Title 210 – National Engineering Handbook

Part 645 – Construction Inspection

Subpart R – Piling

Amended March 2025

645.180 Introduction

A. Piles are structural members driven into the ground. The tip of the pile is the end driven into the ground. The butt is the other end. Bearing piles support loads. Sheet piles are seepage barriers, retaining walls, or flood walls.

   1. Bearing piles can be either end-bearing or friction piles.

      a. An end-bearing pile is driven into the ground until it meets firm resistance with its tip from subsurface rock, dense sand, or gravel.
      b. A friction pile is driven into the ground but only meets softer material and does not penetrate a firm bearing layer. Frictional resistance created between the sides of the pile and the surrounding soil develops the load-carrying capacity.

   2. Sheet-piling reduces the lateral movement of water, prevents the movement of adjacent soil material, or both. It consists of vertical planks of wood, steel, precast concrete, vinyl, or fiber-reinforced polymer placed tightly against one another, or interlocked with each other. The builder drives the sheet-piling into the earth to form a solid wall.

645.181 Installation

A. Materials

   1. Piles are wood, concrete, steel, poly vinyl chloride (PVC), fiber reinforced polymer (FRP), or a combination of steel and concrete. The contractor must list the type, quality, and quantity of piles, fasteners, and other related items on the drawings and in the specifications. The contractor must submit proof or certification to the engineer responsible that the piles and related materials comply with the specification requirements. The quality assurance (QA) inspector must ensure the delivered materials are what the contractor submitted and what the engineer approved. Piles have their length marked near the butt. Piles designated for specific locations must have a location identifier painted on them.

   2. The QA inspector's responsibilities related to pile materials include:

      a. Checking the piles upon delivery and marking any unacceptable ones.
      b. Checking pile dimensions and markings.

c. Verifying that piles have the length marked near the butt.
d. Verifying that pile materials comply with specifications for the type of materials.
e. Verifying that piles designated for specific locations have the location printed near the butt.
f. Studying the pile manufacturer's brochures or pamphlets to become familiar with recommended methods of handling, inspecting, and driving.
g. Verifying that butts are flat, smooth, and perpendicular to the long axis.
h. Verifying that the supplier delivered the specified type and quantity of fasteners and related items prior to beginning installation.

B. Steel and Aluminum Pile Materials

1. Steel and aluminum piles come in various grades and shapes. Contractor material submittals must certify or prove, as applicable, that the piles match the grades, shapes, and dimensions in the drawings and specifications.

2. Sheet pile currently produced in the United States typically conforms to ASTM International (ASTM) A328, which has a yield strength of 39 kilopounds per square inch (KSI), or ASTM A572, which has yield strength ranging from 50 KSI to 65 KSI. A corrosion-resistant steel grade meeting ASTM A690 has a yield strength of 50 KSI. Contractor material submittals must include mill certificates verifying that the steel conforms to the specified ASTM standard.

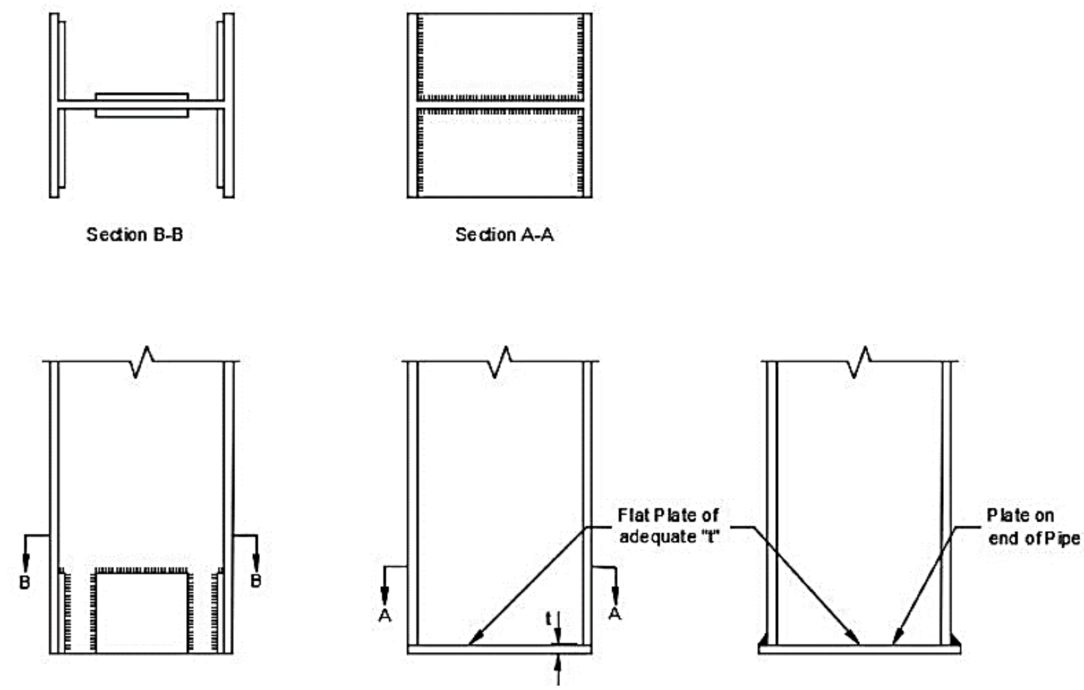
3. Occasionally, suppliers will construct piles from several short lengths to make use of scrap pieces. Although piles are spliced in the field as they are driven, splices must be held to a minimum, and piles made from several short pieces must be rejected. When spliced, the weld or splice must not fail when installed and subjected to its intended end use.

4. Steel bearing piles include H-shapes, I-shapes, and cylindrical shapes. Steel pipe and railroad rails also work as bearing piles. The shape of a steel member refers to the shape of the cross-section of the member and is designated by a letter, or letters, a depth dimension, and a unit weight dimension. For example, HP14x117 means an H-shape (H) suitable for piling (P) that has a nominal depth of 14 inches and weighs approximately 117 pounds per linear foot. The depth is the distance from the outside of one flange to the outside of the other flange. See figure 645R-1 for common steel bearing pile shapes.

Figure 645R-1. Common Steel Bearing Pile Shapes

5. The butt of the steel-pile must be flat and perpendicular to the long axis of the pile. It is common for a short length of the butt of the pile to be reinforced with extra steel welded to the pile as shown in figure 645R-2. The tip may be pointed or rounded to facilitate driving. If allowed by the specifications, piles may be delivered with welded or riveted splices.

Figure 645R-2. Butt of Pile Reinforced with Extra Steel ("t" = thickness)



6. Manufacturers produce steel and aluminum sheet piles in special shapes with interlocking edges called clutches to connect piles side-by-side. Clutches may be hot-rolled or cold-rolled. Hot-rolled clutches are stronger, but most specifications typically allow either type. The QA inspector must check the sheet pile materials as the work site receives them to verify that the clutches conform to the specified shape and are not damaged or deformed in a manner that prevents interlock. See figure 645R-3 for common shapes of aluminum sheet piles and figure 645R-4 for shapes of steel sheet piles.

Figure 645R-3. Typical Aluminum Sheet-Piling Shapes

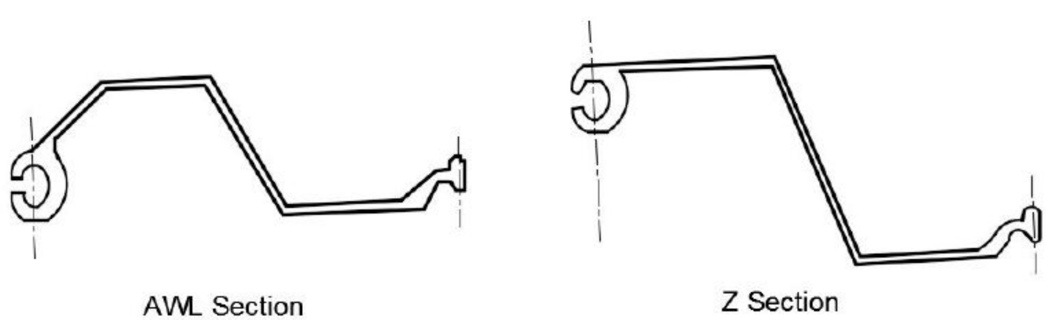
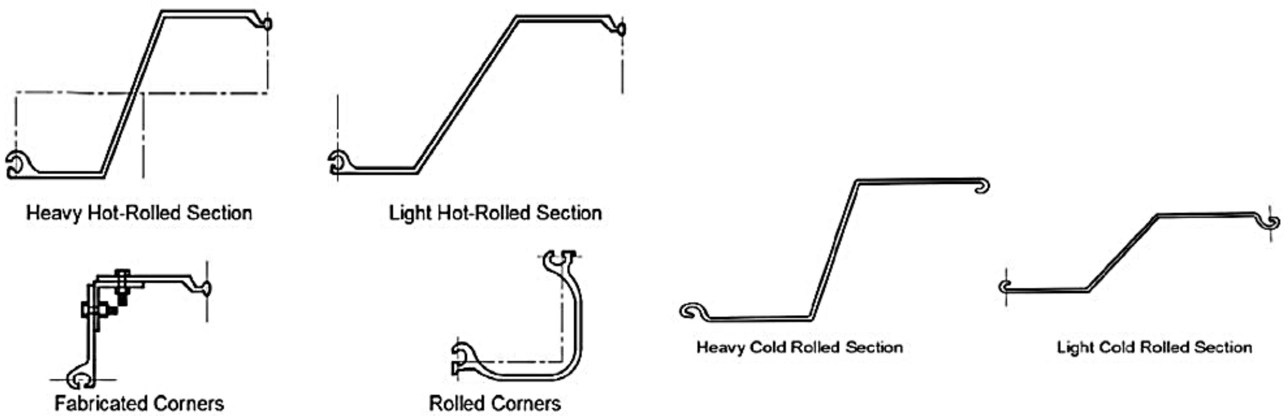


Figure 645R-4. Typical Steel Sheet-Piling Shapes



7. The QA inspector's responsibilities related to steel and aluminum pile materials include checking materials delivered to verify that:
    a. They are the approved grade and type.
    b. Length, diameter or cross-sectional dimensions, weight, and type of piles conform to specifications and approved submittals.
    c. Surface condition and condition of clutches conform to drawings and specifications.
    d. The condition of tip and butt reinforcing or shaping is as specified or noted on approved submittals.
    e. Bent or damaged flanges are rejected or correctly repaired.
    f. Defective rivets or welds are rejected or repaired.
    g. Splices, if allowed, exhibit good fit and quality workmanship.
    h. Piles made from short pieces are rejected.
    i. Sheet-piling clutch shape and dimensions provide for a tight interlock.
    j. Clutches are not damaged or deformed so as to prevent interlocking.

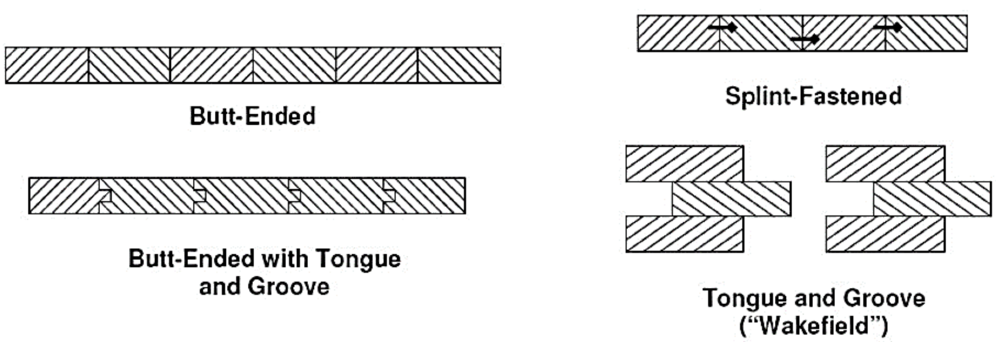
C. Wooden Pile Materials

1. Wooden piles, also called timber piles, are cut from straight, sound trees. Sound means they are free of large or loose knots and other defects that impair strength or durability. Douglas fir, yellow pine, redwood, southern cypress, and similar species are common choices. Wooden pile trees must taper uniformly from butt to tip and be straight so that a straight line from the center of the butt to the center of the tip falls within the pile body. Unless otherwise allowed, trees used for piles must be cut when the sap is down (during the winter) and peeled soon after cutting. See piles in figure 645R-5.

Figure 645R-5. Timber Piles with Steel Points on the Tips (USDA)

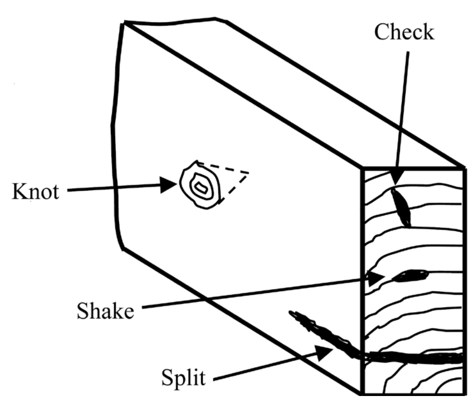
2. Wooden sheet-piling is made from standard dimension lumber. The lumber is placed vertically on end with the individual pieces adjacent to each other (butt-ended) and driven into the ground. The edges of the individual boards may be configured with a tongue-and-groove or other shaped edge, to allow them to be securely joined to the adjacent board. Boards with a smooth edge can be joined with a splint (splint-fastened). "Wakefield" sheet-piling consists of three boards bolted or spiked together, with the center board offset. This arrangement produces a tongue-and-groove joint that is almost watertight if the piles are fitted tightly together. See figure 645R-6 for configurations.

Figure 645R-6. Wooden Sheet-Piling Jointing Configurations



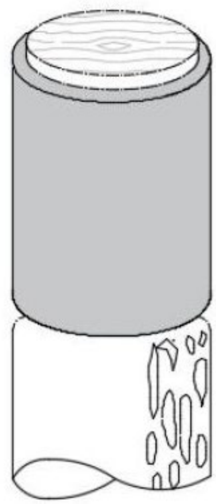
3. Specifications and drawings may require that sheet-piling have a tongue-and-groove or other milled edge. The shape and dimensions of these milled edges must conform to specifications. The materials must be of specified quality and approved by the engineer. Sheet-piling must be dimensioned so that it can be installed to the specified line and grade.
4. Wood preservatives protect wood piles from deterioration. There are many preservatives available, but few are suitable for timber piling. Preservatives used to pressure treat utility poles such as pentachlorophenol and copper naphthenate, are not suitable for saltwater applications. Since many timber piles are installed in salt water, these preservatives must be avoided. For Southern pine marine piling, copper chromated arsenate is the most popular preservative, but creosote is also used. For Douglas fir foundation piling in the West, ammoniacal zinc arsenate and creosote are used.
5. Application rates for timber pile preservatives are specified in pounds of preservative per cubic foot of pile. The preservative type and application rate applied to the piles must be checked to verify that they meet the project specifications. The entire length of the pile must be inspected to verify full and even coverage.
6. Handling piles treated with preservatives with bare skin must be avoided. Care must also be taken to minimize exposure to fumes from the preservatives.
7. Inspection of wooden piling materials requires checking the delivered materials against the drawings, specifications, and approved contractor material submittals. The drawings and specifications typically specify the tree species from which piles are to be manufactured, the kind and amount of preservative treatment, and any special processing requirements. Upon delivery, the QA inspector must check that the piling materials, including all fasteners and other appurtenances, are the same materials identified in the approved contractor's material submittal. Check to see that the piles are straight and dimensioned as shown on the drawings.
8. The piles must conform to the quality requirements specified. They must be free of decay, knots, splits, shakes, checks, crooks, and bends. See figure 645R-7 for examples.

Figure 645R-7. Common Wooden Pile Defects That Must be Rejected



9. Some wooden piles have steel shoes, or points on the tip of the pile as seen in figure 645R-5 and steel bands around the butt of the pile as shown in figure 645R-8. These may arrive on the job attached to the pile or may be installed on the job. Points must be firmly affixed, and bands must fit tightly around the butt of the pile.

Figure 645R-8. A Band Correctly Affixed to the Butt of a Pile



10. Each treated wooden item delivered to the job site must be marked as specified. The markings must at least show the type and amount of preservative applied to the wood. Manufacturers mark piles with brands similar to that shown in figure 645R-9 five feet and 10 feet from the pile butt.

Figure 645R-9. Typical Pile Brand

11. Prior to treating with preservative, the pile must have all bark removed. Upon delivery, treated piles must contain no bark. If bark remains on the pile, it must be removed, and the area that was covered by the bark must be treated with the approved type and amount of preservative. Care must be taken when transporting and handling treated wooden piles to prevent damage to the pile and the preservative. All cuts and breaks must be treated with the specified type and amount of preservative.

12. The QA inspector's responsibilities related to wooden pile materials include verifying that:

    a. The approved type of materials is delivered.

b. Each pile is straight and correctly dimensioned.
c. All wood is free of decay, knots, splits, shakes, checks, crooks, and bends.
d. All tips and butts are correctly prepared for driving.
e. The wood is marked, as specified, indicating the type and amount of preservative has been applied.
f. All bark is removed.
g. All damaged treated piling is rejected.
h. All cuts and breaks are treated with the specified type and amount of preservative.
i. Sheet-piling meets all specified and approved requirements including tongue-and-groove geometry and dimensions, quality, and suitability of materials for use as piling, and design dimensions.

D. Precast Concrete Pile Materials

1. Concrete piles can be precast or cast-in-place. Precast piles are reinforced concrete members that are cast before driving. They are manufactured at an offsite location near a concrete batch plant but may be manufactured onsite. Precast piles may be formed in tongue-and-groove sections for sheet-piling.

2. Precast piles must be constructed in accordance with specification requirements, using approved materials. The QA inspector may be tasked with inspecting the casting operation to verify that these requirements are met. Inspection includes verifying that the approved concrete mix is used and that the fresh concrete slump, temperature, and air content are within specified ranges, the reinforcing steel is maintained in the specified position, and the concrete is consolidated and cured as specified. The QA inspector must verify that the ratio of water to cementitious materials (w/cm) does not exceed the maximum allowed by the approved concrete mix design.

3. Because precast concrete piles are to be moved, there are a few items to inspect in addition to items that are normally inspected on cast-in-place concrete structures. One of these items is the casting floor or the surface on which the piles are to be manufactured. This surface must be level, flat, and firm. Pile forms are set on pallets or blocks so that a forklift or lifting chains or straps can be passed under the forms. By using pallets, the forms can be left on the piles as they are moved out of the casting area to make room for additional piles or other items to be cast. These pallets must be wide enough to allow the forms to be firmly supported with any bracing and blocking required for secure transport of the piles with minimal disturbance. The freshly poured piles may be moved prior to the concrete making its final set, if the steel reinforcement is secured so that it remains in position.

4. Concrete placement must be continuous from start to finish so that there are no cold joints. The forms are three-sided and lay horizontal as they are filled with concrete. Chamfer strips are typically installed in the corners to form chamfered corners that are less prone to chipping than square corners. The top surface of the concrete pour, the bottom-formed surface, and the formed sides become the sides of the pile. For the pile to drive true, the top surface must be

finished to a uniform texture like the formed surfaces. Otherwise, greater frictional drag may develop on that side of the pile, causing it to wander from the intended line as it is driven.

5. Precast piles must not be transported or driven until they have gained sufficient strength to withstand the forces imposed by driving. Compressive strength tests are made from concrete used to make the piles. The compressive strength cylinders are dated to correspond with a manufactured date marked on the pile. Specifications and material submittal documents must indicate the strength that the cylinders must attain before the pile can be driven. It is best to have the date and length of the pile marked on both ends because one end may not be accessible. Likewise, if a pile is stacked with other piles, it may only be possible to read the markings on the tapered end.

6. Lifting points must be painted on each pile. This helps prevent damage to the pile during handling and storage. Cables and straps must be configured to evenly distribute the pile's weight between all lifting points.

7. Piles must be stored so that those that are to be driven first can be accessed without having to move other piles. Moving piles must be minimized to limit the damage potential.

8. When tasked with inspecting the casting operations, the QA inspector's responsibilities related to precast concrete pile casting includes verifying that:

    a. Reinforcement is free from rust and scale and is correctly positioned.
    b. Casting floor is level, flat, and firm.
    c. Pallet boards are of sufficient width to protect piles during movement.
    d. All cut ends of reinforcing tie wire are turned away from form surface.
    e. All inside surfaces of forms are smooth and clean.
    f. Chamfer strips (if used) are in place and firmly attached to form.
    g. Bracing and blocking between and around each piling are firm.
    h. Forms are level, straight, and watertight.
    i. Concrete mix conforms to the approved mix design.
    j. Concrete meets specified requirements for air, slump, and temperature.
    k. Concrete mix w/cm does not exceed the maximum stated in the approved mix design.
    l. Concrete placing is continuous from start to finish to avoid cold joints.
    m. Top surface is leveled and finished to a uniform texture similar to that produced by the forms.
    n. Concrete is cured as specified.
    o. Each pile is stamped or marked near butt and tip to indicate length and manufacture date.
    p. Lifting points are painted on each pile.
    q. Handling the pile is avoided until it attains the required strength.
    r. Lifting cables have a device to equalize the pull at all lifting points.

9. The QA inspector's responsibilities related to delivery of precast concrete piles include checking materials upon site delivery to verify that:

a. For sheet-piling, tongue-and-groove interlocks are not chipped, cracked, or broken.
b. Compressive strength test results show piles attained specified strength before moving.
c. Piles are undamaged.
d. Piles are of uniform shape, true, and straight.
e. Lifting cables have a device to equalize the pull at all lifting points.
f. Warped, bent, or broken piles are rejected.
g. Piles are stored to protect them and minimize movement.

E. Cast-in-Place Concrete Pile Materials

1. Cast-in-place piles are installed by drilling holes in the ground and filling them with concrete. Often these holes are lined with casings made from steel, plastic, or cardboard. Casing materials are specified in the drawings and specifications and approved based on the contractor's submittal for casing materials. Casings must be marked to indicate that they conform to specification requirements.

2. The QA inspector must verify that the size and depth of the hole or casing complies with specification requirements. The hole or casing must be free of water, debris, and soil. Reinforcing steel must be held in-place throughout the concrete pour. Steel may be tied to make a cage of steel that is lowered into the hole or casing. Spacers must be included to hold the cage of steel in the correct location throughout the concrete placement and consolidation operation.

3. The concrete mix must be the approved mix and must meet specification requirements for slump, temperature, and air content. It must have a w/cm at or below the maximum allowed by the approved job mix. Compressive strength specimens (cylinders) must be made to verify compliance with strength requirements. Strength tests may also be required to determine when the piles can support the intended load. If this is necessary, cylinders are made and cured in the same environment as the piles, so that they represent the actual strength of the piles. Otherwise, the specification may allow the piles to be loaded based on a specified elapsed time between casting and loading.

4. Placement must be performed in a manner that will limit concrete segregation potential. The use of a tremie or concrete pump to place the concrete without excessive free-fall will be necessary. The outlet end of the tremie or pump hose must extend to within five feet of the bottom of the hole and be withdrawn to maintain a distance no greater than five feet from the outlet to the surface of the concrete being placed. This distance may be extended to 12 feet if a plasticized concrete mix is used.

5. An internal immersion vibrator that reaches the bottom of the hole is required unless self-consolidating concrete (SCC) is used. The vibrator must be inserted the full depth of the layer being consolidated and into the previous layer. Since it may be difficult to observe the top of the concrete deep in the hole to judge when entrapped air ceases to be expelled, concrete must be

vibrated a bit longer than normal to ensure that it is well consolidated. Over-vibration is not a problem– the concern is with too little vibration.

6. SCC may be used for poured-in-place piles. SCC is a special concrete mix that is proportioned to be self-consolidating and to limit segregation. The mix has a limited amount of coarse aggregate, a high percentage of fine aggregate, and a low water to cementitious materials ratio along with a superplasticizer to increase slump. SCC does not require vibration– it consolidates on its own after placement.

7. The QA inspector's responsibilities related to cast-in-place concrete pile materials include checking materials upon site delivery to verify that:

    a. Casings are marked or otherwise identified to conform with drawings and specifications and approved contractor material submittal documents.
    b. Reinforcing steel bundles are tagged and free from flaking rust.
    c. Reinforcing steel conforms to drawings, specifications, and approved contractor material submittal documents.
    d. Reinforcing steel is secured in place so that it remains in position as concrete is poured and consolidated.
    e. Reinforcing steel is clean and free of oil or other bond breaking substances.
    f. The hole or casing is clean and free of standing water, debris, and soil.
    g. Concrete mix conforms to the approved mix design.
    h. Concrete meets specified requirements for air, slump, and temperature.
    i. Compressive strength cylinders are made to document strength.
    j. Cylinders are made and cured near the poured-in-place piles when strength tests are needed to determine when the piles can be put in service.
    k. Concrete is well consolidated.

F. Micropile Materials

1. Micropiles are small-diameter (4–12 inches), drilled and grouted friction-piles reinforced with steel casing and a central reinforcement bar. They are used as deep foundation support for structural concrete elements. They are an alternative to conventional piling techniques and are used in limited access areas. They are also called mini-piles, pin-piles, needle-piles, or root-piles.

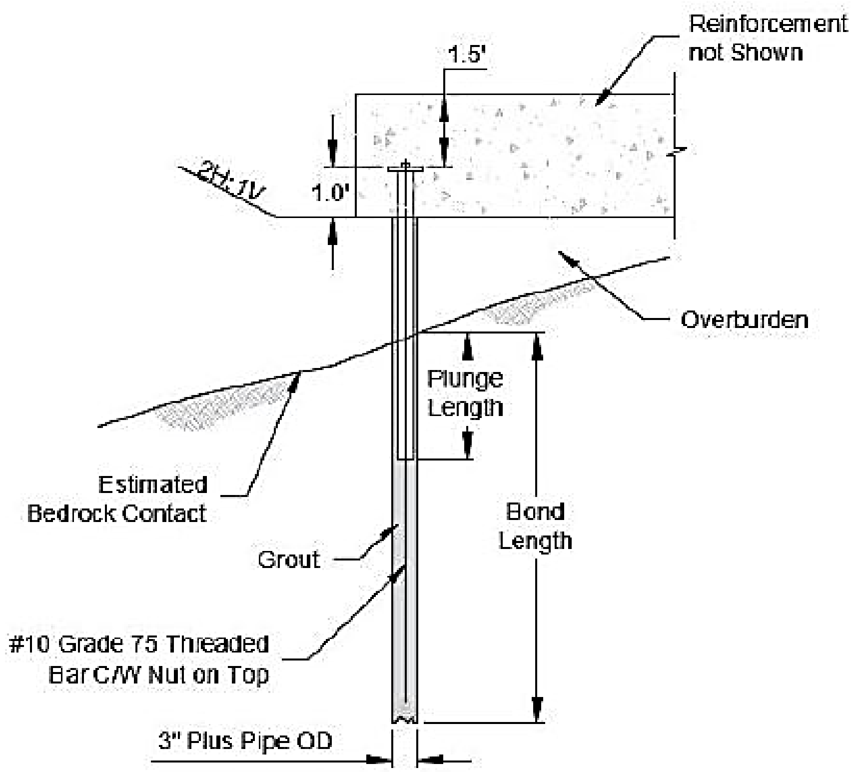
2. Micropiles are friction piles, meaning that they derive their bearing strength through the grout-to-ground bond with the soil and rock throughout their length and therefore are not dependent on the end-bearing capacity of the rock. They can be designed for tension, compression, and lateral loads. The pile strengths are field verified through testing of sacrificial piles.

3. The typical micropile consists of a permanent casing pipe, reinforcing bar with bearing plate and nut, and neat cement grout or sanded grout (see figure 645R-10).

Figure 645R-10. Typical Installed Micropile (NRCS-OK)

4. As with other piling systems, a micropile system design must begin with a detailed geologic investigation. The design engineer will commonly specify the required design load, along with the associated required bond length. The bond length is the depth that the micropile or casing is in contact with sound rock. The plunge length is the depth that the permanent casing extends into the sound rock. The casing is usually omitted through a portion of the solid rock, so the plunge length is always less than the bond length. See figure 645R-11 for a detailed drawing of a typical micropile.

Figure 645R-11. Typical Micropile Detail



5. Micropile casing must be of adequate type and thickness to withstand the stress of advancing it into the foundation (see figure 645R-12). It also must have the specified diameter. It will either be welded or have threaded joints.

The specifications must outline the required welding procedure for any welded joints.

Figure 645R-12. Micropile Casing (NRCS-OK)

6. Reinforcing bars must be the correct size and grade. They must be delivered in bundles and tagged. The tag information must include size and grade (see figure 645R-13).

Figure 645R-13. Reinforcing Bar Tag (NRCS-OK)

7. The bars are commonly threaded at the top to accept a bearing plate and nut and can be spliced together with threaded couplers. The size and grade of the bearing plate must be as specified. See 645R-14 for an example.

Figure 645R-14. Threaded Coupler and Bar (NRCS-OK)

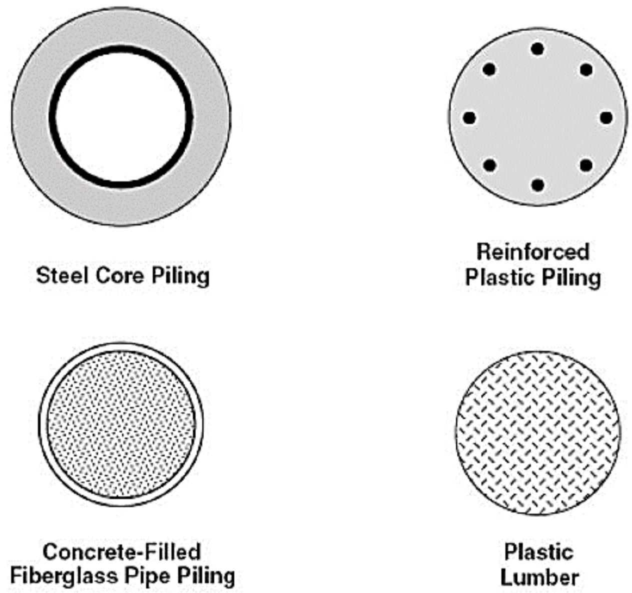
8. The grout used is neat cement or sand-cement grout that will meet the required compressive strength. Approved admixtures may be added to improve flow ability. A grout mix must be submitted and approved by the responsible engineer.
9. The QA inspector's responsibilities related to micropile materials include checking to verify that:
   a. The casing pipe is of the correct diameter, wall thickness, and grade.
   b. The correct welding procedure is used for welded joints of casing pipe.
   c. For threaded joints of casing pipe, the threads are complete and undamaged.
   d. Reinforcing steel is of the correct size and grade.
   e. The correct length of reinforcing steel is used in each micropile.
   f. The size and grade of the bearing plate is correct.
   g. All nuts and couplers are of the correct size and material.
   h. The approved grout mix is used.

G. Vinyl, Fiber Reinforced Polymer, Fiberglass, and Composite Pile Materials

1. Vinyl sheet-piling and FRP piles and sheet piling can have lower maintenance costs and longer service lives than piles made of steel, concrete, or wood. Vinyl and FRP piles are especially suited for marine applications and other corrosive environments. These materials are also used with steel, concrete, and wood to produce "composite piles" that have the strength of steel, concrete, or wood but the protection from corrosion that is afforded by the polymer or fiberglass materials. Several composite pile products are

available, including steel pipe core piles, structurally reinforced plastic matrix piles, concrete-filled fiberglass pipe piles, fiberglass pultruded piles, and plastic lumber piles. See figure 645R-15 for some examples.

Figure 645R-15. FRP Composite Piling Types



2. Steel core piling consists of a recycled plastic shell encasing a steel pipe core. The steel pipe core provides structural strength. Piles are available in 8- to 24-inch outer diameter and up to 75 feet in length. The structural pipe cores range from 4- to 16-inch outer diameter with wall thicknesses ranging from 0.237 to 1.594 inches.
3. Reinforced plastic piling typically consists of an extruded recycled high-density polyethylene plastic matrix reinforced with fiberglass or steel rods. Additives are used to improve mechanical properties, durability, and ultraviolet protection. Polymer-based resins are heavier than wood; foaming of the resin is used to make the product lighter. The matrix may also contain a small percentage of fiberglass to enhance its physical properties. Piles are available in 10- to 16-inch diameters and are reinforced with fiberglass or steel reinforcing bars ranging in diameter from 1 to 1½ inches.
4. Fiberglass pipe piles typically consist of an acrylic-coated fiberglass tube. The fiberglass tube provides structural strength, and the acrylic coating protects the fiberglass against abrasion, ultraviolet light, and chemical attacks. Some piles are filled with concrete after installation to increase their strength. Others are filled and strengthened with concrete and cured prior to driving. Piles are available in 8- to 18-inch diameters with 0.18- to 0.36-inch wall thicknesses. They can be made in any shippable length.
5. Plastic lumber, which may be used as FRP piling, consists of a recycled plastic matrix with randomly distributed fiberglass reinforcement in the matrix. A foaming agent is used to entrain air into the plastic to make it

lighter. Additives are also used to improve mechanical properties, durability, and ultraviolet protection. A variety of structural members conform to lumber industry standards. Plastic lumber piling is available in 10- to 16-inch diameter with standard lengths ranging from 18 to 24 feet. Longer lengths can be custom made.

6. Wood composites exist in various forms, including timber piling encased in fiberglass and extruded mixtures of wood cuttings and polymers. Typically, wood composites are available in sections smaller than 12- inches in diameter or width and come in lengths up to 20 feet.

7. The QA inspector's responsibilities related to vinyl, FRP, fiberglass, and composite pile materials include verifying that:

   a. Materials conform to specified grade and type.
   b. Materials conform to approved submittals.
   c. Length, diameter or cross-sectional dimensions, weight, and type of piles conform to specifications and approved submittals.
   d. Surface condition conforms to material specifications.
   e. The condition of tip and butt reinforcing or shaping is as specified or noted on approved submittals.
   f. Bent or damaged sections are rejected or correctly repaired.

H. Handling and Storage of Piles

1. Handling piles can be very dangerous. They must be unloaded safely in a way that avoids damaging them. A crane must be used for unloading and stacking piles. Piles must be unloaded where overhead utilities can be avoided as the piles are stacked and then moved into the driving position.

2. Each pile must be picked up by at least two lift points in a manner that will prevent undue stress at any point on the pile. A hook on each end of a lifting beam (spreader-bar) holds the pile securely. Precast piles must only be lifted by securely fastened chains or straps attached at marked lifting points.

3. Piles must be stacked on timber or other blocking and braced so that there is no danger of their falling or rolling. Each pile must be stored and taken off the stack in a manner that does not cause the remaining piles to move. Precast piles must be supported on blocks located at lifting points. A clean, well-arranged storage yard free of obstructions and overhead utilities is essential for safe and efficient pile handling and driving operations.

4. When more than one type, size, or length of pile is used, piles that will be needed first must be stored where they can be retrieved without having to move other piles. Piles must be stored in an orderly fashion to avoid unnecessary moving or lifting of piles, until they are retrieved for installation.

5. All fasteners, anchors, and other appurtenances must be kept clean, dry, and organized so that they are readily available for use as needed.

6. The QA inspector's responsibilities related to handling and storage of pile materials include verifying that:

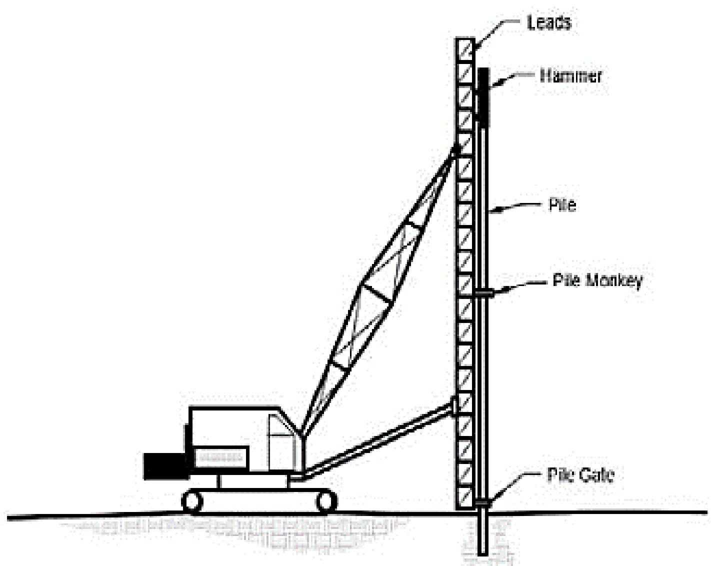
a. Safe storage and handling methods are employed.
b. Materials are not damaged in storage or by handling.
c. Overhead utilities are avoided.
d. Marked lifting points are used.
e. Piles are blocked and braced to avoid falling or rolling.
f. Precast concrete piles are supported on blocks located at lifting points.
g. Pile stack is orderly to avoid unnecessary moving or lifting of piles until they are needed.
h. Fasteners, anchors, and appurtenances are kept clean, dry, and organized.

I. Pile-Driving Equipment

1. Pile-driving equipment consists of a pile driver that holds the pile and the hammer as the hammer drives the pile into the ground. Water-jetting equipment may also be used, if allowed by the specification, to displace the soil ahead of the pile and make it easier to drive the pile into the ground.

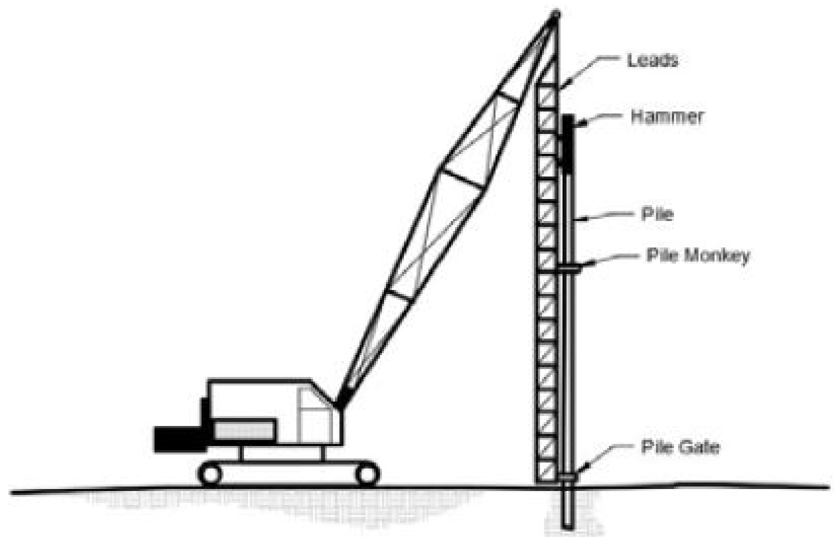
2. A pile driver is a large piece of equipment that supports the pile and hammer in a fixed position while driving the pile into the ground. The equipment must be stable and of adequate size and capacity to lift the pile and to control both the pile and hammer during driving. A typical pile driver is composed of a crane, leads, a hammer, and other appurtenances as shown in Figure 645R-16.

Figure 645R-16. Typical Fixed-Lead Pile Driver



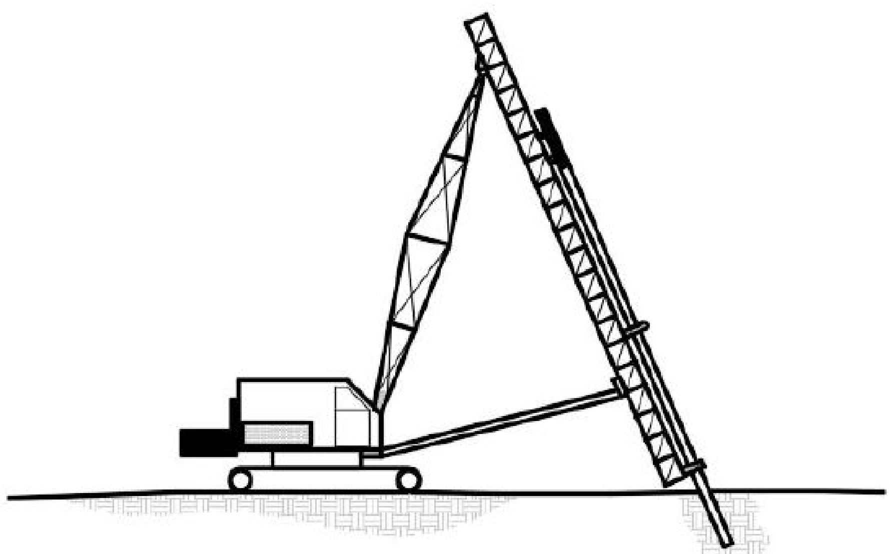
3. The term "leads" refers to the structure on which the hammer travels up and down and with which the hammer and pile assembly is aligned as the pile is being driven. Rails or other guides are affixed to leads to the guide the hammer as it travels up and down within the leads. Leads are either fixed, as shown in Figure 645R-16, or swinging, as shown in Figure 645R-17.

Figure 645R-17. Typical Swinging-Lead Driver



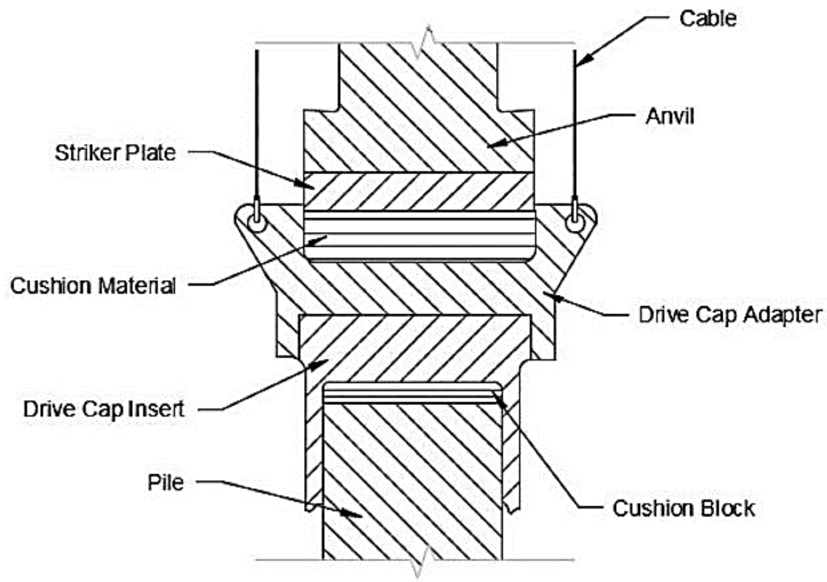
4. Pile drivers are classed as land drivers or floating drivers, according to the type of surface on which they travel. Mobile-crawler or truck-mounted cranes are commonly used on land. Any crane can be equipped with a hammer, leads, and accessory equipment and can be used on land or on a floating barge.
5. Specially configured fixed lead drivers are needed for driving battered piles (piles purposely driven at an angle rather than vertical), as shown in Figure 645R-18.

Figure 645R-18. Typical Fixed-Lead Driver Configured to Drive Battered Piles



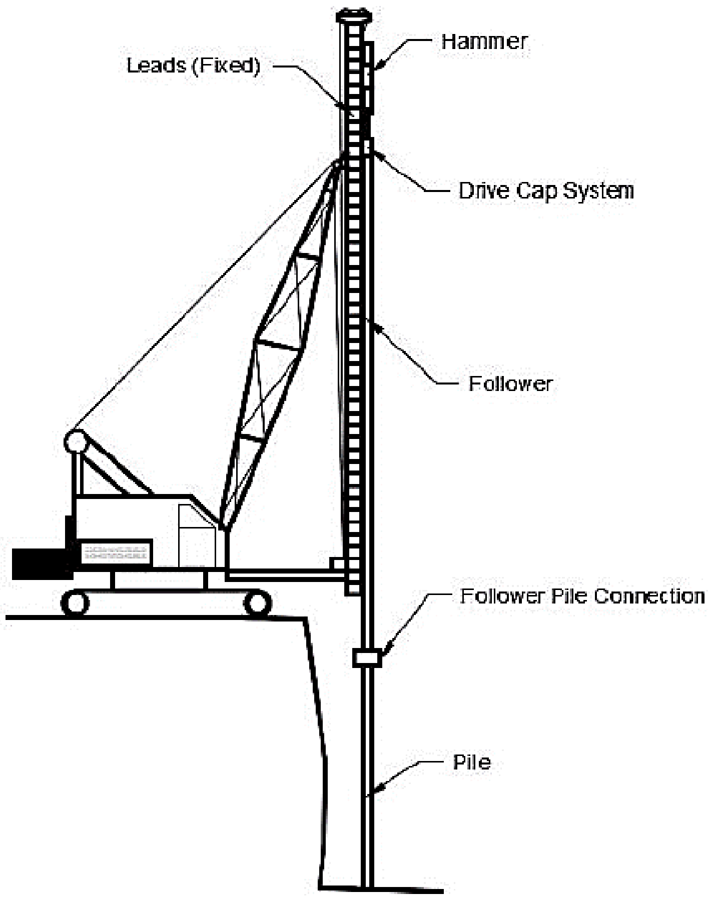
6. A key component of a pile driver is the drive cap system. A drive cap system, such as the one in figure 645R-19, is installed between the hammer and the pile to allow the energy from the hammer to be efficiently transmitted without damaging the hammer or the pile. Various drive cap systems are available.

Figure 645R-19. Drive Cap System



7. The cushioning material used in the drive cap system is typically made of hardwood or several pieces of plywood. If the cushioning material is not frequently replaced, it will become compressed and ineffective at softening the blows. Ineffective cushioning material, an incorrectly sized drive cap insert, or poorly fitted and misaligned drive cap components can damage to the hammer, pile, or both.
8. The selected cushioning material must be of the correct strength. Wood that is too soft acts as a sponge in absorbing the energy of the hammer, while wood that is too hard tends to splinter. Wood blocks must be cut to size and placed with the grain vertical. They must be replaced when they become compressed to less than half their original thickness or when they begin to smoke.
9. A follower is a member placed between a pile hammer and a pile to transmit blows when the pile butt is below the leads (below the reach of the hammer). A follower is also used when the pile butt is under water to avoid submerging the hammer. See figure 645R-20 for a typical pile driving rig with a follower. A follower is usually a section of pipe, or "H" pile, with connections that match both the drive cap system and the pile.

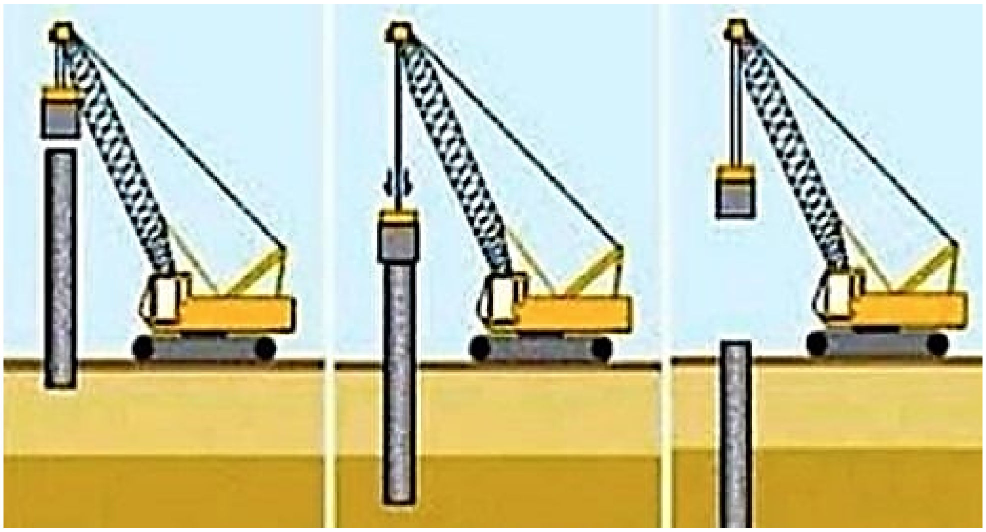
Figure 645R-20. Typical Pile Driving Rig with a Follower



10. Since the follower may absorb some of the energy of the hammer, the first pile in any location must be driven without the use of a follower to be able to make comparisons with operations that use a follower. In water, the first pile driven must be long enough to negate the need for the follower. The information obtained from driving a pile without a follower can then be used to assess how the follower affects the operation. The engineer must approve or disapprove the use of a follower based on this information. It is usually better to drive piles without using a follower whenever possible, because the follower will reduce the efficiency of the pile driver. Underwater hammers and extensions to the leads are alternatives to driving with a follower.
11. Piles have been driven using various types of equipment such as a track-hoe bucket, but the hammers normally used for driving piles are specifically made for that purpose. The driving force provided by these hammers is created by gravity, mechanical power (diesel, air, or steam), or both. Vibratory hammers are also used to install and extract piles.
12. Drop (gravity) hammers are the oldest type of pile-driving hammer. A drop hammer consists of a large weight (10,000 to 15,000 lbs.) raised by a winch and cable to a height above the pile and then dropped onto the top of the pile.

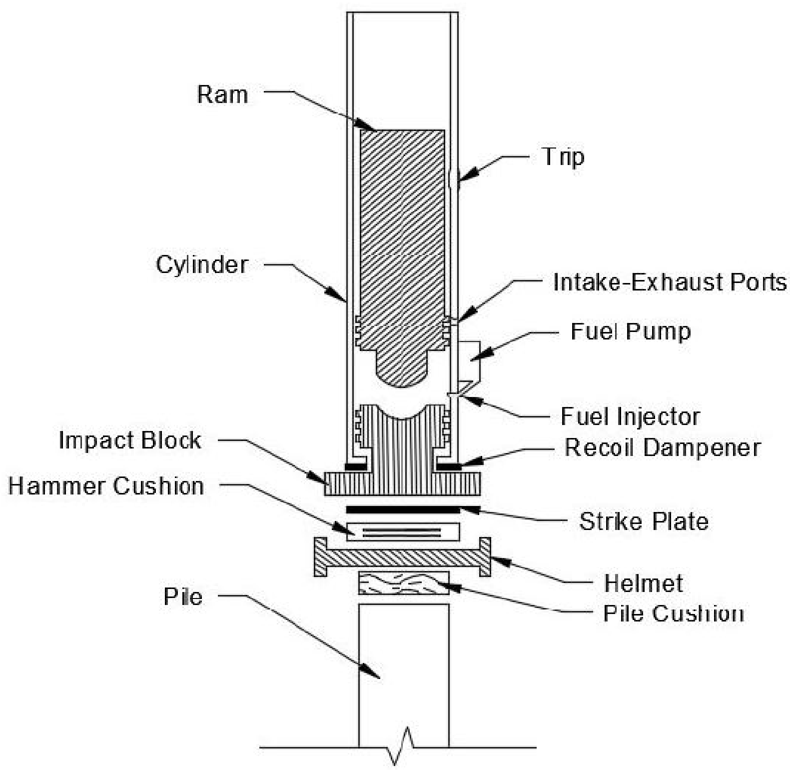
The energy generated by the free-fall of the weight creates the force that drives the pile into the ground. Figure 645R-21 shows a typical drop hammer.

Figure 645R-21. Typical Drop Hammer Pile Driver



13. Power-driven hammers use gravity and mechanical power to create the force that drives the pile. Hammers are selected based on weight, stroke, and speed. A heavy ram working on a short stroke is usually more effective than a lightweight long-stroke hammer. See figure 645R-22 for an example of a power-driven diesel hammer.

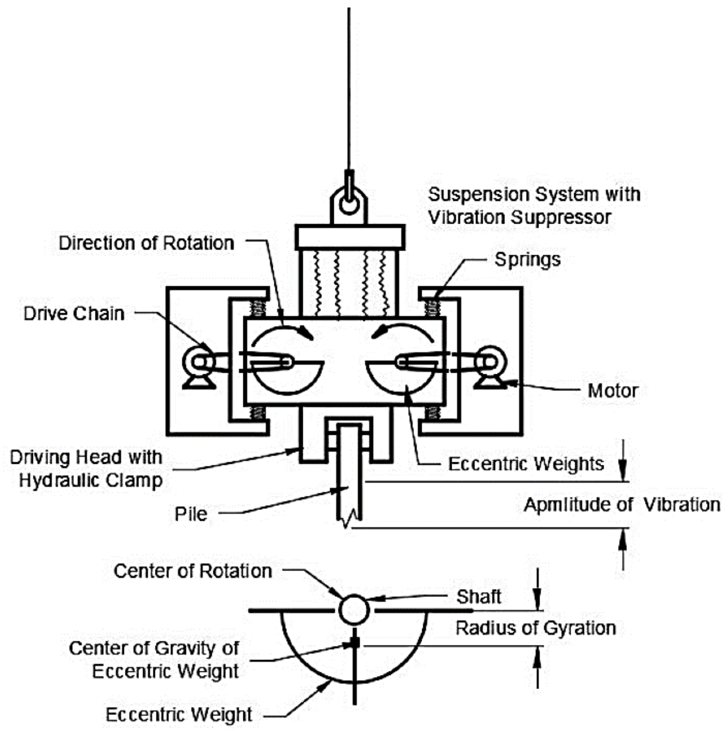
Figure 645R-22. Diesel Hammer Configuration



14. Diesel, steam, and compressed air are all used to power hammers. Many factors can decrease a hammer's efficiency, including wear, incorrect adjustment of fuel injector, poor lubrication, unusually long steam or air hoses, hose leaks, binding guides, and minor drops in steam or air pressure. The hose size and length on steam and air hammers must comply with the manufacturer's specifications. If any power-driven hammer does not operate correctly, it must be shut down until adjusted or repaired.
15. Where steam or compressed air is used, a boiler inspection certificate and other safety items may be required to conform to safety regulations.
16. Single-acting hammers, also called Vulcan hammers, differ from drop hammers in that the ram is raised by air or steam rather than a winch and cable. The ram or hammer falls by gravity. The striking parts of these hammers usually weigh 5,000 to 6,500 pounds and operate at a rate of 40 to 60 blows per minute. The setting of the air or steam intake valve is critical. Incorrect setting permits air or steam to enter the lower side of the cylinder, act as a cushion, and prevent a complete down-stroke. Incorrect setting can also cause the valve to cut off too soon, resulting in a short upstroke.
17. Double-acting hammers use steam or air for both raising and driving the ram. The driving force per blow is usually less than that of a single-acting hammer; but it is fast, delivering 90 to 225 blows per minute. They require uniform pressure to achieve the rated capacity. The intake valve setting and the condition of the rings and cylinder walls directly affect the hammer's impact.
18. Diesel hammers operate under their own power with the ram in the cylinder. Compression takes place within the cylinder on the downward stroke of the ram and tends to cushion the blow. The compressed air and fuel ignite to raise the ram for another blow. A diesel hammer is simple and compact, but noisier than other hammers, more difficult to start, and they spew diesel-laden smoke.
19. Unlike air or steam powered hammers, a diesel hammer is not self-starting. To start, they must be raised and dropped and often require adjustments over several attempts before it will start.
20. The blow is directly related to the ram stroke (fall height). A normal stroke for a diesel hammer is about 10 feet, but it may be less for soft soils and more for hard soils. Experienced operators observe the stroke of a diesel hammer for an indication of the soil conditions and bearing resistance of the pile. As the pile drives, the stroke increases as the resistance to driving increases. A sudden drop in stroke is an indication that the pile has been driven through a hard material into a softer material, or the pile has broken.
21. Diesel hammers are open-end or closed-end. Open-end hammers are single-acting. Closed-end hammers are effectively double-acting because they contain a bounce chamber at the upper end of the cylinder. A closed-end hammer stroke is shorter than an open-end hammer stroke, but it operates with more blows per minute.

22. Vibratory hammers are used to extract and drive piles. They are most effective in granular soils but may also be effective in cohesive soils. Vibratory hammers impart a vibration that is entirely vertical. The hammer clamps onto the pile and causes it to vibrate up and down (see figure 645R-23). As a result of this vibration, the soil next to the pile is mobilized and liquefied. Soil in this state will not support the weight of the pile and hammer. Thus, the pile is driven into the soil. This soil also offers little resistance from friction on the pile, so a vibrating pile can be easily lifted. Vibratory hammers come in various sizes. Large, heavy hammers are for driving or extracting heavy piles.

Figure 645R-23. Vibratory Hammer Configuration



23. A jet of water under pressure is sometimes needed to help drive a pile. Usually, the water jet is worked alongside the pile. The water flow must be regulated for each soil condition. In granular soils, a jet with holes that distribute an equal upward and downward cutting force is most effective. In cohesive soils, a downward jet must be used. Only enough jetting must be used to place the pile. Over-jetting can reduce the coefficient of friction on the pile being driven and loosen the soil around adjacent piles already in place. Jets cannot be used for driving piles in coarse gravels because they remove the fines and allow the coarse material to concentrate in the hole, making driving even more difficult. Water-jetting must only be used when allowed by the specifications or approved by the engineer.

24. The QA inspector's responsibilities related to pile driving equipment include:

    a. Obtaining and studying the brochure printed by the hammer manufacturer to learn hammer capabilities and limitations.

b. Verifying that the pile driving equipment is stable and capable to lift the pile and to control both the pile and hammer during the driving.
c. Verifying that the contractor has a current boiler inspection certificate and other safety requirements, when using steam or compressed air.
d. Verifying that the drive cap system allows the energy from the hammer to efficiently transmit to the pile without damaging it.
e. Verifying that the cushioning material is of the correct strength, correctly sized, and placed with the grain vertical.
f. Verifying that the cushioning material is replaced when compressed to one-half its original size or when it begins to smoke.
g. Verifying that followers are only used when approved.
h. Verifying that double-acting hammers are operating at manufacturer's rated speeds.
i. Verifying that the condition of the hammer is being checked for wear, incorrect adjustment, poor lubrication, long hose lengths, leaks, and drops in steam or air pressure.
j. Verifying that the water jetting equipment is of the type recommended for the soil.
k. Verifying that water flow is correctly regulated.
l. Verifying that water jetting is not used for driving piles in coarse gravels.

J. Determining Bearing Capacity

1. Bearing pile specifications require that the piles be driven to a minimum depth and have a minimum bearing capacity. Driving piles to a minimum depth of penetration is required to ensure stability, particularly if some erosion of the material surrounding the piling is expected.

2. Depths for end-bearing piles are specified to reach the supporting strata. The bearing value of these piles is based on the strength of the supporting strata and the designed strength of the pile. As piles are driven to the supporting strata, the resistance to penetration increases. Continued driving after the bottom of the pile reaches the supporting strata is overdriving, which may damage the pile. Regardless of whether the pile is an end-bearing or friction pile, overdriving can damage piles and must be avoided.

3. The bearing capacity of a friction pile can only be determined by loading a test pile that was driven at the site. However, the bearing capacity can be estimated by a bearing capacity formula. Either the test-pile method or the formula method is specified as a basis for determining the bearing capacity of each pile. NRCS Construction Specification (CS) 13 "Piling," includes specific instructions for performing piling load tests. If load tests are not required, the bearing capacity formula may be used as specified in CS-13 to estimate bearing capacity.

4. Although many bearing capacity formulas have been devised, NRCS prefers the Engineering News formula[1] to determine the bearing capacity of friction piles whenever the formula method is specified. The formula has three forms:
   a. For gravity (drop) hammers: R = 2WHR/(S+1.0)
   b. For single-acting hammers: R = 2WHR/(S+1.0)
   c. For double-acting hammers: 2H[W+(AxP)]/(S+1.0) or R = 2WHR/(S+1.0)
   d. Where:
      (1) R = Bearing capacity, in pounds or tons
      (2) W = Weight of the striking parts of the hammer, in pounds or tons
      (3) H = Height of fall (stroke), in feet
      (4) A = Area of piston, in square inches
      (5) P = Pressure of steam or air exerted on the hammer piston or ram, in pounds per square inch
      (6) E = The manufacturer's rating for foot pounds of energy developed by double-acting hammers, or 90 percent of the average equivalent energy, in foot-pounds, developed by diesel hammers with enclosed rams, as evaluated by gauge and chart readings
      (7) S = Average rate of penetration for the last 5 to 10 blows of a gravity hammer or the last 10 to 20 blows for steam, air, or diesel-powered hammers, in inches per blow
5. To determine that the pile is driven to the specified bearing capacity, the applicable bearing formula can be used to solve for "S" as follows:
   a. For gravity (drop) hammers: S = 2WHR/(R-1.0)
   b. For single-acting hammers: S = 2WHR/(R-1.0)
   c. For double-acting hammers: 2H[W+(AxP)]/(R-1.0) or S = 2E/R -0.1
      (1) For example, a pile with a required bearing capacity (R) of 70 tons driven by a W=10-ton gravity hammer with a drop height (H) of 6 feet results in S = (2×10×6 / 70) − 1.0 = 0.71 inches per blow. Whenever the rate of penetration averages 0.71 inches per blow for the last 5 to 10 blows of the hammer, it has attained the required bearing capacity. Continued driving would be overdriving and must not be allowed.
   d. These formulas only apply when:
      (1) The hammer falls freely.
      (2) The pile head is not crushed.
      (3) The penetration is quick and uniform.
      (4) A follower is not used.
6. If there is hammer-bounce after the blow, deduct twice the height of the bounce from "H" to determine its value in the formula. If the hammer in the above example problem bounced up one foot after impact, H would be reduced by 2 feet, resulting in S being reduced to 0.14 inches per blow.

[1] Engineering News. 1888. 20:50-512

7. All field driving data and calculations must be completely documented to show that the contractor has driven each pile to the required bearing capacity. Worksheet 645 WS R.1 in Appendix B can be used for this purpose.

8. The QA inspector's responsibilities related to verifying the attainment of bearing capacity include:

   a. Verifying that end-bearing piles are driven to the specified supporting strata, but not overdriven as to damage the pile.
   b. Documenting test pile loading results when the test-pile method is used.
   c. Documenting that all friction piles are driven to the depths determined from test-pile loading whenever the test pile method is used.
   d. Verifying that the required bearing capacity (R) is attained for each pile driven, whenever the formula method is used by verifying that:
      (1) The hammer falls freely.
      (2) The pile head is not crushed.
      (3) The penetration is quick and uniform.
      (4) A follower is not used.
      (5) "H" is reduced by twice the amount in the case of hammer-bounce.
      (6) The correct bearing capacity formula is used.
      (7) Documenting all field driving data and bearing capacity calculations.

K. Preparing to Install Piling

1. It is best to drive individual piles in one continuous operation. Interruptions, causing the pile to be stationary at one elevation, could allow soil to settle and pack around the pile, making it harder to drive to completion. Correct planning and preparation can avoid interruptions.

2. Where several piles are to be driven, a master plan and schedule showing the location of each pile relative to the structure must be provided in the design. The schedule must list the type, size, and total length of each pile to be driven at each specific location.

3. Unless otherwise specified or allowed, all materials and equipment must be approved and on site in good working order, prior to lifting the first pile into driving position.

4. Sheet-piling can be driven before all excavation is completed. However, bearing piles (especially friction piles) must not be driven until all excavation within their area is completed.

5. When driving piles, the soil surrounding the pile tends to heave. This heave can damage buried utilities, even if the pile does not strike the utility. It can also damage structures that are close enough to be affected. The amount of heave and the safe distance at which piles can be driven from utilities or structures is dependent on the size of the pile or cluster of piles, the type of soils, soil conditions, etc. In addition to heave, ground vibration can also damage buried utilities or structures in the immediate area. Piles must never be driven within 20 feet of concrete that is less than seven days old, including concrete cast-in-place piles, with or without pre-driven shells or casings.

6. Ground heave and vibration may damage or disturb overhead utility poles, towers, and other supports. Working around overhead power lines with driving equipment is extremely dangerous. Utility owners must be consulted when utilities are located near the area where piles are planned.
7. Piles will be driven to a minimum specified depth and to a depth determined by one of three criteria: refusal, specified depth, or bearing capacity. The QA inspector must review the specification requirements prior to driving and obtain any information needed to verify that the piles are:
   a. Not overdriven as to damage the pile.
   b. Driven to the minimum specified depth.
   c. Driven to the depth determined by the specified criteria.
8. When driving to refusal, the specification requires that driving cease whenever the pile can only be driven a specified short distance by a specified number of blows of the hammer. For example, the specification might read, "Continue driving until 10 blows of the hammer results in the pile being driven only 1 inch or less."
9. When driving to a specified depth, that depth is usually determined based on boring logs. However, piles are rarely driven in the same location as boring logs. It may be necessary to adjust the depth in the field, depending on the actual depth of the bearing layer below the pile. This is especially important for end-bearing piles because they are supported by a bearing layer.
10. Where the bearing capacity formula is specified, the average penetration per number of blows (S) must be determined. Whenever the penetration rate slows to the calculated rate, driving must cease to avoid overdriving and damaging the pile. The average penetration per number of blows can be determined using the bearing capacity formula, see section 645.181(J). In preparation for driving, the QA inspector must review brochures or other available information from the hammer manufacturer to obtain the values needed for computing bearing capacity with this formula.
11. As the pile is being driven, the depth and rate of penetration can be determined by observing reference marks on the leads or the pile. For friction piles, driving must cease whenever the rate of penetration indicates that bearing strength has been attained according to the bearing formula. For end bearing piles, driving must cease whenever the rate of penetration slows to refusal. The QA inspector must verify that piles or leads are marked so that a determination of the penetration depth and penetration per number of blows can be made quickly with minimal driving delay.
12. Sometimes contractors want to overdrive piles to avoid having to cut them off at planned grade. Overdriving damages the pile in a way difficult to detect if the damaged portion is not visible. The QA inspector must be aware of signs of overdriving and verify that it is avoided, but that the required bearing capacity is achieved. Prior to beginning the driving operation, the QA

inspector must check boring logs to anticipate driving resistances and types of materials to be expected.

13. On some jobs, the specifications require that the first piles installed be driven next to or at the exact location of borings, and that the pile lengths shown on the pile schedule be compared to that expected based on the boring logs. If possible, these test piles must be driven prior to delivering the remaining piles to verify that the piles are long enough or that they are not so long that significant portions will have to be cut off and wasted.
14. Specifications often include load tests to verify the bearing piles will support the intended load. When specified, the QA inspector must be familiar with these requirements, including:
    a. The amount of test load to be applied.
    b. When the test can be started after the pile is driven.
    c. The rate of loading.
    d. The frequency and accuracy at which settlement must be measured.
    e. The length of time the load must remain on the pile to complete the test.
15. The QA inspector's responsibilities when preparing to install piles are to:
    a. Verify coordination with utility company if utilities are present.
    b. Review drawings, specifications, and pile driving plan to verify that all materials to be incorporated into the work have been approved and are available onsite before driving begins.
    c. Determine if piles are to be driven to refusal, a specified depth, or a bearing capacity based on specified formula.
    d. Check boring logs to anticipate the driving resistances and types of materials to be expected.
    e. Verify that all excavation within the area to be occupied by bearing piles is complete before driving begins.
    f. Verify that piles are not driven within 20 feet of concrete that is less than seven days old.
    g. Verify the marked pile locations match the drawings and pile driving plan.
    h. Verify the length and size of each pile matches the plan and schedule.
    i. Verify the contractor has a boiler certificate, if using steam.
    j. Verify the engineer approved the jetting, where jetting is planned.
    k. Verify that piles or leads are marked so that the penetration depth and rate can be determined quickly.
    l. Verify that all equipment for performing required load tests, if applicable, is on site and in working order prior to installing test piles.
    m. Verify the accuracy of pile schedule and lengths by:
        (1) Driving several piles adjacent to or at boring locations,
        (2) Noting blows per foot of penetration, and
        (3) Comparing driving resistance with that anticipated from boring logs.

L. Driving

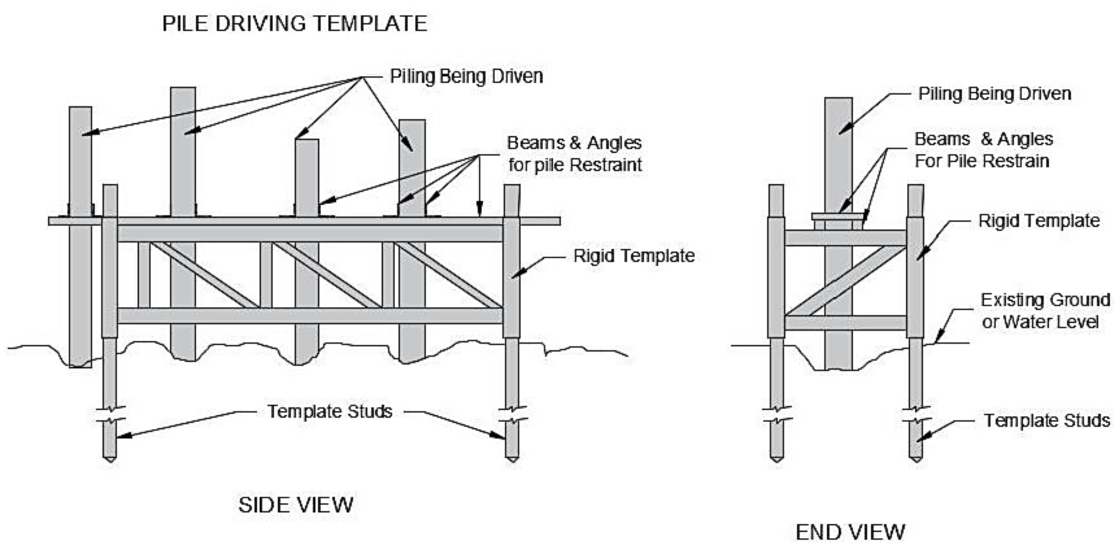
1. This is an example of pile driving steel piles:

   a. Mark the pile location correctly at the site.
   b. Excavate the soil at the pile location to remove shallow obstructions and then backfill, if needed.
   c. Set up the pile driver.
   d. Erect and drive the bottom section of pile into the ground.
   e. Extend the pile, if necessary, by welding on an additional section after the previous section has been installed.
   f. Use a spirit level to periodically check and adjust the pile so that it remains plumb.
   g. Continue driving until the pile is driven to final depth, including using a follower when the cutoff level is deep.
   h. In the case of obstructions, extract the pile and drive a steel tubular pile down to punch through the obstructions, or use a "down-the-hole" hammer to predrill the obstructing layer before reinserting the steel pile.

2. Care must be taken during pile handling and driving to avoid damaging the pile or the hammer. The pile driver must be securely anchored to avoid a shift in position. If the hammer shifts while driving, the hammer blow will be out of line with the axis of the pile, damaging both the pile and the hammer.

3. Most pile drivers have leads, but some operate without leads. The pile driving template in figure 645R-24 shows a structure used to guide piles driven without leads. Bracing made of timber or other material may be used when a template is unavailable. The template or bracing must be sturdy enough to support the pile and maintain it in position during driving.

Figure 645R-24. Pile Driving Template

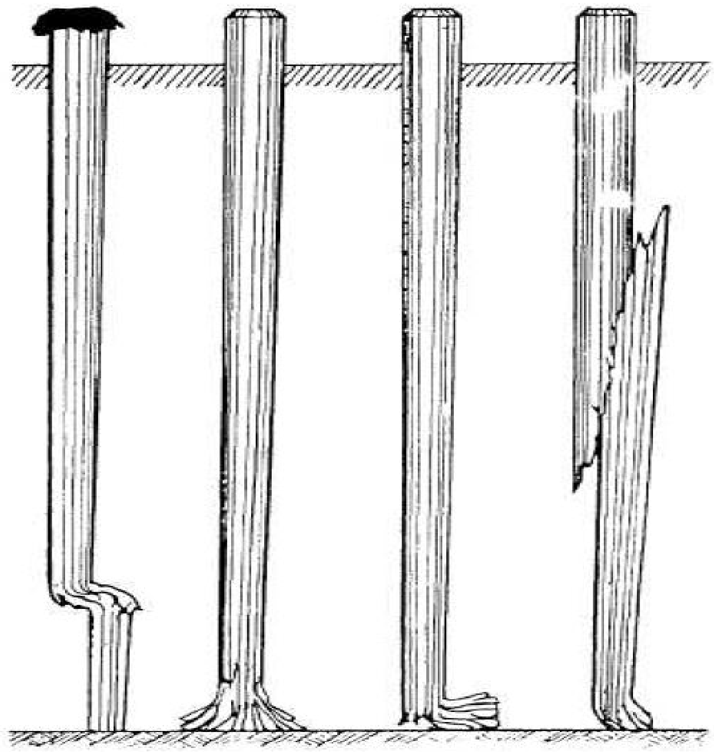


4. Piling tends to creep or move out of alignment during driving. To combat this tendency, the first pile must be driven plumb or, for battered piles, at the desired angle. As the pile is driven, the leads will lean with the pile. A guy wire and winch can be used to realign the leads as the pile is being driven. If a pile hits an obstruction that causes it to begin moving away from the desired alignment, it may be possible to stop driving that pile and support it with

adjacent piles. If jetting is allowed, it can be used to make driving and realignment easier.

5. Some tolerance in alignment may be allowable, but if the pile is driven outside of the allowable tolerance, it must be cut off and abandoned. A new pile can then be driven beside the abandoned pile. In some cases, the pile may be pulled and redriven, if doing so does not disturb the ground to the extent that it will not support the new pile as needed to attain the specified bearing strength.
6. Water jetting can damage the foundation of existing structures or loosen previously placed piles. If allowed, it is best to apply jetting of equal magnitude to opposite sides of the pile at the same time. Applying jetting to only one side tends to draw the tip of the pile in the direction of the jet, making it difficult to keep the pile plumb or otherwise aligned. Jetting must only be used when specified or approved by the engineer. The depth of jetting must be limited so that a portion of the pile is driven after jetting ceases. After all jetting in the immediate area ceases, friction piles must be redriven or retapped to verify the bearing capacity. End-bearing piles must also be retapped to verify they have not been disturbed by jetting and are still resting on the bearing strata.
7. Driving piles causes ground vibration. The amount of vibration depends on the driving effort and the resistance to driving. In granular soils, ground vibration may consolidate the soil. When driving piles in granular materials, watch for signs of consolidation and ground settlement near adjacent structures that may weaken foundations. Watch for other damage from vibration energy transferred to the structure. Vibration can damage plumbing, windows, window seals, etc. Notify the responsible engineer of any concerns.
8. Watch the piles for any indication of a split or break below the ground. If driving suddenly becomes easier, or if the pile suddenly changes direction, a break or split has probably occurred. When this happens, the pile must be pulled or abandoned in place, and another pile driven beside it. Figure 645R-25 shows wooden piles damaged during driving. The first pile has a damaged butt and a break near the tip. The damaged butt may have been caused by ineffective cushioning material in the drive cap system or lack of correctly affixed bands around the butt. The second pile has a broomed tip. The third pile has a broomed and broken tip. Tip damage and pile fracture is caused by continued driving after the pile bottoms out on subsurface rock, dense sand, or gravel. The fourth pile is fractured in a manner that indicates significant driving occurred after the pile bottomed out on a material of firm resistance.

Figure 645R-25. Examples of Wooden Piles Damaged During Driving



9. An experienced QA inspector who studies the boring logs and observes the reaction of the pile during driving can make sound deductions about the penetrated material and the pile condition during and after driving. Observe the ground surface and in-place piling for heaving. A bouncing hammer or kicking pile can indicate refusal. Continued driving may damage or break the pile. Sound and vibration are good indicators of the driving conditions.
10. "Springing" means that the pile vibrates too much laterally from the blow of the hammer. Springing may occur when a pile is crooked, when the butt is not correctly squared off, or when the pile is not in line with the hammer fall. In all pile-driving operations, the hammer must fall in line with the pile axis, or the butt of the pile and the hammer may be damaged, and the hammer energy will be lost. Excessive bouncing may come from a hammer that is too light. It usually occurs when the pile butt gets crushed, when the pile meets an obstruction, or when the pile penetrates to a solid footing. Double-acting hammers with too much steam or air pressure may also cause bouncing.
11. Whenever the formula method is specified for determining bearing capacity, the pile driver must be in good condition with the ram operating at full stroke, rated speed, and under the full recommended pressure. The hammer's movement must be aligned with the pile's axis. Cushioning materials must provide protection to the butt of the pile without absorbing too much energy. These materials compress, losing their ability to protect the butt of the pile and must be replaced often. When driving piles in groups or clusters, driving the

inner piles last can force the outer piles out of alignment and reduce their bearing capacity.

12. The QA inspector's responsibilities related to driving piles include:

    a. Verifying correct handling of piles and insisting that lifting points be used.
    b. Verifying that piles are installed at planned locations and driven vertically, or if battered, on the axis they are to follow.
    c. Verifying that diameter and depth of pilot holes meets specifications and pile driving plan.
    d. Verifying that the sequence of driving conforms to plan.
    e. Verifying that inner piles are driven first in friction pile clusters.
    f. Recording penetration of pile immediately after setting and prior to driving.
    g. Verifying that the hammer is centered over the pile.
    h. Checking for sturdiness and elevation when a template or timber bracing is used for guiding piles.
    i. Checking any deviation from planned location and verify that any deviating pile is cut off, abandoned, or pulled and replaced with a new pile driven at planned location.
    j. Verifying that if jetting is used:
        (1) The existing structures are not damaged.
        (2) The previously driven piles are loosened.
        (3) The jetting depth does not exceed permitted depth.
        (4) The pile remains plumb.
        (5) The piles are retapped after the jetting is complete.
    k. Verifying that pile driving is terminated if it becomes apparent that ground vibration may cause damage to adjacent structures.
    l. Notifying the engineer of ground vibration concerns.
    m. Checking the behavior of the pile during driving by:
        (1) Comparing hardness of driving at various depths against that expected from boring logs.
        (2) Watching for changes which indicate broken piles, obstructions, or driving irregularities.
        (3) Checking, when piles are driven in groups or clusters, for heaving of the ground around the piles.
    n. Verifying that pile driving is terminated if observed ground heave could damage any structure.
    o. Notifying the engineer of heaving concerns.
    p. Checking uplift on piles by measuring pile grade immediately after installation and recheck later.
    q. Verifying that each pile is driven to the specified minimum depth.
    r. Verifying that end bearing piles are driven to the specified supporting strata by checking depths against boring logs.
    s. Notifying the engineer of excessive hard driving or the presence of boulders, soft spots, old foundations, and other unfavorable conditions not shown on the drawings or otherwise expected.

t. Verifying, when driving to refusal, that the number of blows per inch (or fraction of an inch penetration) does not exceed the specified blows per inch for the last ten blows.

u. Verifying, whenever the formula method is specified, that:

   (1) The ram (hammer) is operating at full stroke, rated speed, and under full manufacturer-recommended pressure.

   (2) Evidence of reduced hammer speed occurs.

   (3) Cushioning materials conform to resistance formula requirement.

   (4) Recording of readings taken immediately after resumption of driving.

   (5) Driving ceases when the average penetration (S) equals the value obtained by the bearing capacity formula.

   (6) Required bearing capacity (R) is attained for each pile driven.

v. Preventing overdriving by:

   (1) Verifying that contractor avoids overdriving when specific depths of penetration are unattainable due to some unforeseen underground condition.

   (2) Observing sound and any vibration of the pile during driving for evidence of overdriving.

   (3) Watching for indications of overdriving, such as hammer bouncing, apparent loss of energy, and pile bending, kinking, or butt damage.

   (4) Checking for signs of worn out or insufficient cushioning material during driving.

   (5) Pulling an occasional pile to check for damage from overdriving, if allowed by specifications.

w. Checking workmanship, materials, and line and grade of completed work.

x. Verifying that permissible tolerances in alignment, plumbing, and grade are maintained.

y. Verifying that each pile is driven continuously until attaining required depth or penetration.

z. Noting the tip grade, if driving is suspended, at the time of the suspension and the duration of the delay.

aa. Verifying that approval is obtained for relocation of piles or driving additional piles.

bb. Notifying the engineer of deviations from the pile schedule.

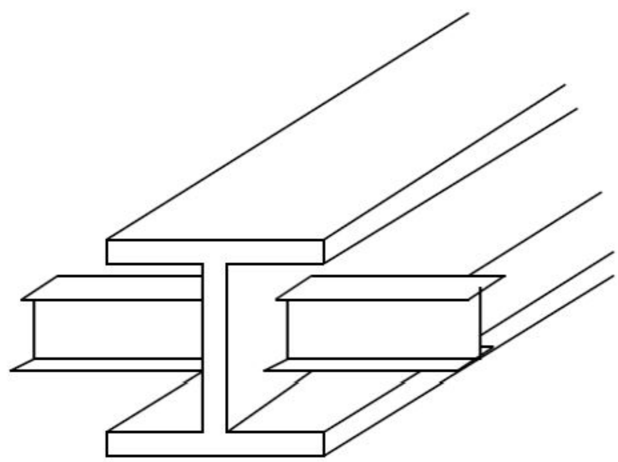
M. Driving Steel Piles

1. The combination of a steel pile’s strength and the minimal soil displacement their driving causes, allows most of the hammer’s energy to transmit directly to the tip. Despite their strength and efficiency, sometimes steel piles require drilled pilot holes to reach the specified penetration. By weld-splicing sections together, steel piles can be 200 feet or longer.

2. H-piles and I-piles do not displace as much soil as round or square piles. They can be used in urban areas or adjacent to structures where heave of the surrounding ground could cause problems. They can be driven in groups without predrilling, thereby reducing the risk of excessive vibrations from drilling, which might cause adjacent structures to settle.

3. A disadvantage of H-piles and I-piles is their tendency to bend. If they are driven to great depths, considerable curvature may result. They are susceptible to deflection upon striking boulders, obstructions, or an inclined bedrock surface. Steel piles may be strengthened by welding stiffening plates on the pile to resist bending and on the tip to help penetrate harder materials. In areas underlain by dense cohesive soil, heavy H-piles with strengthened tips are common to penetrate resistant layers and withstand hard driving.
4. When large pile groups are driven at close spacing in granular soils, vibration from driving will compact the soil. This may increase the driving resistance, requiring additional effort to drive piles after the first pile or first few piles are installed. It may also increase vibration and settlement of adjacent structures.
5. “Winged piles” consist of short lengths of steel H-section welded to the bottom of standard H-section piles (see figure 645R-26). These short lengths of steel act as a footing to provide end-bearing strength in sand.

Figure 645R-26. Winged Pile Configuration



6. Hollow steel piles can overcome some of the problems caused by the flexibility of slender H-sections. Hollow steel piles can be round “tube” piles or square “box” piles. Steel tube piles are manufactured in seamless, spiral-welded, or lap-welded sections. There is no difference between the two types of welding with respect to the allowable driving stresses. Tubes come in sizes from 1 to 6 feet outside diameter, and with wall thickness ranging from ¼ to 1 inch. There are also hollow steel piles with thicker walls for increased strength or corrosion prevention.
7. Hollow steel piles are typically filled with concrete after driving. Soil and debris must be removed from inside the tube before placing concrete. Water must be removed from inside the tube before placing concrete unless the concrete mix is designed to be placed in water.
8. When driving into stiff clays, dense granular soils, or rock, the pile tip can be protected from buckling by a stiffening ring or different types of cast-steel shoes. The stiffening ring can be placed on the inside or outside of end-

bearing piles, but an internal stiffening ring must be used if the pile is a friction pile. In very hard driving conditions, tip protection must consist of a thicker wall of about 1 to 1½ pile diameters in length that has been butt-welded to the main pile.

9. Hollow steel piles are normally installed by driving, but in difficult ground conditions they can be installed by a combination of drilling and driving the pile into the ground. In granular soils they can be installed more easily using a vibratory hammer.

10. Hollow steel piles can be driven either closed-ended or open-ended. If open-ended piles do not plug, they will cause very little soil displacement when driven. But they do tend to plug, especially in fine-grained soils where cohesion prevents the soil from entering the pile base. This will result in soil displacement and heave unless the plug of soil is removed as the pile is driven. In granular soils, plugging is less likely. However, it must be assumed that the end will plug in most soils, so expect ground heave. Ground heave is reduced by jetting, pre-drilling (soil loosening), or pre-coring (soil removal).

11. Whether or not the plug needs to be removed during driving depends on the soil type, pile diameter, and the installation method. The tendency to plug is greatest in long piles with small diameters driven in cohesive soils. Removing the plug facilitates pile penetration but may be time-consuming and costly.

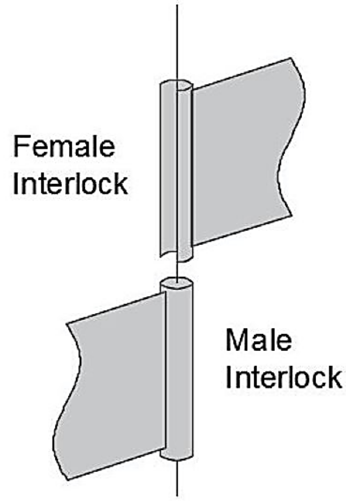
12. If driving conditions permit, it is preferable to drive box piles or tube piles with a closed end, since this permits inspection of the pile shaft after driving, and usually gives a higher pile-bearing capacity. After driving, the pile shaft may be filled with concrete. This method is frequently used in marine structures where corrosion of the pile interior could cause failure. Alternatively, piles may be driven open-ended and then, if required, be cleaned over their full depth and filled with concrete. If long piles are driven, a convenient method is to drive the first section open-ended. The following sections can be provided with a closed end. The upper part of the pile, which may be subject to corrosion, remains empty and can be filled with concrete.

13. Steel sheet-piling consists of a series of steel sections with interlocking grooves or guides, called clutches, along each edge. Each pile is connected, clutch to clutch, with a pile previously driven and then driven itself as close as possible to the same depth. This drives a continuous wall into the ground.

14. When sheet piles tend to creep or move out of alignment during driving, it sometimes helps to drive adjacent sheet piles in pairs or drive sheet piles in stages, with each adjacent pile being driven one-third the depth or less.

15. Sheet piles often have a clutch with a C-shaped (female) interlock on one side that gets clogged with soil as the sheet pile is driven. When possible, drive the sheets with the male interlock leading (as seen in figure 645R-27) to avoid clogging the female interlock. If the female interlock must lead, crimp the bottom of the interlock or insert a bolt or other object in the bottom to prevent clogging with soil.

Figure 645R-27. Sheet-Piling Clutch with Male Interlock Leading



16. Sheet-piling must be driven within or against some type of guide frame or template. Horizontal templates are recommended at two levels for vertical light steel walls – one near the ground level and the other near the cutoff elevation. For sites with difficult driving conditions, such as those containing cobbles or other obstructions, templates must be provided on both sides of the piling. The templates or guide frames must be close enough to the sheet-piling to support correct alignment. A guide system may consist of mobile or fixed beams (anchored to temporary piles called spuds) made of timber or steel.
17. Sheet piles can be installed with high frequency vibrators or hammers. A hammer that is too heavy will damage light-weight sheet piling. A light single or double-acting hammer is usually adequate when driving one sheet at a time. Driving more than one sheet at a time or driving into highly resistant soil may require a heavier hammer. A light drop hammer (1,000–1,500 pounds) can be used if carefully controlled.
18. For lightweight steel, two sheets are usually driven together. Sand and gravel require a rapid driving action. Clay soils require a heavier hammer and a slower driving action. The use of steel driving heads is recommended to spread the impact of the light hammer on a single sheet and of the heavy hammer when driving two sheets. Driving heads must fit the shape of the piling and be thick enough to withstand the driving action without distortion.
19. As sheet-piling is driven, lateral forces may move the piling out of line (known as walking) and out of plumb. This will draw adjacent piling out of line and out of plumb. Continual, gradual adjustments to line and plumb must be made to avoid abrupt changes. Every tenth piling must be pinned or otherwise supported to maintain line and plumb.
20. After the piling is in place, the cutoffs and other structural adjustments are made, including installing walers, tiebacks, and bracing where applicable (see figure 645R-28). Walers must be installed in a way that allows the wall to expand and contract independent of the waler. Anchors and tiebacks, if

required, must be correctly located and installed to prevent misalignment or structure failure. Bracing may help rigidity. Bolting, welding, and deadman installation must be inspected to ensure the structure matches the drawings.

Figure 645R-28. Example of Steel Sheet Piling with Bracing (NRCS)

21. A sheet-piling wall is typically capped with concrete, steel, or wood. All bracing, welding, walers, paint, etc. must be installed and inspected prior to installing the wall cap.
22. The QA inspector's responsibilities related to driving steel piles are to verify that:
    a. Stiffening plates are installed on H- or I-piles, if required.
    b. Wings are installed on wing piles.
    c. Stiffening rings or steel shoes are installed on hollow steel piles, where required or needed.
    d. External stiffening rings are not used on friction bearing piles.
    e. The ends of hollow steel piles are closed, when specified.
    f. The insides of open-ended piles are cleaned of soil, water, and debris before filling with concrete.
    g. Damaged butts are cut off.
    h. The number of splices per pile are limited.
    i. Cutoff elevations are within allowable tolerances.
    j. The interlocking groove (clutch) of sheet pile matches the adjacent sheets.
    k. The guide form is accurately located and secured.
    l. The initial pile is accurately located, aligned, and plumbed.
    m. Driving operations do not rupture sheet pile interlock.
    n. Splices are staggered.
    o. Handling and pulling holes are provided if needed.
    p. Sheet-piling is left slightly higher than cutoff elevation.
    q. Every tenth sheet pile is pinned to prevent "walking" and to maintain plumb.
    r. Waler installation allows sheet-piling expansion and contraction.
    s. Caps are not placed on sheet-piling before bracing or welding is done.

N. Driving Wooden Piles

1. Wooden (timber) piles are typically installed using small hammers (1,000 – 1,500 pounds) to avoid splitting the piles. The butt of a wooden pile must be fitted with a tight steel or iron band to prevent "brooming" (crushing and spreading of the wood during driving). Before driving, a pile cap with a helmet and cushioning material must be fitted to protect the butt of the pile. A mild steel shoe must be fitted to protect the point of the pile during driving, unless the driving is in soft soils.

2. In easy driving conditions, the weight of the hammer must not be less than half the weight of the pile. In hard driving conditions, the hammer must be at least as heavy as the pile. Hard driving of a timber pile is likely to broom the butt, crush the tip, and fracture the pile. The risk of damage may be reduced by limiting the hammer drop height and the number of blows of the hammer. Drilling pilot holes, water jetting, or adding vibration to the driving effort may make driving easier and help reduce the potential for damage to the pile.

3. After driving, the butt must be cut off square to remove unsound wood and then be treated with preservative. Thus, the initial length of the pile must be longer than the required in-place length to allow for cutting off the butt. Permanent softwood piles must be cut off below the lowest anticipated ground water level.

4. "Wakefield" piling (see figure 645R-6) is fabricated on site. The QA inspector must verify the use of approved materials, including grade and size of lumber, and size and length of nails, spikes or bolts used to fabricate the piling and ensure that tongue-and-groove dimensions and nailing or fastening provide for a secure, tight fit.

5. The QA inspector's responsibilities related to driving wooden piles include verifying that:

    a. Tight steel or iron bands are used around the butt.
    b. The butt is recut to remove unsound material.
    c. Pile length will allow for cutting off the butt.
    d. Holes in treated piles are filled with hot creosote or other approved material and, where not used, tightly closed by a treated plug.
    e. Treated piles have no holes bored or spikes driven to support scaffolding.
    f. Shoes are used where needed.
    g. Pile painting conforms to specified requirements.
    h. Only approved materials are used for Wakefield piling.
    i. The Wakefield piling has tongue-and-groove dimensions and nailing or fastening that creates a secure, tight fit.

O. Driving Concrete Piles

1. Precast concrete piles can be reinforced with standard concrete reinforcement or, in the case of prestressed piles, reinforced with steel cables placed in tension prior to being embedded in the concrete. Manufacturers make precast concrete piles with square cross-sections ranging from 10 to 18 inches across and up to 60 feet long. Other pile sections exist and may include hexagonal,

circular, triangular, and "H" shapes. Tongue-and-groove precast concrete piles are used for sheet-piling. Precast piles are produced in a factory or on site. The production process affects the pile's quality.

2. Precast piles are most susceptible to damage when handling. The designer or manufacturer must and mark and specify the lifting points on the pile. The QA inspector must verify that piles are only lifted at the marked lifting points and that the load is equally distributed between these points. When piles are stored, they must be supported near the lifting points.
3. Damage to a concrete pile may not be plainly visible. Incorrect storage or handling must be reported to the responsible engineer. Incorrectly stored or handled piles must not be used until the engineer clears them for use.
4. Pile section length is often dictated by practical considerations such as transportation, handling problems on sites with restricted area, the height of the pile driver, and the available facilities at the casting yard. Piles can be spliced by welding of steel end plates, using epoxy to form the joint, or the use of epoxy mortar with dowels. The pile sections must be aligned correctly to prevent excessive bending stresses at the joint during driving. Some piles are equipped with prefabricated joints. Extending precast piles without one of these splicing methods or prefabricated joints is a lengthy process. It requires removing some of the concrete from the projecting pile butt to provide a suitable lap for the steel reinforcement and casting concrete to form the joint. This process dictates that pile driving cease until the concrete used to form the joint has gained sufficient strength to withstand driving.
5. Prestressed concrete piles are prestressed during the manufacturing process. Embedded steel cables oriented parallel to the pile axis are placed in tension just prior to pouring the concrete around them. These cables allow the pile to withstand greater loads than similar precast piles without prestressed steel. Prestressed concrete piles resist damage from mishandling and poor driving technique better than non-prestressed concrete piles. However, they are more vulnerable to damage from striking obstructions during driving. They are also difficult to cut after installation and require special cutting techniques. Thus, they are most suitable for applications where cutting is not required.
6. Prestressed concrete piles require high-strength concrete and careful control during manufacture. Casting is done in a factory where the curing conditions can be strictly regulated. Special manufacturing processes, such as compaction by spinning, can be employed to produce high-strength concrete.
7. The tips of precast concrete piles are typically damaged in soils containing a significant number of boulders. Hard steel points (driving shoes) must be affixed to the tip of prestressed piles for protection when penetrating boulder-laden soils or weak rock.
8. The QA inspector's responsibilities related to driving concrete piles include verifying that:
    a. The specified lifting points are marked.

b. The piles are lifted at lifting points.
c. Stacked piles are supported near lifting points.
d. The engineer is notified when piles are mishandled.
e. The engineer gives approval to use mishandled piles before installation.
f. The pile is equipped with correct driving shoe when necessary to guard against tip damage.
g. Splicing is done correctly and that it conforms to design and plan.
h. Spliced pile sections are aligned correctly before continued driving.
i. Warped, bent, or broken piles are rejected.
j. Tongue-and-groove interlocks on concrete sheet-piling are not chipped, cracked, or broken.
k. Sheet-piling interlocks on concrete sheet-piling are fully grouted, if required.

P. Installing Cast-in-Place Piles

1. A cast-in-place concrete pile is constructed by driving a hollow steel shell into the ground and filling it with concrete. The hollow steel tubes that form the shell are an integral part of the pile and bear a large portion of the load. Otherwise, the shell is treated as a form to hold the hole open until the concrete is in place. The shell is sometimes corrugated to increase its stiffness. When driving a corrugated shell, a heavy steel mandrel is inserted in the shell during driving to protect the shell from collapse.

2. Driving a casing for large cast-in-place piles can cause ground heaving. The QA inspector must be aware of ground heaving potential and confer with the engineer when there are potential problems related to ground heaving.

3. In some instances, the hole is not lined or cased. It is important to verify that the earth is moist, and that the integrity of the hole is maintained throughout the concrete pouring operation.

4. The approved concrete mixture must be used, and the concrete placed in the manner specified. Refer to Title 210 National Engineering Handbook, Part 645 “Construction Inspection,” Subpart L “Concrete” for details about concrete mixtures and correct placement technique.

5. Segregation of the concrete mix and poor consolidation are specific concerns when placing concrete in a tall narrow column containing steel reinforcement. Concrete must be placed through a tremie or pump hose with the outlet lowered near the bottom of the hole and risen as the concrete is deposited to limit free-fall distance and the attendant segregation.

6. The concrete mix may be designed to be self-consolidating. Self-consolidating mixtures are characterized by low coarse aggregate content, high fine aggregate and cementitious materials content, and high slump attained by the addition of a superplasticizer. If a self-consolidating concrete (SCC) mix is not used, an immersion vibrator that extends to the bottom of the hole must be used. The end of the vibrator must be lowered into the hole inside the reinforcing steel cage prior to beginning concrete placement. The vibrator

must be operated and raised as the tremie or pump-line is raised. Over-vibration is not as common as under-vibration, so the vibrator must be withdrawn slowly and remain in operation to ensure consolidation.

7. Vibrators that attach to reinforcing steel may be used if the reinforcing steel can be held firmly in place, without being displaced by the vibration. This is impossible to do if the hole is not cased, because there is no way to brace the steel against the earthen hole without collapsing or otherwise damaging the hole and having loose soil fall to the bottom of the hole.

8. Concrete mixtures can be designed with a special anti-washout admixture additive to allow the mix to hold together while being placed in water. While not common, the specifications may allow it.

9. The QA inspector's responsibilities related to installing cast-in-place concrete piles include:

   a. Checking the driven casing for ruptures and plumb before installing reinforcement or placing concrete.
   b. Checking that the driven casing is thoroughly cleaned.
   c. Checking for ground heave and conferring with the engineer when there is potential for problems related to ground heave.
   d. When a casing is not used, verifying that the earth is moist, and that the integrity of the hole is maintained throughout the concrete pouring operation.
   e. Checking the prepared pile hole before placing reinforcement to verify full dimensions and to see that no swelling or movement of the soil occurs before placing concrete.
   f. Verifying that the casing or prepared pile hole is free of water before placing concrete if the concrete mixture is not designed for placing in water.
   g. Checking to ensure that reinforcing steel is rigidly assembled, lowered into the shell or unlined hole, and adequately secured in correct position throughout the concrete placement operation.
   h. Verifying that there are no loose reinforcement bars.
   i. Checking reinforcement for cleanliness.
   j. Verifying that an approved concrete mix is used and that it conforms to specifications for temperature, slump, and air content.
   k. Verifying that concrete is correctly placed by pump or with a tremie to limit segregation potential.
   l. Verifying that concrete is placed within the allotted time.
   m. Verifying that concrete cylinders are made and handled as specified.
   n. Verifying that concrete is consolidated by a method consistent with specified requirements.
   o. Verifying that protection and curing of concrete is conducted as specified.
   p. Verifying that the specified elapsed time after placing concrete has transpired before placing a load on the pile.

Q. Installing Micropiles

1. A typical micropile installation starts by drilling a hole through the soil into rock that can provide adequate frictional bonding capacity at a certain length. Permanent steel casing pipe is advanced as the micropiles are drilled into the foundation and then pulled back to a predetermined location, so that it remains some distance into the bedrock.
2. Drilling is done with a rotary drill configured so that it can advance the casing down the hole as it drills. The rotary drill pumps air, water, or both down the hole, flushing the drill cuttings to the surface as it is advanced. For harder rock, an air-powered down-hole hammer may be needed.
3. After the hole is drilled and cleared of soil and rock tailings, steel reinforcement is installed; grout is then placed with a tremie extended to the bottom of the drill hole. As grout is placed, the tremie is extracted from the hole. The top of the pile is typically capped with a bearing plate and nut.
4. Micropiles are classified as type A through E, based on how they are grouted, as explained below:
   a. Type A—The grout is gravity-flowed through a tremie which extends to the bottom of the hole. The tremie is extracted from the hole as grout is discharged from the bottom to the surface.
   b. Type B—Neat cement grout is injected into the drill hole under pressure while withdrawing the temporary drill casing.
   c. Type C—Begins with type-A installation. After 15 to 30 minutes grout is injected through a sleeved grout pipe without a packer at pressures greater than 145 pounds per square inch (psi).
   d. Type D—Installed similarly to type C except the primary grout is given time to fully harden before grout is pumped through a sleeved grout pipe with a packer at high pressure (300 to 1,200 psi).
   e. Type E—Grout is injected through a continuously threaded hollow-core steel bar.
5. Installation of micropiles is a complex process. Previous experience is of great value in successful completion of a project. For that reason, it is common for construction specifications to require a level of demonstrated experience on similar projects. The specifications may require that the contractor possess a minimum number of years' experience in the construction and load testing of micropiles, to have successfully completed at least a specific number of projects, or both.
6. The drilling equipment and methods must be suitable for drilling through the conditions to be encountered, without causing damage to any overlying or adjacent structures or services. The drill hole must remain at the specified minimum diameter along its full length throughout the grouting operation.
7. The specifications must outline allowable construction tolerances, such as the following:
   a. Centerline of piling must not be more than three inches from the specified location.

b. The pile must be plumb within two percent of the total length of the planned alignment.
c. The top elevation of the pile must be plus one inch or minus two inches from the maximum vertical elevation indicated.
d. The centerline of the reinforcing steel must be within ½ inch of the indicated horizontal location.

8. The contractor must observe the conditions in the vicinity of the micropile construction daily for signs of ground heave or subsidence and notify the QA inspector who, in turn, must notify the responsible engineer if these conditions are observed. The contractor must immediately suspend and modify drilling or grouting operations if these conditions are observed.
9. Reinforcement may be placed either prior to grouting or placed into the grout-filled drill hole before temporary casing (if used) is withdrawn. The reinforcement surfaces must be free of deleterious substances such as soil, mud, grease, or oil that might contaminate the grout or coat the reinforcement and impair bond.
10. Centralizers and spacers are sometimes used to keep the reinforcement in the correct horizontal location. The specifications will prescribe the designated spacing and the allowable materials. Centralizers and spacers must permit the free flow of grout without misalignment of the reinforcing bar and permanent casing. The reinforcing steel must be inserted into the drill hole to the desired depth without having to be driven or forced into the hole. The contractor must redrill the hole if the reinforcing steel cannot easily be inserted.
11. The specifications will require the micropiles to be grouted the same day they are drilled. Grout admixtures, if allowed, must be mixed in accordance with manufacturer's recommendations. The grouting equipment must produce a well-blended grout, free of lumps and undispersed cement.
12. For pressure grouting operations, the contractor must have means and methods of measuring the grout quantity and pumping pressure. The grout pump must be equipped with a pressure gauge to monitor grout pressures, with a second pressure gauge at the point of injection into the pile top. The pressure gauges must be capable of measuring pressures of at least 100 psi or twice the actual grout pressures used, whichever is greater.
13. The grout must be kept in agitation prior to placement. Grout must be placed within one hour of mixing. The grouting equipment must be sized to enable each pile to be grouted in one continuous operation. The grout must be injected from the lowest point of the drill hole, and injection must continue until uncontaminated grout flows from the top of the pile.
14. The grout may be pumped through grout tubes, casing, hollow-stem augers, or drill rods. Temporary casing, if used, must be extracted in stages, ensuring that, after each length of casing is removed, the grout level is brought back up to the ground level before the next length is removed. The tremie pipe or casing must always extend below the level of the existing grout in the drill

hole. The grout pressures and grout takes must be controlled to prevent excessive heave or fracturing of rock or soil formations. Upon completion of grouting, the grout tube may remain in the hole but must be filled with grout.

15. The QA inspector's responsibilities related to micropile installation include checking to verify that:

    a. The contractor has proven the specified minimum experience.
    b. The specified minimum hole diameter is maintained throughout the grouting operation.
    c. The centerline of the piling is where specified.
    d. The pile is plumb to the degree specified.
    e. The top elevation is within the allowable tolerance.
    f. There are no observable signs of ground heave or subsidence.
    g. The reinforcing steel surface is free of deleterious substances such as soil, mud, grease, or oil.
    h. The reinforcing steel is inserted to the desired depth without difficulty and not driven or forced.
    i. Holes are redrilled if necessary to allow easy reinforcing steel insertion.
    j. Centralizers or spacers, if used, are of allowable materials and spaced correctly.
    k. Centralizers or spacers keep the reinforcement in place without restricting the flow of grout.
    l. The horizontal position of the reinforcing steel is within allowable tolerance.
    m. Micropiles are grouted the same day the holes are drilled.
    n. The approved grout is used.
    o. The grout is well blended and free of lumps and undispersed cement.
    p. The grouting equipment has the required pressure monitoring gauges.
    q. The grouting pressure (if required) meets specification requirements.
    r. The grout is kept in agitation prior to placement.
    s. The grout is placed within one hour of mixing.
    t. Each micropile is grouted in one continuous operation.
    u. The tremie pipe or casing always extends below the level of the existing grout.
    v. Grout pressures are controlled to prevent excessive heave or fracturing of rock or soil formations.

R. Driving Vinyl, FRP, and Aluminum Sheet Piles

1. Vinyl, FRP, and aluminum piles and sheet piles are driven using similar equipment and methods as steel piling. Not being as rigid as steel, vinyl materials tend to bend and wander more than steel. Problems arise in stiff clay soils and soils containing rock inclusions and hard layers. Therefore, soil borings are needed to determine if these polymer materials can be installed and used for the intended purpose.

2. Sheet piles made of polymer materials such as PVC or FRP must be installed carefully. When driving PVC materials in stiff clays or dense sands, a steel

mandrel is often driven with the pile and extracted upon completion of driving. The purpose of the mandrel is to support the pile only during driving. Figure 645R-29 shows a steel mandrel used to drive vinyl sheet piling with a vibratory hammer. The mandrel must be the same shape as the pile and must remain in intimate contact with the pile as it is being driven.

3. Unlike PVC, FRP is strong enough to be driven without a mandrel. This allows FRP to be driven with much less energy than PVC with a mandrel, because the thickness of the mandrel makes it hard to drive. Additionally, FRP acts more like steel in terms of maintaining the interlock between piles. Historically, PVC sheet piling interlock is difficult to maintain.
4. As with other types of sheet piling, it is important that the first pile be driven plumb, oriented with the specified alignment, and in the specified location. Every tenth pile must be checked to verify location, alignment, and plumb. If needed, adjustments must be made gradually to bring the string of piling back into alignment and plumb. A guide form, such as that seen at ground-level in figure 645R-29, is helpful to keep the piles aligned.
5. The clutch of the pile being driven must match that of the adjoining pile, and adjoining piles must remain interlocked throughout the driving process. If the interlock is broken, the pile being driven must be extracted, reconnected to the adjacent pile, and redriven.

Figure 645R-29. Installation of Vinyl Sheet Pile with Mandrel (Wolf Remediation, Ltd.)

6. Polymer materials are spliced by heat-bond butt-welding the ends of the piles. Aluminum is spliced by welding or mechanical coupling. Spliced sheet piles must be oriented so that the splice of one pile is not aligned with that of the sheet on either side to which it is adjoined.
7. In sands and gravels, the preferred method of driving is with a vibrating hammer. Jetting may be added if allowed by the specification. A vibrating hammer or a combination of vibration and impact may also work in clay soils.
8. Horizontal walers connected to soldier piles (see figure 645R-30) or anchored to earthfill behind the sheet-pile wall are often used to support piles. If the piling is to be supported by walers, they must be attached to allow the piling to expand and contract independent of the walers. The walers must be located at the specified elevation or height. All walers and connectors must be of the approved materials and installed as specified.

Figure 645R-30. Vinyl Sheet Pile with Walers and Soldier Piles

9. The QA inspector's responsibilities related to driving vinyl or FRP sheet-piling are to verify that:
   a. Guide form alignment is accurate.
   b. Location, alignment, and plumb of initial pile are accurate.
   c. Every tenth sheet pile is checked for alignment, location, and plumb.
   d. Each clutch matches and interlocks with the adjacent pile.

e. Driving operations do not rupture interlock.
f. Piling is supported by a mandrel when necessary to prevent damage to the pile when driving.
g. Splices are staggered.
h. Sheet-piling is left slightly higher than cutoff elevation.
i. Walers are installed as specified at the specified elevation with the specified hardware.
j. Waler installation will allow expansion and contraction of sheet-piling.

645.182 Sampling and Testing

A. Test Pile Driving

1. A test pile is driven to judge the adequacy of the planned pile driving operation. By driving one or more test piles, the pile materials, pile driving equipment, and other aspects of the operation can be refined before mobilizing the remaining equipment and materials to complete the job.
2. The designer or contractor may decide to drive test piles. If test piles are specified, the contractor must follow the specified requirements. Otherwise, the contractor may decide that driving a test pile or two would provide valuable information that might result in changes to the planned operation. If the contractor makes the determination that test piles are necessary, specific requirements for driving the test piles would be left up to the contractor. In either case, driving test piles is beneficial to help avoid the mobilization of inadequate equipment or materials.
3. The test consists of comparing penetration rates with geologic information to determine if design assumptions were correct. This helps verify the planned equipment and materials are adequate for the job.
4. Test piles must be driven without the use of jets if possible.

B. Load Testing

1. Load testing piles consists of applying an incremental load, usually twice the design load, and leaving this load in place for a specified time. The pile is considered to have a bearing capacity equal to or exceeding the design load if the permanent settlement after testing does not exceed a specified amount. Test loads of sand, steel ingots, or concrete can be set directly on the exposed pile butt or be placed on a rigid platform resting on the butt. Test loads can also be applied by jacks between the pile butt and a beam anchored to piles on either side.
2. Pile load tests may be conducted for vertically loaded piles in accordance with ASTM D1143 "Standard Test Methods for Deep Foundations Under Static Axial Compressive Load," or for laterally loaded piles, ASTM D3966 "Standard Test Methods for Deep Foundations Under Lateral Load." The procedure and performance required for load tests must be specified in the piling construction specification. Document the process, test, and results.

3. Tensile tests (figure 645R-31), compression tests, or both can be performed to verify the capacity of micropiles.

Figure 645R-31. Micropile Tensile Load Test (NRCS-OK)

645.183 Records and Reports

A. Daily Diary Entries

1. Daily diary entries must record the type, number, and length of piles driven, the driving operations, and other descriptions of the work performed. The QA inspector must note any checklist items that required intervention. Appendix C contains a sample entry for pile driving construction inspection.

B. Master Plan and Pile Schedule

1. It is important to prepare a master plan showing the location of each pile in the structure. A pile schedule must accompany the plan so that the type, size, and length of each pile shown on the plan can be referenced to the pile schedule. The design engineer may prepare the master plan and schedule or require this of the contractor. The actual work must be cross-checked with this plan throughout the job. The pile number is recorded in the pile-driving record exactly as shown on the plan and schedule. Changes to the plan and schedule must be clearly identified and made a part of the as-built plans.

C. Pile-Driving Record Using a Field Notebook

1. Sample notes for pile driving are provided in appendix D to illustrate how a field notebook can be set up for recording pile driving data. One field book or section of a specific field book is used to keep a continuous record of all pile driving operations for a given structure or job. The notebook headings must be compatible with the heading shown on worksheet 645 WS R.1.

D. Pile Driving Record Using 645 WS R.1

1. Worksheet 645 WS R.1, “Pile Driving Record,” may be used in lieu of the field notebook. An example of a completed 645 WS R.1 is provided in appendix B. If the worksheet is used, any sketches needed to describe the location and approximate dimensions of the driving site can be drawn on the back of the worksheet, included in a field notebook, or attached on a separate sheet of paper. Make sure sketches are kept with or cross-referenced to the worksheet so that they can be easily accessed when reviewing the worksheet.

645.184 References

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