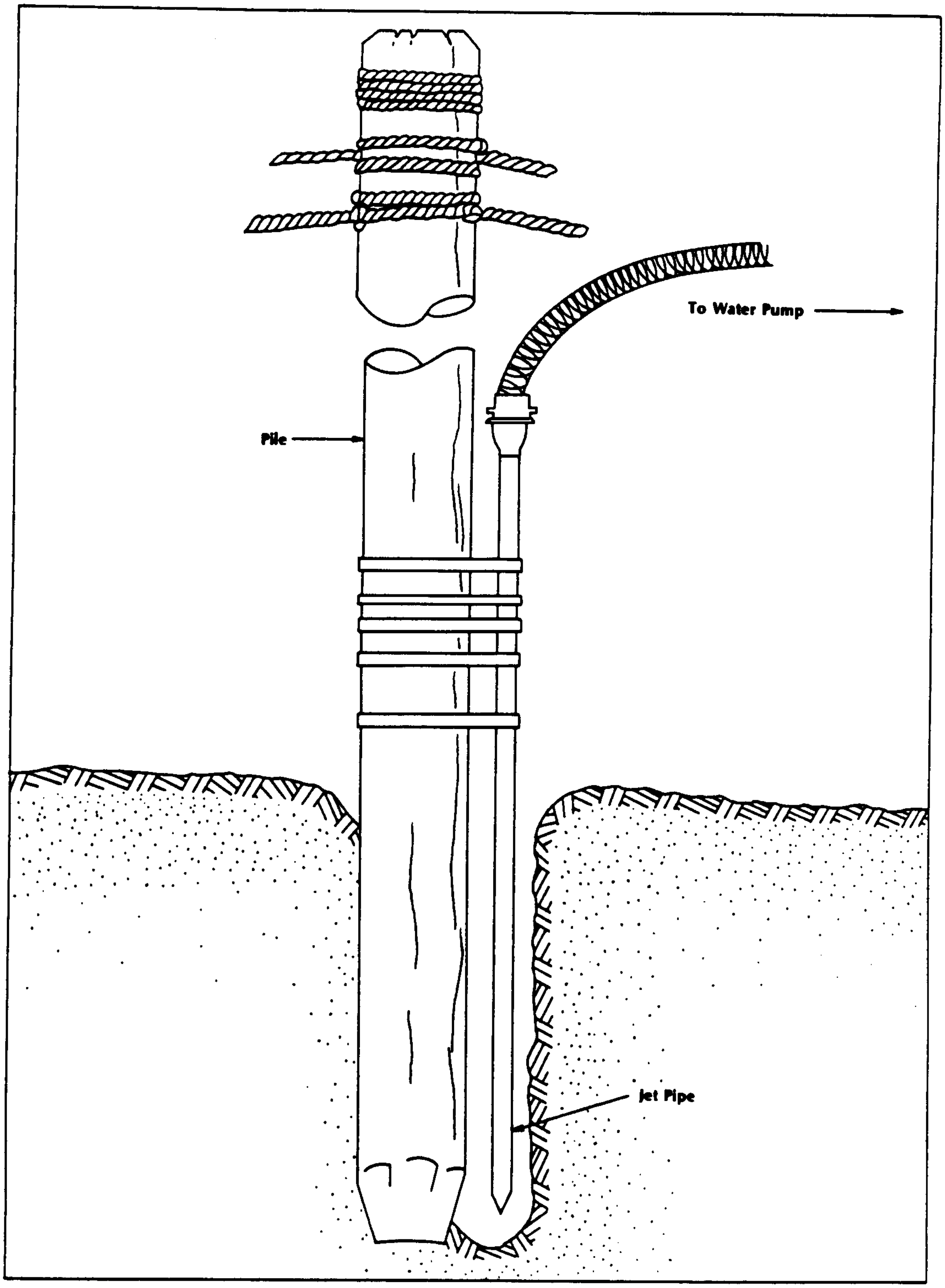

Figure 4-13 Jetting pile by pipes and hoses

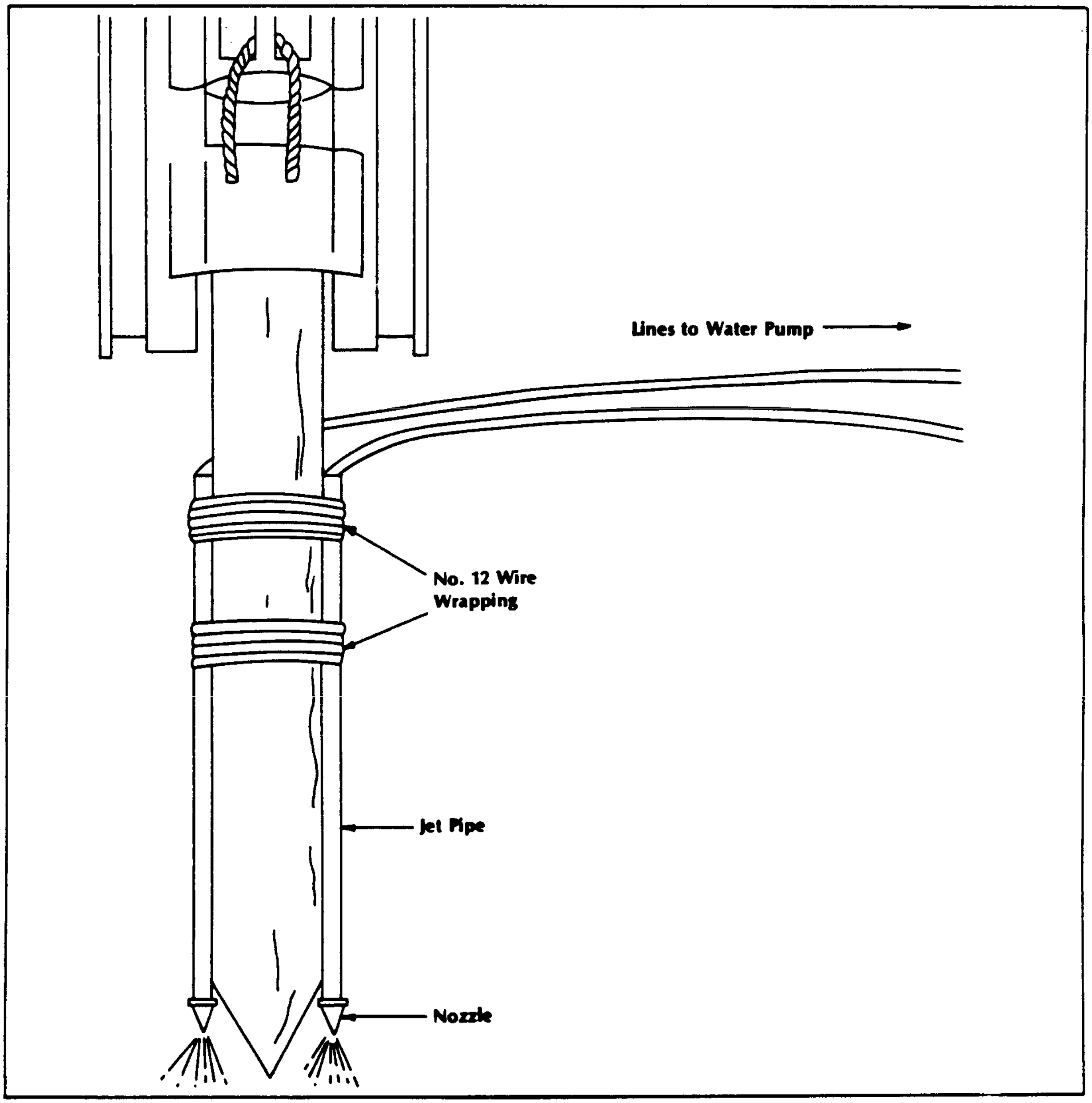

Figure 4-14 Use of jet pipes near pile tip

seated with reasonable soil resistance before full driving energy is used. The ultimate bearing capacity of the pile is generally not significantly affected by jetting. However, jetting will greatly reduce the uplift capacity of a pile.

4-9. Predrilling.

It may be necessary to predrill pilot holes if the soils above the bearing stratum are unusually stiff or hard. Predrilling keeps the preservative shell of treated timber piles

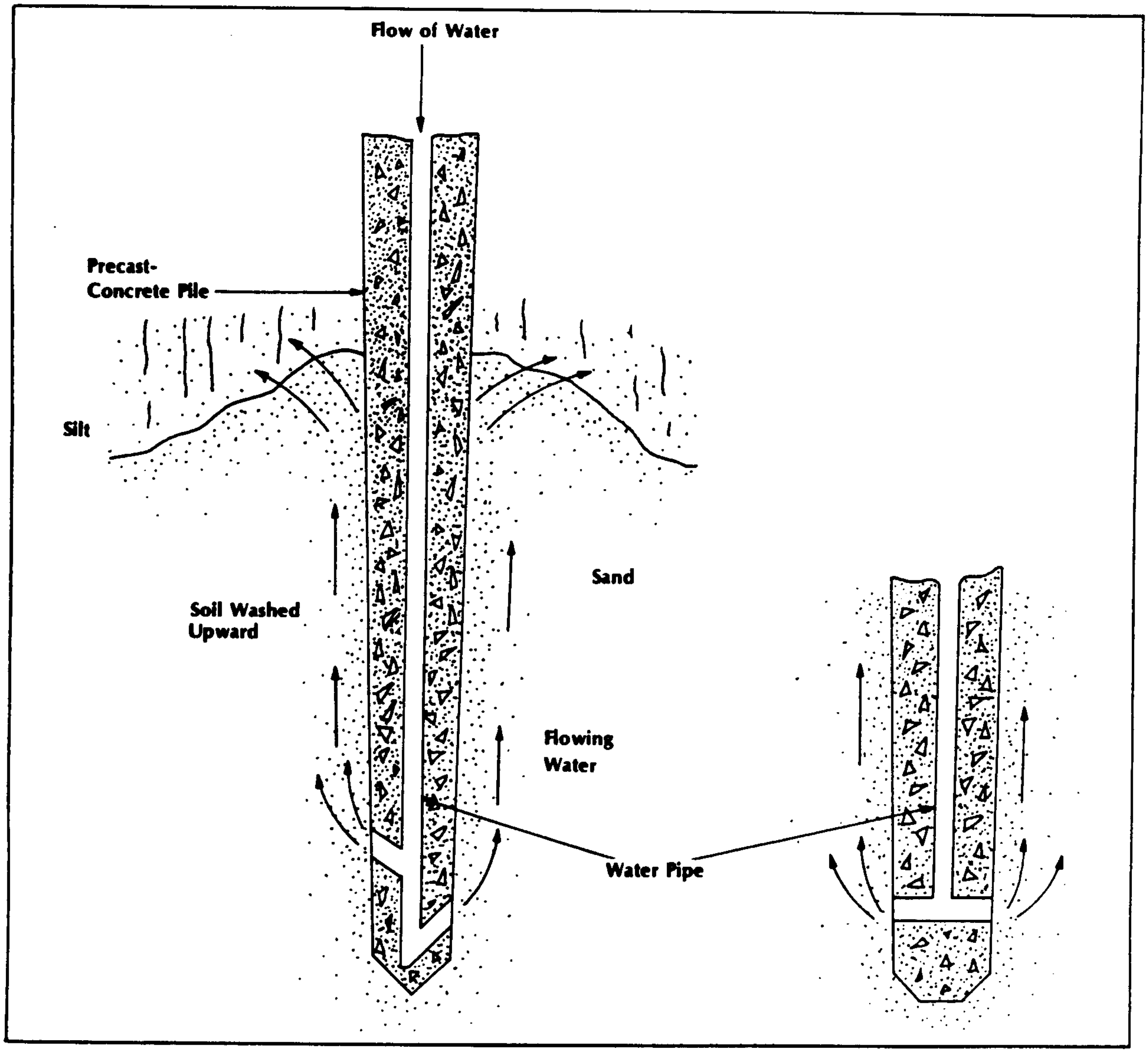

Figure 4-15 Precast concrete piles with internal jetting pipes

intact. Predrilling also reduces underwater heave and lateral displacement of previously driven adjacent piles. Holes are drilled slightly smaller than the diameter of the pile and to within a few feet of the bearing stratum. The pile is inserted, and the weight of the hammer forces the pile down near the bottom of the drill hole displacing any slurry. The pile is then driven to the required penetration or resistance.

a. Rotary equipment. Predrilling should be done with wet rotary equipment which leaves the hole filled with a slurry of mud. The method employs a fishtail bit that contains a water jet within the drill stem. The water and drill cuttings form a slurry which lines the walls and stops sloughing of unstable soil layers. Additives (such as bentonite) can also be used to stabilize the walls of the drill hole.

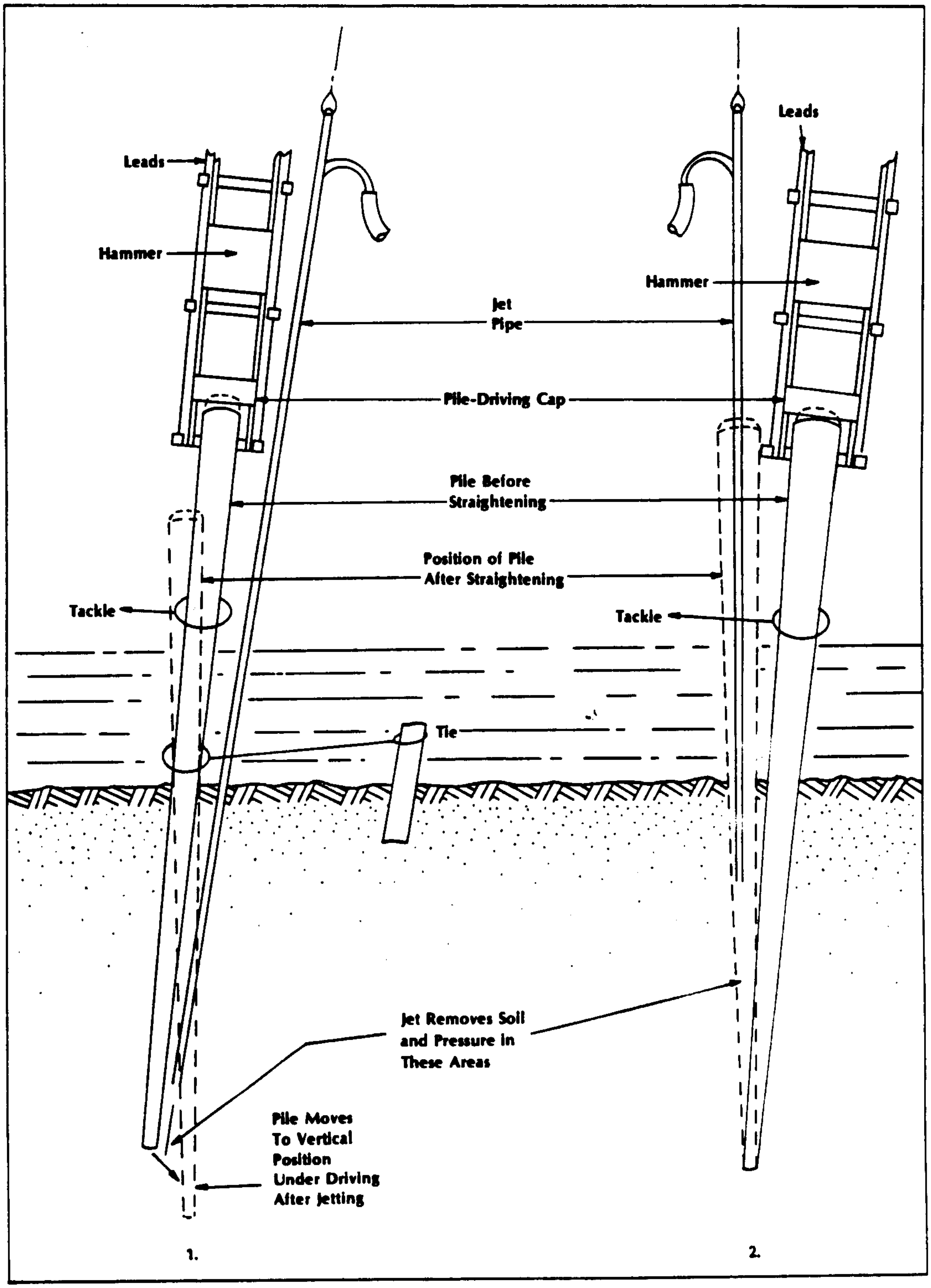

Figure 4-16 Realigning piles by jetting

b. Augers. Augers which remove all material from the hole can cause a quicksand action. Sand or soil may flow into the drilled hole below the water table. Augers should be used only above groundwater tables and in soils where a drill hole will stand open without collapsing.

4-10. Special placement techniques.

a. Spudding. Spuds can penetrate debris or hard strata so the pile can reach the bearing stratum. Spuds consist of heavy pile sections, usually with special end reinforcement. When heavy piles (such as steel or precast concrete piles) are driven, the pile may be raised and dropped to break through a layer of hard material or an obstruction. In a similar operation, a pilot pile is withdrawn, and the final pile is driven in the hole.

b. Jacking. A pile may be jacked into position. This method is usually used when it is necessary to underpin the foundation of a structure and headroom is limited or when vibration from conventional driving could damage an existing structure. The pile is jacked in sections using a mechanical or hydraulic screw jack reacting against the weight of the structure. The pile is selected for the specific situation, and it is built up in short, convenient lengths.

c. Vibrating. High-amplitude vibrators are used for driving piles in saturated sand and gravels, Vibratory hammers are particularly advantageous for driving sheet piling.

4-11. Driving piles in water.

a. Positioning piles. When piles are driven in water, different methods may mark the desired pile positions. When a number of bents are to be constructed, a stake is placed at each abutment approximately 6 inches from the pile centerline (figure 4-17). A wire rope is stretched between the two stakes, and a piece of tape or cable clip is fastened to the rope at each pile bent position. Piles are then driven at each tape or cable clip.

b. Using floating pile drivers. When a floating pile driver is used, a frame for positioning piles may be fastened to the hull. A floating template is sometimes used to position piles in each bent (figure 4-18). Battens are spaced along the centerline desired for each pile. The battens are placed far enough apart so that, as the pile is driven, the larger-diameter butt end will not bind on the template and carry it underwater. If the piles are driven under tidal water, a chain or collar permits the template to rise and fall with the tide. If the ends of the battens are hinged and brought up vertically, the template may be withdrawn from between the bents and floated into position for the next bent provided the pile spacing is uniform.

c. Using floating rigs. If a floating rig is available, it can be used to drive the piles for an entire structure before the rest of the work. In general, more piles can be driven per man-hour with floating equipment because the driver is easily moved. As soon as the piles in one bent have been driven, the rig may be positioned to drive the next bent, while the bent just driven is braced and capped. Floating pile. driver rigs are difficult to position where currents are strong and adequate winches are unavailable. Otherwise, they can be positioned easily either end-on or side-on to the pile bent which is being driven. Batter piles can be driven in any desired direction by adjusting the spotter or catwalk, without using a moon beam.

d. Driving from bridge or wharf. When pile driving uses mobile equipment operating from a deck of a bridge wall structure, two procedures may be used in moving the pile driver forward.

(1) *Walking stringer method.* As each bent is driven, the piles are aligned, braced, cut,

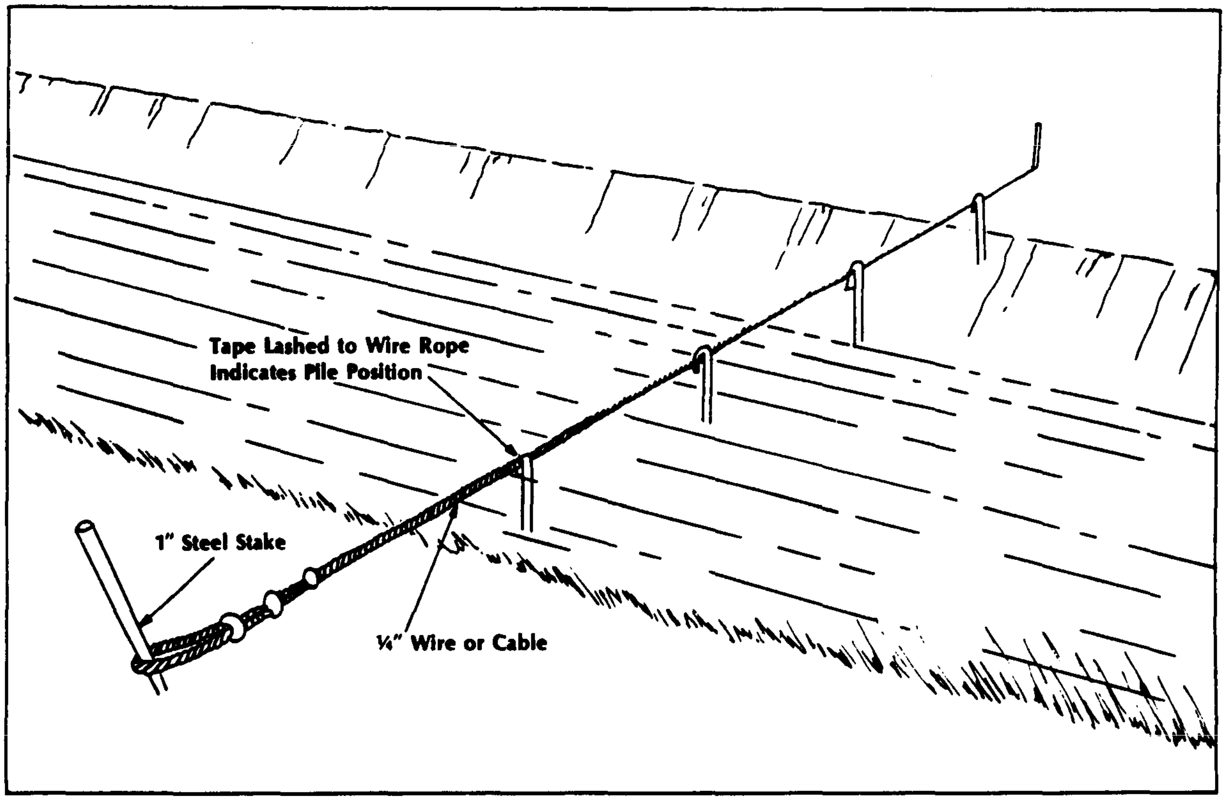

Figure 4-17 Wire rope guideline to position piles

and capped. The movable stringers are made by placing spacer blocks between two or three ordinary stringers so the driving rig can advance into position to drive the next bent. The movable stringers are laid onto the bent which has just been completed. When the advance row or rows of piles have been braced, cut, or capped, the pile driver picks up the temporary stringers behind and slings them into place ahead. The installation of permanent stringers and decking follows behind the pile driver. Variations of this method are possible when a skid-mounted piledriver is used. This method gives the pile driver less idle time than the method described in (2) following. Since the decking operations are completely separate, individual crews can be developed to drive, cut, cap, and deck. These crews become more proficient and are more rapid than crews that work at all three operations. This is hazardous because the machinery is supported by loose stringers and decking. Skill and organization are required because several operations may be in progress at the same time. Piles must move through the decking crews to reach the driving point, so planning is important.

(2) *Finish-as-you-go method.* Instead of using movable stringers, each bent or bench, including the permanent stringers or decking, may be completed before the rig is moved forward. This method is safer and requires less organization, since one operation follows another. The pile driver may be idle or set stringers. To complete each panel, personnel rotate jobs.

e. Driving from temporary earth causeways. An excellent method for driving

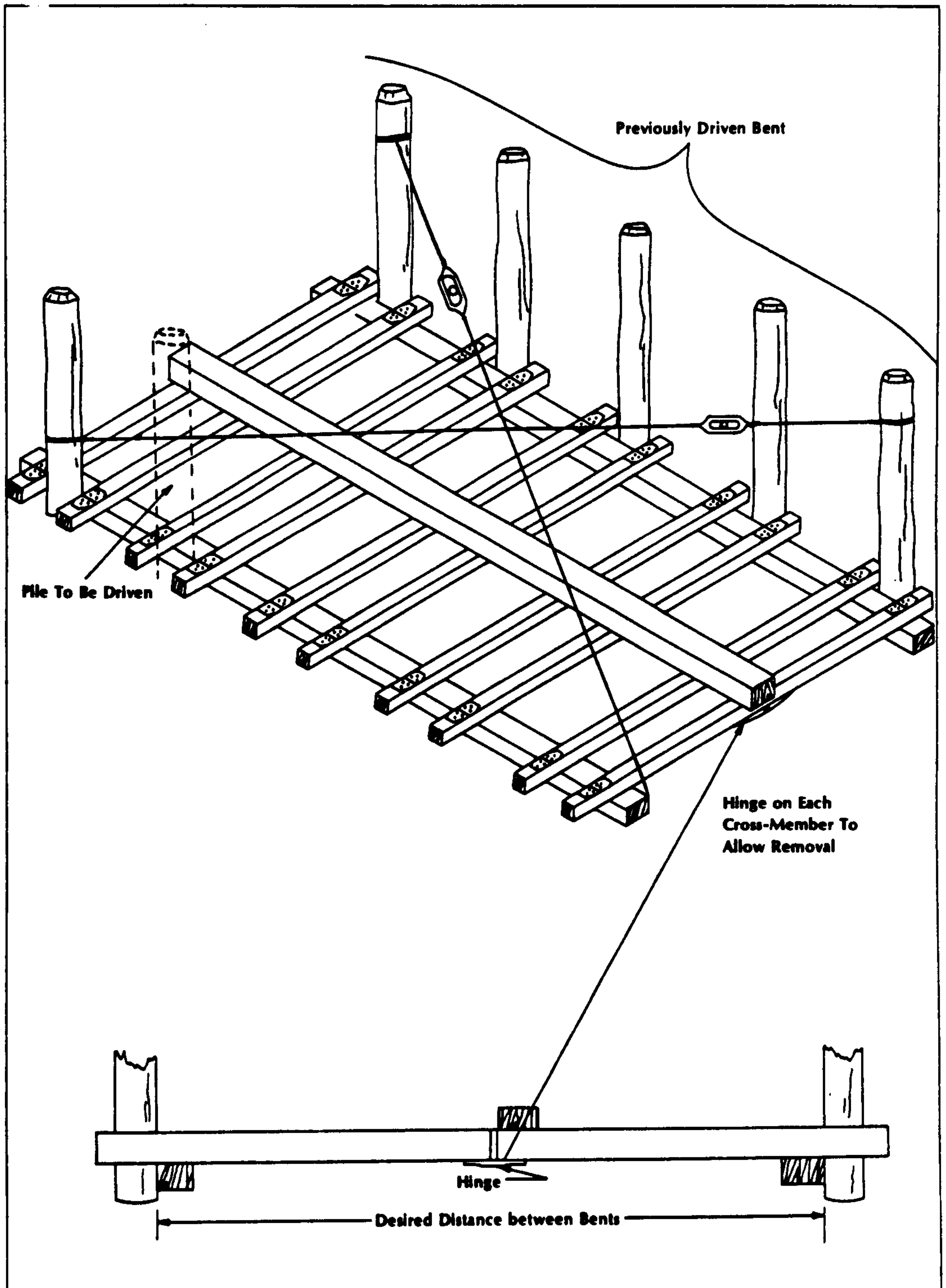

Figure 4-18 Floating template for positioning piles

piles for a bridge or wall structure in shallow water is to extend a temporary earth cause way from the shore. Piles may then be driven using a mobile rig operating on the causeway. In the usual case, piles are driven through the fill. This is the fastest method of building bridges and other structures, where height limitations permit and required penetrations are not unusual.

f. Driving from the 50-ton standard trestle. Used in depths up to eight feet, this trestle can drive two or three times as many piles as a bridgemounted trestle. This method involves constructing the bays (support structures) and using them as a platform. After completing a pile bent, a pile driver walks the standard trestle by striking the bay nearest the completed work, swinging it, and re-erecting it ahead.

g. Aligning. When all piles in a bent have been driven, they can be pulled into proper position with block and tackle and an aligning frame (figures 4-19, 4-20). Bracing and subsequent construction of pile bents are described in TM 5-312.

4-12. Driving underwater.

It is sometimes necessary to drive piles underwater rather than use a pile follower. Special pile hammers are designed for driving underwater. Recommendations by the manufacturer should be followed in preparing and rigging the hammer for underwater driving. Diesel hammers cannot operate underwater.

4-13. Pulling piles.

Piles split or broken during driving or driven in the wrong place ordinarily should be pulled. In some cases, it may be necessary to pull piles to clear an area. Sheet piles and, occasionally, bearing piles that have been driven for a temporary structure may be salvaged by pulling. Piles should be removed as soon as possible, since the resistance to pulling may increase with time. Common methods for pulling piles are described below.

a. Direct lift. If a pile is located so that a crane of substantial capacity can be moved directly over it, pulling by direct lift is possible. A sling should be wrapped around the pile and the pull steadily increased until the pile begins to move or is extracted. Jetting can be used to help loosen a pile. The boom should be snubbed to a stationary object to keep it from whipping back if the pile suddenly comes loose or the lifting tackle breaks.

b. Hammer and extractor lift. Piles may be pulled with air or steam-powered extractors or with inverted acting hammers rigged for this use. Vibratory hammers are effective. Usually, a 25-ton lift on the extractor will be adequate, but multiplereeved blocks in a derrick may be needed. If piles are difficult to pull, additional driving may break them loose. Use a safety line at the tip of the boom in case the connecting line or cable breaks.

c. Tidal lift. Piles in tidewater maybe pulled by attaching the slings to barges or pontoons at low tide and allowing the rise of the tide to exert the lifting force. To keep barges from tipping, a barge should be placed on either side of the pile; and the lifting force should be transmitted by girders extending across the full width of both barges.

4-14. Pile driving in cold weather.

It is possible to conduct pile-driving operations in severe cold even though the ground is frozen. Frost up to two feet thick can be broken successfully by driving a heavy pilot pile or a heavy casing. Ground can be thawed to a shallow depth by spreading a layer of several inches of unflaked lime over the area, covering the layer with snow, then

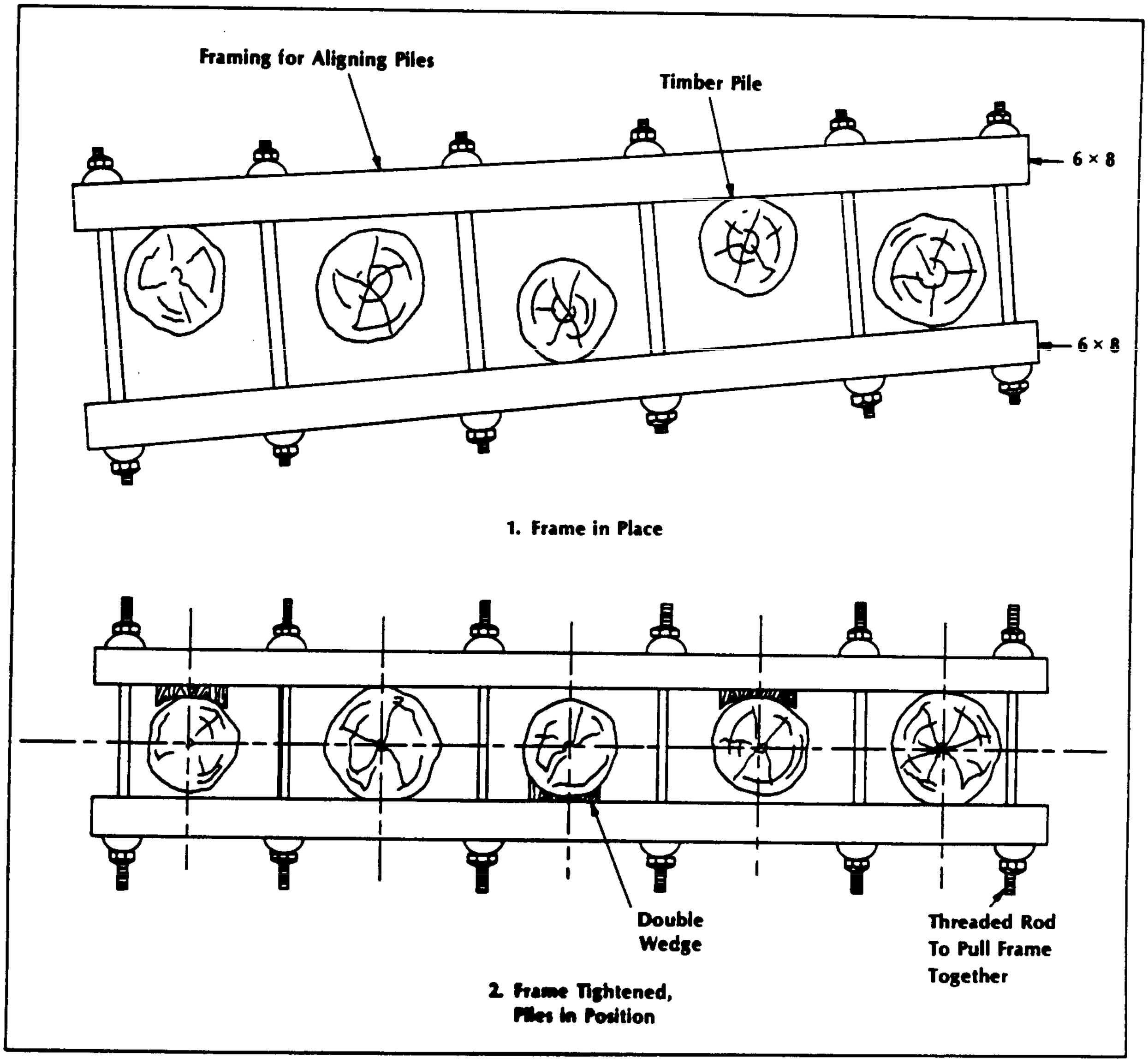

Figure 4-19 Aligning frame for pile bent

with a tarpaulin, which in turn is covered with snow. This method will melt a layer of frost 3 feet thick in 12 hours. Earth augers are effective in drilling holes in frozen ground and may aid pile driving. Holes cut in sound river ice act as guides for piles for bridge foundations. Auxiliary equipment such as a steam or air hammer and other machinery require special handling in cold weather. Instructions furnished by the manufacturer must be carefully followed.

4-15. Pile installation in permafrost.

Construction operations under arctic conditions and in permafrost areas are discussed in TM 5-349. Pile installation methods in permafrost include steam or water thawing, dry augenng, boring, and driving.

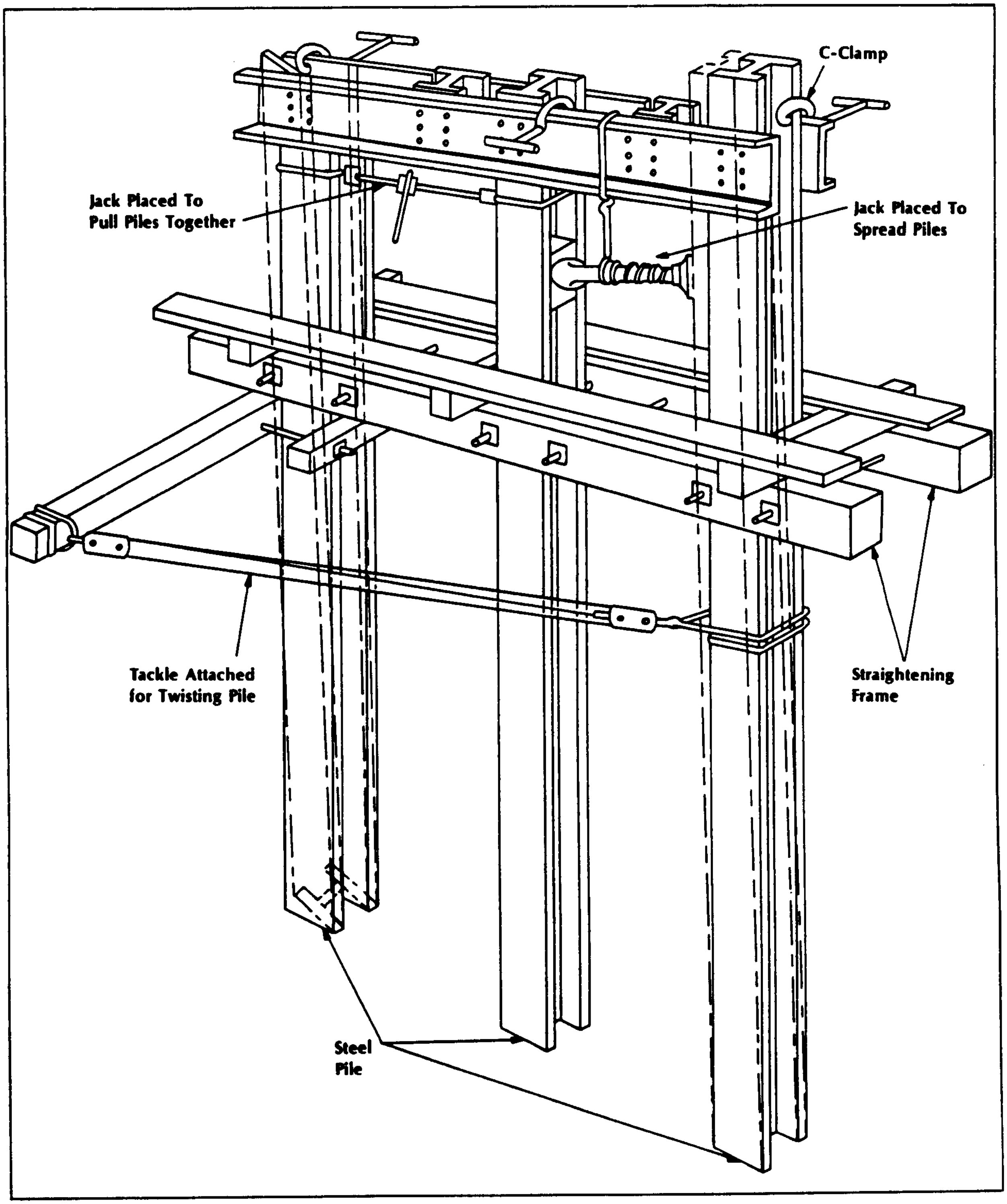

Figure 4-20 Aligning and capping steel pile bents

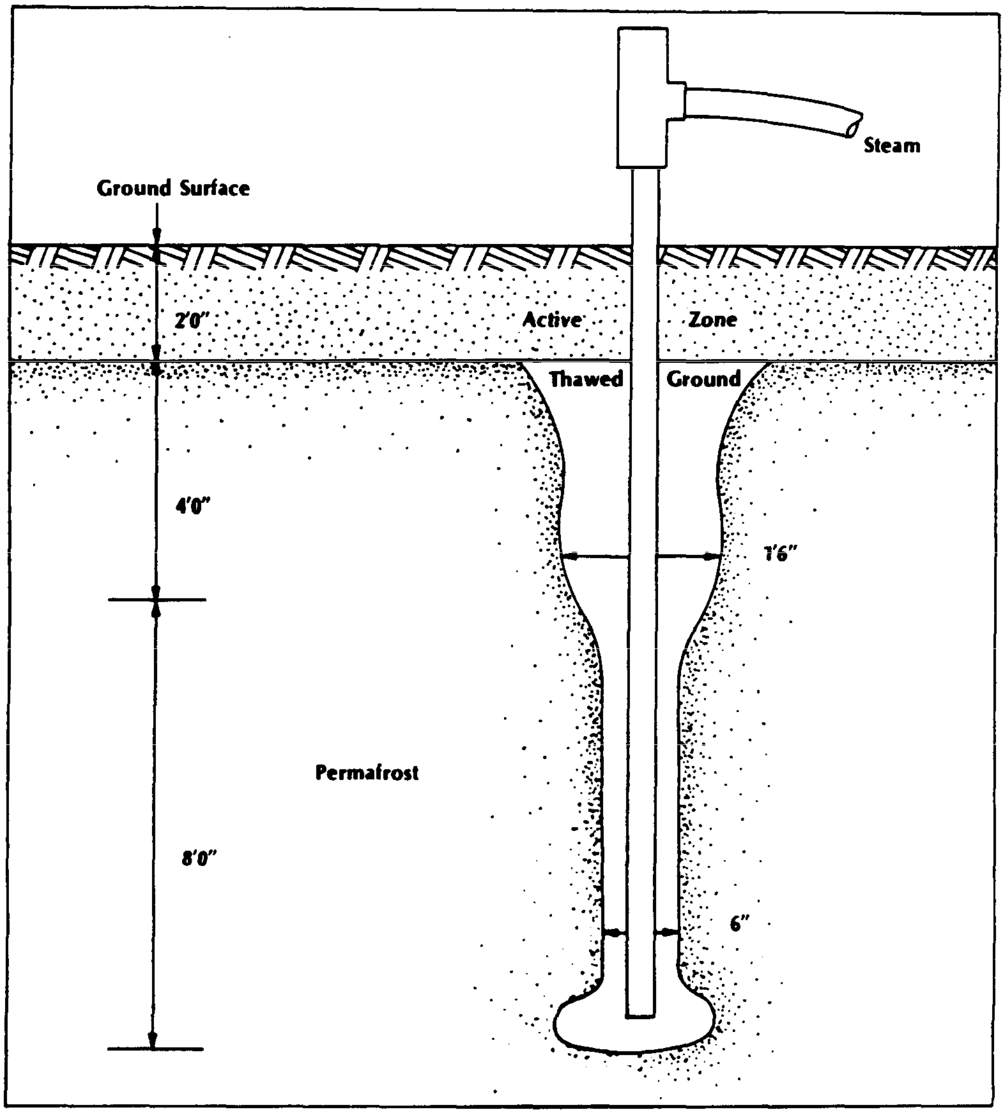

Figure 4-21 Approximate shape of thawed hole in sand-silt soil after 1½ hours of steam jetting

a. Steam or water thawing. Piles can be installed in permafrost by prethawing the ground with steam points or water. Steam at 30 psi delivered through a l-inch steel pipe is satisfactory for depths up to 15 or 20 feet. For greater depths, higher steam pressure (60 to 90 psi) and larger pipes (2-inch) are used. Water jetting is used if the soil is sandy. The pile is hammered lightly into the ground, and the steam aids the penetration while scaffolding or an A-frame facilitates handling long sections of steam-jetting and water-jetting pipes. The steam demand is approximately 15 to 20 cubic feet per foot of penetration. When the final depth is reached, the steam point is kept in the hole to make the hole big enough to accept the pile. If the soil is sandy, the steam point is kept in place for ½ hour; if the soil is clay, it may remain for up to 3 hours. Figure 4-21 shows the approximate

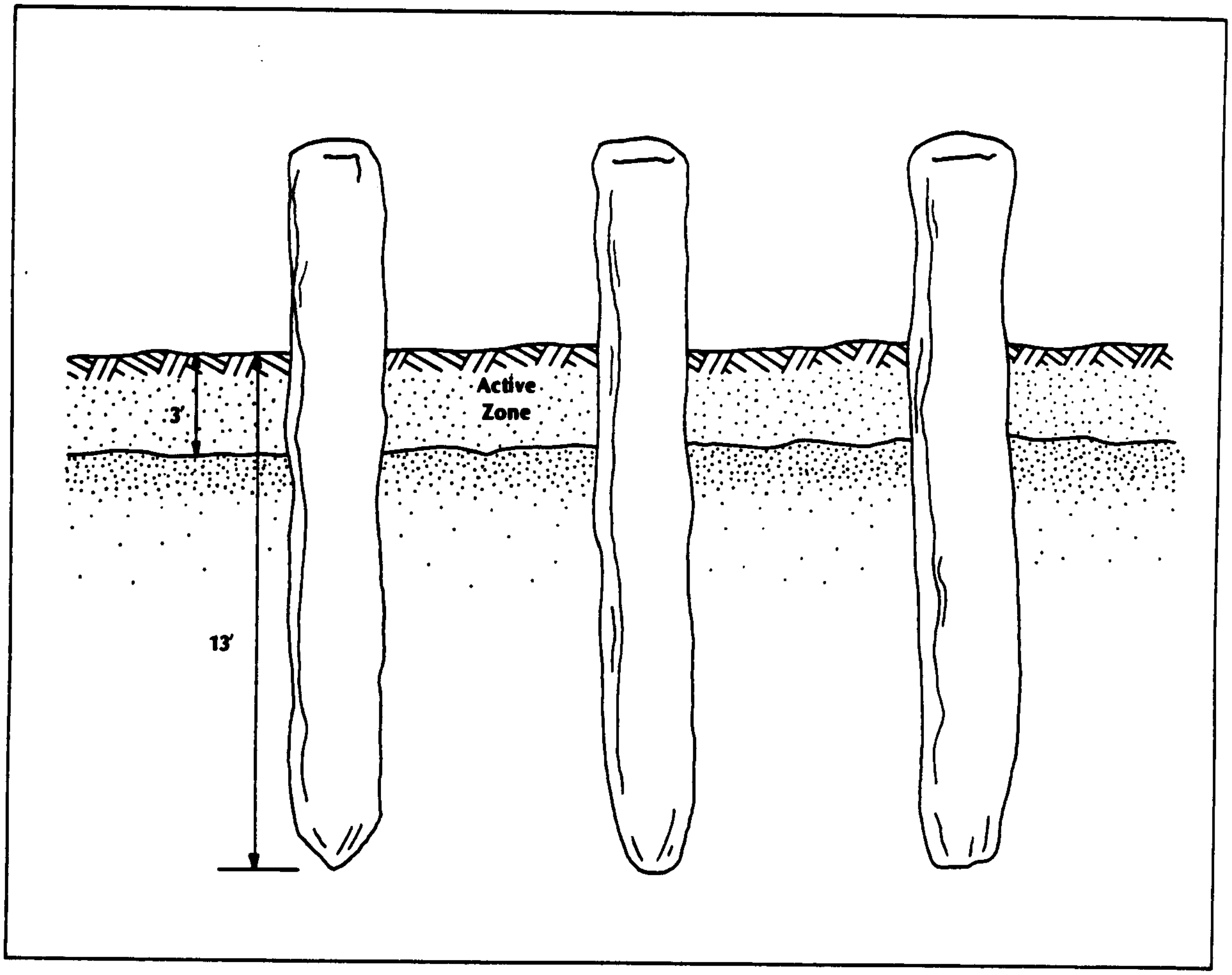

Figure 4-22 Piles driven through 3 feet of active zone to a depth of 13 feet after thawing

shape of the hole thawed in sand-silt soil after 1½ hours of stem jetting.

(1) *Setting the pile.* After the hole has been thawed properly, the pile is placed by the usual methods. After three to four days of thawing, a series of piles may be set (figure 4-22). Wooden piles have a tendency to float when placed in the thawed hole and therefore must be weighted or held down until the permafrost begins to refreeze.

(2) *Disadvantages.* Steam or water thawing has the disadvantage of introducing so much heat into the ground that freeze back may be indefinitely delayed. Piles may not develop adequate bearing capacity, or-host heave may work them out of the ground and damage supported structures. Steam or water thawing should not be used in areas where the mean annual permafrost temperature is greater than 20°F. This method may be used in colder permafrost only with exceptional precautions to control heat input into the ground if other methods of installation are not possible.

b. Dry augering. Pile holes maybe drilled in the permafrost using earth augers with specially designed bits for frozen ground.

Holes 2 feet in diameter can be advanced at rates of up to about 1 foot per minute in frozen silt or clay, depending on the type of bit, ground temperature, and size of equipment. Holes up to 4 feet or more in diameter can be drilled readily in such soil. Drilling with an auger is the easiest method when the frozen ground surface permits ready mobility and steam and water do not have to be handled. This method is not feasible in coarse, frozen soils containing boulders.

(1) *Hole drilling.* The holes maybe drilled undersized, and wood or pipe piles maybe driven into the holes. However, the holes usually are drilled oversized; and a soil-water slurry is placed in the annulus' space around the pile and allowed to freeze back, effectively transferring the imposed pile loads to the surrounding frozen soil.

(2) *Slurry.* Silt from a borrow pit or from the pile hole excavation can be used for slurry as can gravelly sand, silty sand, or plain sand. Clays are difficult to mix and blend, and when frozen they are not strong. Gravel, unsaturated soil, water, or concrete should not be used for backfill in permfrost areas. Organic matter must not be used in slurry. Details on dry augering are contained in TM 5-852-4.

c. Boring. Holes for piles may be made by rotary or churned drilling or by drive coring (under some conditions) using various bits and drive barrels. Frozen materials are removed with air, water, or mechanical systems. Procedures are the same as for dry-augered holes.

d. Driving. Conventional or modified pile driving procedures, including diesel and vibratory hammers, may be used to drive open-ended steel pipe and H-piles to depths up to 50 feet or more in frozen ground composed of silty sand or finer-grained soils at ground temperature above 25°F. Under favorable conditions heavy pipe and H-piles can be driven into the ground at lower temperatures. Freeze back is complete within 15 to 30 minutes after driving. The H-pile driven in frozen soil should not be smaller than the HP 10 x 42, and the rated hammer energy should not be less than 25,000 foot-pounds.

4-16. Cutting and capping of piles.

a. Timber piles. The capping of timber-pile bents should bear evenly on every pile in the bent. The piles should be cutoff accurately by following sawing guides nailed across all piles in the bent (figure 4-23). After the piles are cut and treated with preservatives, the cap is placed and fastened to the piles by drift pins driven through holes bored from the top of the cap into each pile. If a concrete cap is used, the tops of timber piles should be cut square, treated with preservative, and embedded in the concrete at least 3 inches.

b. Steel piles. Steel-pile bents are cut to the proper elevation using a welding torch. A working platform and cutting guide fastened with C-clamps can be used for this purpose (figure 4-20). Capping of steel piles with steel members follows the same procedure as outlined for timber piles, but the members are joined by welding or riveting, and steel plates are used rather than timber splices or scabs. If the cap is reinforced concrete, the top of the pile should be embedded at least 3 inches in the concrete. A well-designed reinforced concrete pile cap does not require steel plates to transmit a compressive load to H-piles. If the piles are subject to uplift, cap plates or additional embedment is required.

c. Concrete piles. Cutting concrete piles requires concrete saws, pneumatic hammers, and an acetylene cutting torch. A V-shaped channel is cut around the pile at the level of the desired cutoff. Reinforcing bars are exposed and cut with the torch at the desired

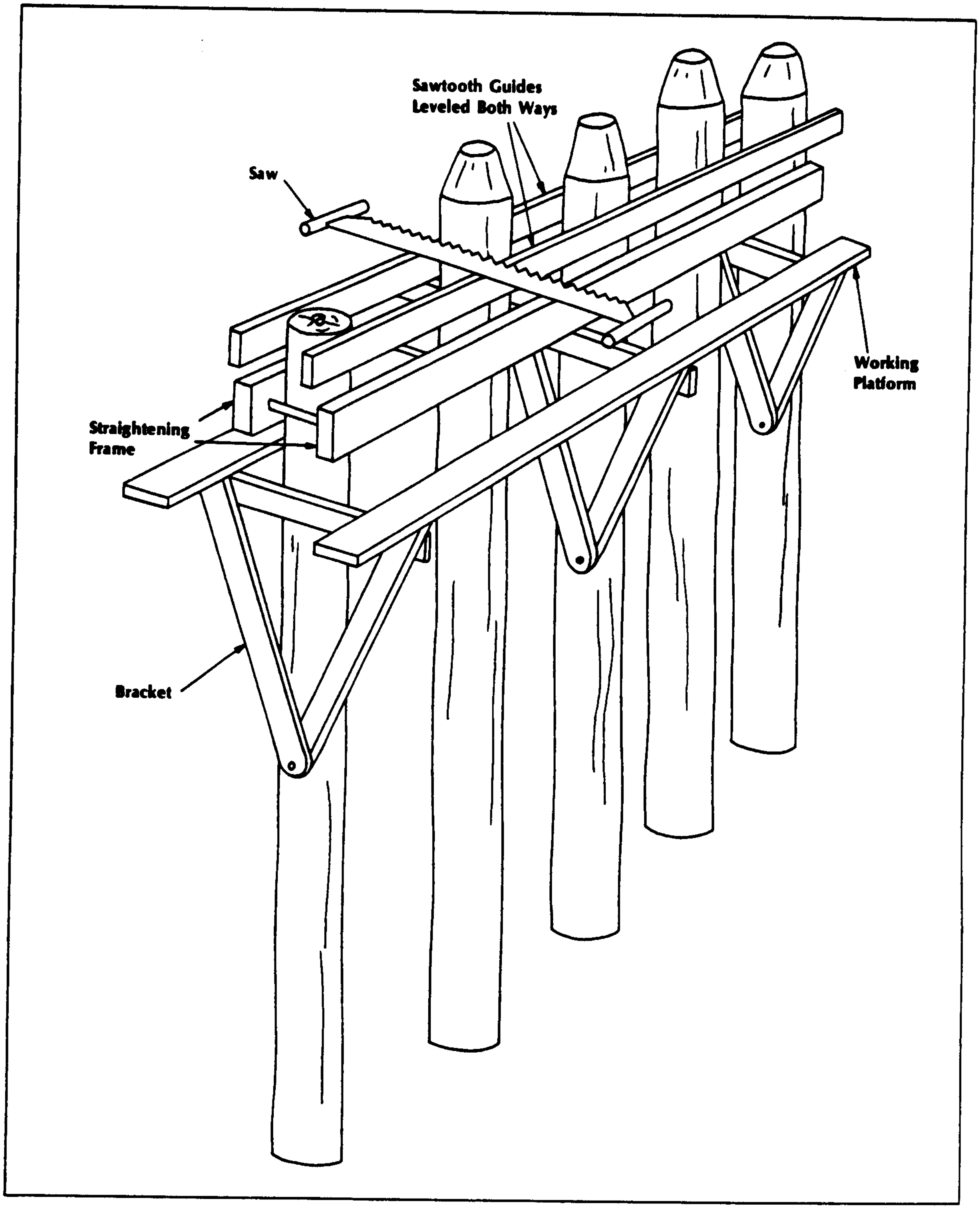

Figure 4-23 Cutting timber pile bent to final height

point above the cutoff. If possible, the reinforcing bars should project into a concrete cap for bonding. The head of the pile can be broken off by wedging or pulling with a line from a crane. The cap is placed on top of the piles by casting in place or drilling grout holes at the proper position in a precast cap. Another suitable method is to drill holes and to grout in bolts or reinforcing steel, depending on the type of cap used.

d. Anchorage. The uplift force on a structure is transmitted to the pile by a bond between the pile surface and the concrete of the pile cap, or by a mechanical anchorage. The ultimate bond between concrete and freshly-embedded timber piles may be 60 psi or more; however, long submergence may cause some deterioration of the outer layer of wood which reduces the bond value. When the embedded portion of timber piles is submerged, a working stress for a bond of not more than 15 psi should be used without considering the end surface of the pile. When the load in tension is greater than the strength which can be developed by the bond, a mechanical anchorage can be used. The resistance of a wood pile to extraction from concrete maybe increased by notching the embedded portion of the pile and considering the longitudinal shearing strength of the timber.

Section III. PREPARATION AND USE OF PILES

4-17. Sheet piles.

a. Alignment. When sheet piles are driven as permanent structures, such as bulkheads, the first pile must be driven accurately, maintaining alignment throughout. A timber-aligning frame composed of double rows of studs, to which one or two rows of wales and diagonal bracing are spiked, may be required to maintain alignment, in soft soils. Normal practice is to drive the ball end of interlocking steel sheet piles to prevent soil from being trapped and forcing the interlock open during driving.

b. Steel sheet piles. Interlocking steel sheet piles can be driven by one of two basic methods.

(1) *Single pile or pair of piles.* In this method the driving leads must be kept vertical and stable, with the hammer centered over the neutral axis of the pile. This requires a firm, level foundation for the driving equipment.

(2) *Preassembled sheet piles.* The piling and wall are formed and driven along the line. The piling is set with both axes vertical. Vibration in the hammer or the pile will drive the piles out of alignment. Z-piles are driven in pairs. Single or pairs of short piles are driven to full depth in soft ground to prevent creep. Long piles are driven into the ground as follows.

- Set waling along the line of sheeting.
- Drive a pair of sheet piles to part depth.
- Set a panel of a dozen single piles or pairs in the walings.
- Drive the last pile or pair in the panel part way.
- Drive the piles between the first and last pile or pairs of piles to full depth.
- Drive the first pile to full depth.
- Drive the last pile two-thirds its full penetration to act as a guide for the first pile of the next panel.

c. Concrete sheet piles. Concrete sheet piles are frequently placed by jetting. If a watertight wall is required, the joints are grouted after driving is completed. The soil at

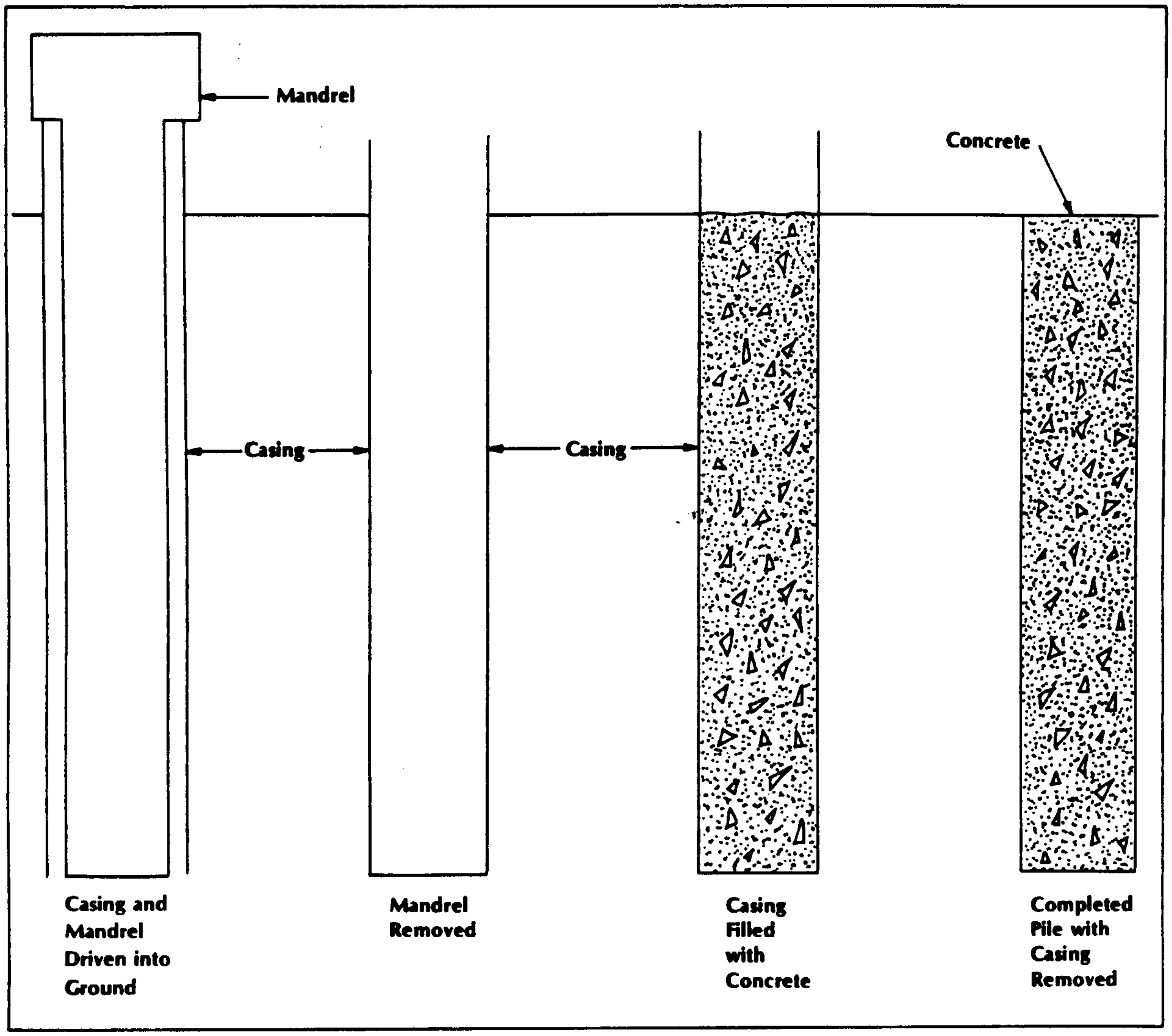

Figure 4-24 Procedure for placing cast-in-ground concrete piles

the bottom of the pile is slushed out by a water jet pipe of sufficient length to reach the bottom of the pile. A tremie is used to place grout underwater. Flexible fillers such as bituminous material may be placed in joints at intervals of 25 to 50 feet. If a cap is placed on the sheet pile wall, the flexible joints continue through the cap. In reinforcing previously driven sheet piles, frictional drag may occur. To counteract this, the piles may be bolted or welded to a stiff waling. If a pile has been drawn down, an additional length is usually welded on rather than attempting to jack up the pile.

4-18. Drilled piles.

Power-driven earth augers are used to drill holes to the size and depth required (figure 4-24). Commercial drilling rigs are available in a wide variety of mountings and driving arrangements. If the holes remain open and dry until concreting is completed, the foundation can be constructed rapidly and economically. If the walls of the hole are unstable and tend to cave in, the hole maybe advanced using a slurry, similar to drilling mud alone or in combination with casing.

a. Slurry. Slurry is a mixture of soil, bentonite, and water which forms a heavy, viscous fluid mixed by lifting and lowering the rotating auger in the hole. When the slurry obtains the proper consistency, the hole is advanced through the cohesionless zone using the auger. The slurry stabilizes the wall of the hole, preventing inflow of groundwater. Slurry is added at the bottom of the hole as depth is advanced.

b. Dry hole. If the hole is dry, the concrete is allowed to fall freely from the ground surface. The cement and aggregate may separate if the concrete falls against the sides of the shaft. If the diameterie small, a short, vertical guide tube is located at the center of the top of the shaft where the concrete is introduced. Reinforcement may be provided through a circular cage inside which the concrete can fail freely. A slump of about 6 inches is suitable under most conditions. Higher slumps are used in heavily reinforced piers. The presence of even a small amount of water in the bottom of the shaft may reduce the strength of the concrete. Bags of cement are sometimes laid on the bottom to absorb the excess water before the concrete is placed. Tremied concrete can be placed in an uncased slurry fill hole; however, refined techniques and experienced specialist contractors are mandatory.

4-19. Shell-type piles.

In shell-type, cast-in-place concrete piles, the light steel casing remains in the ground and is filled with concrete after it has been inspected and has been found free of damage (figure 4-25).

Section IV. SUPERVISION

4-20. Manpower.

The size of the pile-driving crew depends upon a number of variables: equipment available; type, length, and weight of piles being driven; and driving conditions. The minimum crew is 5 in most situations. In driving light timber piles with a drop hammer or a crane fitted with pile-driving attachments, 1 person would be needed as a supervisor, 1 as a crane operator, and 3 as helpers in handling the piles and hammer. One person should serve as an inspector, recording blow counts and penetrations. A carpenter may be needed to cut off the piles. A larger crew is required to drive long, steel bearing piles under hard driving conditions. If a steam hammer is used, a boiler engineer and fire fighter will be required. If an additional crane or winch is needed to place the piles into position, additional personnel are required. A welder may be needed to cut off the piles at the correct elevation or to weld on additional sections. The crew may consist of 10 to 12, including supervisors and 4 or 5 laborers.

4-21. Productivity.

The rate at which piles can be installed depends upon many factors, such as equipment, length and weight of the piles, and driving conditions. A normal-sized crew can install from 1 ½ to 5 timber bearing piles per day (day operations) and from 3 to 6 steel sheet piles per hour. Figures for pile-driving operations can be established from experience with a particular crew, equipment, piles, and driving conditions.

4-22. Safety.

a. Safety precautions. Standard safety and accident prevention procedures developed for general construction operations also apply

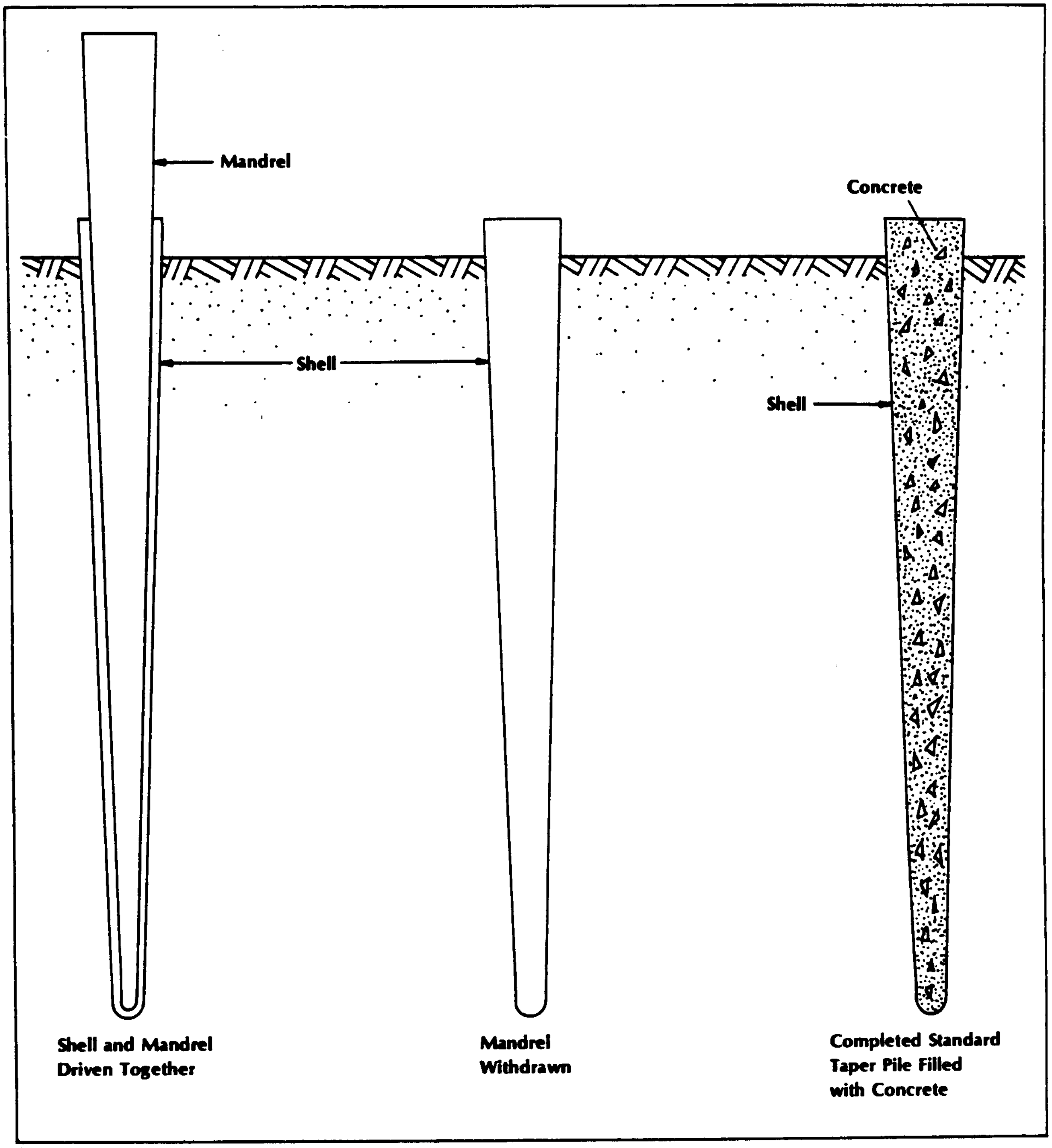

Figure 4-25 Procedure for placing shell-type, cast-in-place concrete piles

to pile-driving operations. Pile driving is a hazardous operation, and adequate care must be taken to protect personnel from injury.

- Proper individual protective equipment (shoes, gloves, helmets, and ear plugs) should be worn at all times. All equipment guards should be maintained and in place.

- Cooperation between equipment operators and personnel is essential to avoid accidents. Hand signals must be used during pile installation operations (figure 4-26).

- Personnel must be kept clear when piling is being hoisted into the leads and during the first few feet of driving. Mill scale, for example, may be driven off a steel pile during driving.

- Operators must never stand under or near a pile hammer. If an y adjustment is to be made at or below a hammer, the hammer should be stopped and rested on a pile or secured by placing the hammer-retaining pin through the pile leads. Ladders should be provided on frames and leads to give access to the hammer.

- All equipment, particularly pile leads, must be examined frequently for any cracks or loose bolts.

- Diesel pile hammers must be cleaned regularly to avoid an accumulation of diesel oil which may become a fire hazard. They should be fitted with a trip wire or rope so that the hammer can be stopped from ground level and workers do not have to climb ladders to operate the fuel cutoff.

- The exhaust of steam hammers must be controlled so that workers are not endangered by discharges of steam or scalding water. All hoses and hose connections must be in good condition and properly secured to the hammer inlet. The end of the hose must be tied to the hammer to prevent a flying end if the connection should break loose.

- Helmets, driving caps, anvil blocks, and other parts receiving impact must be inspected regularly for damage or fracture. Worn parts should be replaced before wear becomes excessive, and particular care taken to avoid wear that will develop a stress concentration on a moving part.

- The hammer must be kept at the bottom of the leads whenever possible.

b. Handling procedures. Creosoted timbers can cause skin bums. When creosoted piles are driven, a fine spray is created when the hammer strikes the pile. This material on the skin should be washed off immediately with soap and water. Cream or lotion maybe used to protect the skin from creosote. Goggles protect the eyes. Hand and power tools used to prepare piles for driving and to cut off, straighten, and align piles after they are driven must be used safely. When it is necessary to cut off the tops of driven piles, piledriving operations should be suspended except when the cutting operations are located at least twice the length of the longest pile from the driver.

c. Water procedures. If piling is carried out over water, workers should wear life jackets. Life belts with a suitable length of cordage should be available on the attendant floating craft.

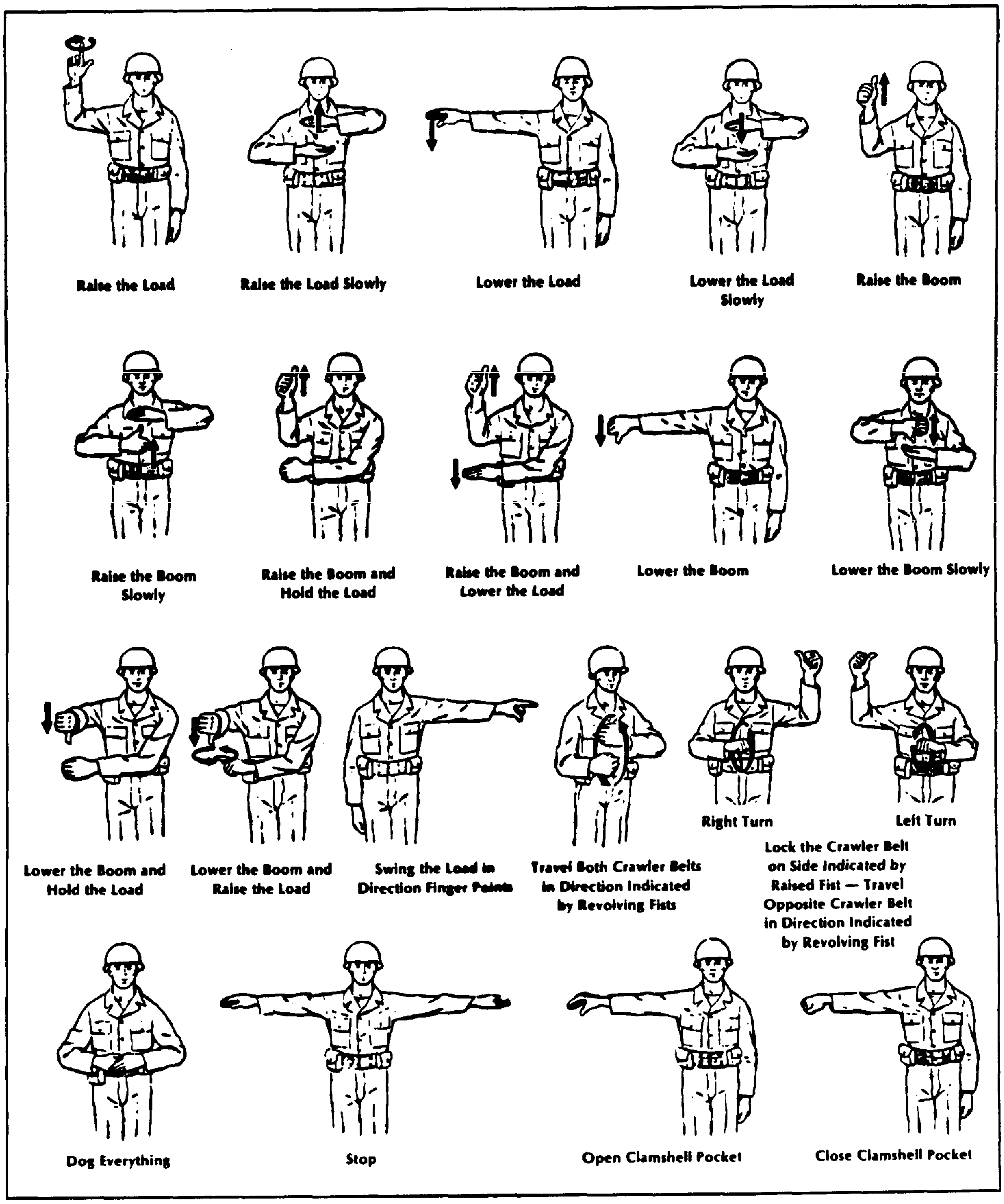

Figure 4-26 Hand signals for pile-driving operations