Chapter 18  Piling
In accordance with Federal civil rights law and U.S. Department of Agriculture (USDA) civil rights regulations and policies, the USDA, its Agencies, offices, and employees, and institutions participating in or administering USDA programs are prohibited from discriminating based on race, color, national origin, religion, sex, gender identity (including gender expression), sexual orientation, disability, age, marital status, family/parental status, income derived from a public assistance program, political beliefs, or reprisal or retaliation for prior civil rights activity, in any program or activity conducted or funded by USDA (not all bases apply to all programs). Remedies and complaint filing deadlines vary by program or incident.

Persons with disabilities who require alternative means of communication for program information (e.g., Braille, large print, audiotape, American Sign Language, etc.) should contact the responsible Agency or USDA's TARGET Center at (202) 720-2600 (voice and TTY) or contact USDA through the Federal Relay Service at (800) 877-8339. Additionally, program information may be made available in languages other than English.

To file a program discrimination complaint, complete the USDA Program Discrimination Complaint Form, AD-3027, found online at How to File a Program Discrimination Complaint and at any USDA office or write a letter addressed to USDA and provide in the letter all of the information requested in the form. To request a copy of the complaint form, call (866) 632-9992. Submit your completed form or letter to USDA by: (1) mail: U.S. Department of Agriculture, Office of the Assistant Secretary for Civil Rights, 1400 Independence Avenue, SW, Washington, D.C. 20250-9410; (2) fax: (202) 690-7442; or (3) email: program.intake@usda.gov.

USDA is an equal opportunity provider, employer, and lender.
Table of Contents

645.1800 Introduction................................................................................................................................. 3
645.1801 Installation........................................................................................................................................ 3
   A. Materials ................................................................................................................................................. 3
   B. Steel and Aluminum Pile Materials ......................................................................................................... 3
   C. Wooden Pile Materials .......................................................................................................................... 6
   D. Precast Concrete Pile Materials .............................................................................................................. 9
   E. Cast-in-place Concrete Pile Materials ..................................................................................................... 10
   F. Micropile Materials ............................................................................................................................... 11
   G. Vinyl, Fiber Reinforced Polymer, Fiberglass, and Composite Pile Materials ........................................ 14
   H. Handling and Storage of Piles ................................................................................................................. 15
   I. Pile Driving Equipment .......................................................................................................................... 16
   J. Determining Bearing Capacity ................................................................................................................. 23
   K. Preparing to Install Piling ....................................................................................................................... 24
   L. Driving ................................................................................................................................................... 26
   M. Driving Steel Piles .................................................................................................................................. 30
   N. Driving Wooden Piles ............................................................................................................................ 33
   O. Driving Concrete Piles ............................................................................................................................ 34
   P. Installing Cast-In-Place Piles .................................................................................................................. 35
   Q. Installing Micropiles ............................................................................................................................... 36
   R. Driving Vinyl, Fiber-Reinforced Polymer, And Aluminum Sheet Piles ................................................ 38
645.1802 Sampling and Testing ..................................................................................................................... 40
   A. Test Pile Driving ...................................................................................................................................... 40
   B. Load testing.............................................................................................................................................. 41
645.1803 Records and Reports ....................................................................................................................... 41
   A. Daily Diary Entries ................................................................................................................................. 41
   B. Master Plan and Pile Schedule ............................................................................................................... 41
   C. Pile-Driving Record Using a Field Notebook ......................................................................................... 42
   D. Pile Driving Record Using 645 WS 18.1 ................................................................................................. 42
645.1804 References ..................................................................................................................................... 42

Table of Figures

Figure 18-1: Common Steel Bearing Pile Shapes ......................................................................................... 4
Figure 18-2: Butt of Pile Reinforced With Extra Steel ................................................................................... 4
Figure 18-3: Typical Steel Sheet-Piling ........................................................................................................... 5
Figure 18-4: Typical Aluminum Sheet-Piling .................................................................................................. 5
Figure 18-5: Timber Piles With Steel Points on the Tips .............................................................................. 6
Figure 18-6: Wooden Sheet-Piling ................................................................................................................ 7
Figure 18-7: Common Defects That Must be Rejected ................................................................................. 8
Figure 18-8: A Band Properly Affixed to the Butt of a Pile ....................................................................... 8
Figure 18-9: Typical Pile Brand ................................................................................................................... 8
Figure 18-10: Typical Micropile .................................................................................................................. 12
Figure 18-11: Typical Micropile Detail ......................................................................................................... 12
Figure 18-12: Micropile Casing .................................................................................................................. 13
Figure 18-13: Reinforcing Bar Tag ........................................................................................................... 13

Figure 18-14: Threaded Coupler ................................................................. 14
Figure 18-15: FRP Composite Piling Products ........................................ 14
Figure 18-16: Fixed-Lead Driver ............................................................. 16
Figure 18-17: Swinging-Lead Driver ..................................................... 17
Figure 18-18: Fixed-Lead Driver Configured to Drive Battered Piles ....... 17
Figure 18-19: Drive Cap System ............................................................. 18
Figure 18-20: Typical Pile Driving Rig With a Follower ...................... 19
Figure 18-21: Drop Hammer ............................................................... 20
Figure 18-22: Diesel Hammer ............................................................. 20
Figure 18-23: Vibratory Hammer ......................................................... 22
Figure 18-24: Pile Driving Template .................................................... 27
Figure 18-25: Wooden Piles Damaged During Driving ....................... 28
Figure 18-26: Winged Pile ................................................................. 30
Figure 18-27: Sheet-Piling Clutch with Male Interlock Leading .......... 32
Figure 18-28: Steel Sheet Piling With Bracing .................................... 33
Figure 18-29: Vinyl Sheet Pile and Mandrel ....................................... 39
Figure 18-30: Vinyl Sheet Pile With Walers and Soldier Piles .......... 40
Figure 18-31: Micropile Tensile Load Test ....................................... 41
645.1800 Introduction

Piles are structural members driven into the ground. Bearing piles support loads and sheet piles are installed as a seepage barrier, retaining wall, or flood wall. Bearing piles can be either end bearing or friction piles. An end-bearing pile is a pile that is driven until its tip meets firm resistance from subsurface rock, dense sand, or gravel. The “tip” of the pile is the end driven into the ground. The other end is called the “butt.” A friction pile is a pile that, when driven into softer material without penetrating a firm bearing layer, will still develop considerable load-carrying capacity through the frictional resistance between the sides of the pile and the surrounding soil. Sheet-piling is used to reduce the lateral movement of water or to prevent the movement of adjacent soil material, or both. Sheet-piling consists of vertical planks of wood, steel, precast concrete, vinyl, or fiber-reinforced polymer. The planks are placed tightly against one another, or interlocked with each other, and driven into the earth to form a solid wall.

645.1801 Installation

A. Materials

(1) Piles are made of wood, concrete, steel, poly vinyl chloride (PVC), fiber reinforced polymer (FRP), or a combination of steel and concrete. The type, quality, and quantity of piles, fasteners, and other related items should be listed on the drawings and in the specifications. The contractor should submit to the responsible engineer proof or certification that the piles and related materials comply with specification requirements. Upon delivery to the site, the inspector should check to see that the delivered materials are those represented by the contractor’s submittal and approved by the responsible engineer. Pile lengths should be printed on the piles near the butt. Piles designated to be driven in specific locations should have a location identifier painted on them.

(i) Verifying the piles are checked as delivered and marked unacceptable if applicable.
(ii) Verifying pile dimensions and markings are checked.
(iii) Verifying pile lengths are marked near the butt.
(iv) Verifying pile materials comply with specifications for the type of materials.
(v) Verifying piles designated for specific locations have the location printed near the butt.
(vi) Studying manufacturer’s brochures or pamphlets to become familiar with recommended methods of handling, inspecting, and driving.
(vii) Verifying butts are flat, smooth, and perpendicular to the long axis.
(viii) Verifying the specified type and quantity of fasteners and related items are delivered prior to beginning installation.

B. Steel and Aluminum Pile Materials

(1) Steel and aluminum piles come in various grades and shapes. Contractor material submittals should certify or provide proof, as applicable, that the pile materials to be used are of the grades, shapes, and dimensions called for in the drawings and specifications.

(2) Sheet pile currently produced in the United States usually meets ASTM A328, which has a yield strength of 39 KSI, or ASTM A572, which has yield strength ranging from 50 KSI to 65 KSI. There is also a corrosion-resistant steel grade meeting ASTM A690, which has a yield strength of 50 KSI. Contractor material submittals should include mill certificates verifying that the steel conforms to the specified ASTM standard.
(3) Occasionally suppliers will construct piles from several short lengths in order to make use of scrap pieces. Although piles are spliced in the field as they are driven, splices should be held to a minimum and piles made from several short pieces should be rejected.

(4) Steel bearing piles include H-shapes, I-shapes, and cylindrical shapes. Steel pipe and railroad rails are also used for bearing piles. The shape of a steel member refers to the shape of the cross-section of the member and is typically designated by a letter, or letters, a depth dimension, and a unit weight dimension. For example, “HP14x117” denotes 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. Several common shapes of steel bearing piles are shown in figure 18-1.

**Figure 18-1: Common Steel Bearing Pile Shapes**

![Diagram of steel pile shapes](image)

(5) The butt of the steel-pile should 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 18-2. 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 18-2: Butt of Pile Reinforced With Extra Steel**

![Diagram of butt reinforcement](image)
Steel and aluminum sheet piles are manufactured in special shapes and have interlocking edges called clutches to connect piles side-by-side. Clutches may be hot-rolled or cold-rolled. Hot-rolled clutches are usually stronger, but specifications typically allow either type. The inspector must check sheet pile materials as they are delivered to verify that the clutches are shaped as specified or otherwise approved and are not damaged or deformed in a manner that would prevent interlock. Several common shapes of steel sheet piles are shown in figure 18-3 and aluminum sheet piles are shown in figure 18-4.

Figure 18-3: Typical Steel Sheet-Piling

Figure 18-4: Typical Aluminum Sheet-Piling

The inspector’s responsibilities related to steel and aluminum pile materials include verifying materials are checked when delivered to verify—

(i) They are the approved grade and type.
(ii) Length, diameter or cross-sectional dimensions, weight and type of piles conform to specifications and approved submittals.
(iii) Surface condition and condition of interlocks conform to drawings and specifications.
(iv) The condition of tip and butt reinforcing or shaping is as specified or noted on approved submittals.
(v) Bent or damaged flanges are rejected or properly repaired.
(vi) Defective rivets or welds are rejected or repaired.
(vii) Splices, if allowed, exhibit good fit and quality workmanship.
(viii) Piles made from short pieces are rejected.
(ix) Sheet-piling clutch shape and dimensions provide for a relatively tight interlock.
(x) Clutches are not damaged or deformed so as to prevent interlocking.
C. Wooden Pile Materials

(1) Wooden (a.k.a. timber piles) are cut from straight, sound trees that are free of large or loose knots and other defects that would impair strength or durability. Douglas fir, yellow pine, redwood, southern cypress, and similar species are commonly used for wooden piles. Trees used for wooden piles should be uniformly tapered from butt to tip. Wooden piles must 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 should be cut when the sap is down (generally during the winter) and peeled soon after cutting. Figure 18-5 shows a set of timber piles.

**Figure 18-5: Timber Piles With Steel Points on the Tips**

(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 that have 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 that makes it fairly watertight if the piles are tightly fitted together. Figure 18-6 shows the butt-ended, butt-ended with tongue and groove, splint-fastened, and Wakefield sheet-piling configurations.
Figure 18-6: Wooden Sheet-Piling

(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 are commonly used to protect wooden piles from deterioration. The pressure treating industry has 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 salt water applications and since many timber piles are installed in salt water, these preservatives cannot be used. Copper chromated arsenate (CCA) is the most prevalent preservative used to treat Southern Pine marine piling. Creosote is also used. For Douglas fir piling, ammoniacal zinc arsenate (ACZA), which was formulated years ago to treat Douglas fir, and creosote are used in the West for foundation piling.

(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 should be checked to verify that they meet the project specifications. The entire length of the pile should be inspected to verify full and even coverage of the preservative.

(6) Piles that are treated with preservatives should be handled without contact with the skin. Care should 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 inspector should 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 should conform to the quality requirements specified. They should be free of decay, knots, splits, shakes, checks, crooks and bends. Examples of defects that must be rejected are shown in figure 18-7.
(9) Some wooden piles have steel shoes, or points on the tip of the pile as seen in figure 18-5 and steel bands around the butt of the pile as shown in figure 18-8. These may arrive on the job attached to the pile or be installed on the job. Points should be firmly affixed, and bands should fit tightly around the butt of the pile.

Figure 18-8: A Band Properly Affixed to the Butt of a Pile

(10) Each treated wooden item delivered to the job site should be marked as specified. As a minimum the markings should show the type and amount of preservative applied to the wood. Piles are typically branded with a brand similar to that shown in figure 18-9. Industry standards require the brand to be located in two places, five feet and 10 feet from the butt of the pile.

Figure 18-9: Typical Pile Brand

ABCOD07SPC22530
Supplier’s BrandYear of Treatment or Year and MonthSpecies of Timber and PreservativeRetention (pcf)Length (ft)

(11) All of the bark should be removed from the pile before it is treated with preservative. Upon delivery, treated piles should contain no bark. If bark remains on the pile, it should be removed and
the area that was covered by the bark should 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 inspector’s responsibilities related to wooden pile materials include verifying—
   (i) Approved type of materials is delivered.
   (ii) Each pile is straight and properly dimensioned.
   (iii) Wood is free of decay, knots, splits, shakes, checks, crooks and bends.
   (iv) Tips and butts are properly prepared for driving.
   (v) The wood is marked, as specified, to indicate that the specified type and amount of preservative has been applied.
   (vi) All bark has been removed.
   (vii) Damaged treated piling is rejected.
   (viii) All cuts and breaks are treated with the specified type and amount of preservative.
   (ix) 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 often 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 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 inspector should 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 fork lift 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 casted. 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. In order for the pile to drive true, the top surface must be finished to a uniform texture similar to 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 should 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 or, if a pile is stacked with other piles, it may only be possible to read the markings on the tapered end.

(6) Lifting points should be painted on each pile. This will help prevent damage to the pile during handling and storage. Also, cables and straps should be configured to allow the weight of the pile to be evenly distributed between all lifting points.

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

(8) When tasked with inspecting the casting operations, the inspector’s responsibilities related to precast concrete pile casting includes verifying—

(i) Reinforcement is free from rust and scale and is properly positioned.

(ii) Casting floor is level, flat, and firm.

(iii) Pallet boards are of sufficient width to allow piles to be moved without damage.

(iv) All cut ends of reinforcing tie wire are turned away from form surface.

(v) All inside surfaces of forms are smooth and clean.

(vi) Chamfer strips (if required or otherwise used) are in place and firmly attached to form.

(vii) Bracing and blocking between and around each piling are firm.

(viii) Forms are level, straight, and watertight.

(ix) Concrete mix conforms to the approved mix design.

(x) Concrete meets specified requirements for air, slump, and temperature.

(xi) Concrete mix w/cm does not exceed the maximum stated in the approved mix design.

(xii) Concrete placing is continuous from start to finish to avoid cold joints.

(xiii) Top surface is leveled and finished to a uniform texture similar to that produced by the forms.

(xiv) Concrete is cured as specified.

(xv) Each pile is stamped or marked near butt and tip to indicate length and manufacture date.

(xvi) Lifting points are painted on each pile.

(xvii) Handling of pile is not permitted until the required strength has been attained.

(xviii) Lifting cables are provided with a device to equalize the pull at all lifting points.

(9) The inspector’s responsibilities related to delivery of precast concrete piles include checking materials upon site delivery to verify—

(i) For sheet-piling, tongue-and-groove interlocks are not chipped, cracked, or broken.

(ii) Compressive strength test results show piles attained specified strength before moving.

(iii) Piles are undamaged.

(iv) Piles are of uniform shape, true, and straight.

(v) Lifting cables are provided with some device to equalize the pull at all lifting points.

(vi) Warped, bent, or broken piles are rejected.

(vii) Piles are stored so that moving is minimized to limit damage potential.

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 should be marked to indicate that they conform to specification requirements.

(2) The inspector should 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 proper location throughout the concrete placement and consolidation operation.

(3) The concrete mix must be the approved mix and 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 (645-18-H, 1st Ed., Amend. 84, Oct 2018)
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 likely be necessary. The outlet end of the tremie or pump hose should 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 superplasticized concrete mix is used.

(5) Unless self-consolidating concrete (SCC) is used, an internal immersion vibrator that will reach to the bottom of the hole is required. The vibrator should 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 should be vibrated a bit longer than normal to ensure it is well consolidated. Over-vibration is generally 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 is characterized by a limited amount of coarse aggregate, a high percentage of fine aggregate, and a relatively low water-cementitious materials ratio along with a superplasticizer to increase slump. SCC does not require vibration; it consolidates on its own incidental to placement.

(7) The inspector’s responsibilities related to cast-in-place concrete pile materials include checking materials upon site delivery to verify—

(i) Casings are marked or otherwise identified to conform with drawings and specifications and approved contractor material submittal documents.
(ii) Reinforcing steel bundles are tagged and free from flaking rust.
(iii) Reinforcing steel conforms to drawings, specifications, and approved contractor material submittal documents.
(iv) Reinforcing steel is secured in place so that it remains in position as concrete is poured and consolidated.
(v) Reinforcing steel is clean and free of oil or other bond breaking substances.
(vi) The hole or casing is clean and free of standing water, debris, and soil.
(vii) Concrete mix conforms to the approved mix design.
(viii) Concrete meets specified requirements for air, slump, and temperature.
(ix) Compressive strength cylinders are made to document strength.
(x) 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.
(xi) 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 commonly used as deep foundation support for structural concrete elements. They are an alternative to conventional piling techniques and often chosen for areas with limited access. 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 (figure 18-10).
Figure 18-10: Typical Micropile

(4) As with other piling systems, a detailed geologic investigation is required prior to design of a micropile system. 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. Figure 18-11 shows a detailed drawing of a typical micropile.

Figure 18-11: Typical Micropile Detail

(5) Micropile casing must be of adequate type and thickness to withstand the stress of advancing it into the foundation (figure 18-12). It also must have the specified diameter. It will either be welded or have threaded joints. The specifications should outline the required welding procedure for any welded joints.
Figure 18-12: Micropile Casing

(6) Reinforcing bars must be the correct size and grade. They should be delivered in bundles and tagged. The tag information should include size and grade (figure 18-13).

Figure 18-13: Reinforcing Bar Tag

(7) The bars are commonly threaded at the top to accept a bearing plate and nut and can be spliced together with threaded couplers similar to the one seen in figure 18-14. The size and grade of the bearing plate must be as specified.
(8) The grout will be 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 should be submitted and approved by the responsible engineer.

(9) The inspector’s responsibilities related to micropile materials include checking to verify—
   (i) The casing pipe is of the correct diameter, wall thickness, and grade.
   (ii) The correct welding procedure is used for welded joints of casing pipe.
   (iii) For threaded joints of casing pipe, the threads are complete and undamaged.
   (iv) Reinforcing steel is of the correct size and grade.
   (v) The correct length of reinforcing steel is used in each micropile.
   (vi) The size and grade of the bearing plate is correct.
   (vii) All nuts and couplers are of the correct size and material.
   (viii) The approved grout mix is used.

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

(1) Vinyl sheet-piling and fiber reinforced polymer (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. Some of these are depicted in figure 18-15.

**Figure 18-14: Threaded Coupler**

![Threaded Coupler](image)

**Figure 18-15: FRP Composite Piling Products**

- Steel Core Piling
- Reinforced Plastic Piling
- Concrete-Filled Fiberglass Pipe Piling
- Plastic Lumber

(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 (HDPE) plastic matrix reinforced with fiberglass or steel rods. Additives are used to improve mechanical properties, durability, and ultraviolet (UV) 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 1 ½ 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, 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. There are a variety of structural members that 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 inspector’s responsibilities related to vinyl, FRP, fiberglass, and composite pile materials include verifying—
   (i) Materials conform to specified grade and type.
   (ii) Materials conform to approved submittals.
   (iii) Length, diameter or cross-sectional dimensions, weight, and type of piles conform to specifications and approved submittals.
   (iv) Surface condition conforms to material specifications.
   (v) The condition of tip and butt reinforcing or shaping is as specified or noted on approved submittals.
   (vi) Bent or damaged sections are rejected or properly repaired.

H. Handling and Storage of Piles

(1) Handling piles can be very hazardous. They must be unloaded in a safe manner that avoids damaging them. A crane should be used for unloading and stacking piles. Piles should 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) will hold 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 being used, piles that will be needed first should be stored where they can be retrieved without having to move other piles. Piles should 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 should be kept clean, dry, and organized so that they are readily available for use as needed.

(6) The inspector’s responsibilities related to handling and storage of pile materials include verifying—

   (i) Safe storage and handling methods are employed.
   (ii) Materials are not damaged in storage or by handling.
   (iii) Overhead utilities are avoided.
   (iv) Marked lifting points are used.
   (v) Piles are blocked and braced to avoid falling or rolling.
   (vi) Precast concrete piles are supported on blocks located at lifting points.
   (vii) Pile stack is orderly to avoid unnecessary moving or lifting of piles until they are needed.
   (viii) 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 18-16.

Figure 18-16: Fixed-Lead 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 guide the hammer as it travels up and down within the leads. Leads are either fixed, as shown in figure 18-16, or swinging, as shown in figure 18-17.
(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 be used on land or 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 18-18.

(6) A key component of a pile driver is the drive cap system. A drive cap system, such as the one in figure 18-19, 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. There are various drive cap systems available.
Figure 18-19: 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, with use it will become compressed and ineffective at softening the blows. Ineffective cushioning material, an improperly sized drive cap insert, or poorly fitted and misaligned drive cap components can cause damage to the hammer, pile, or both.

(8) The selected cushioning material must be of the proper 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 should 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. A typical pile driving rig with a follower is shown in figure 18-20. A follower is usually a section of pipe, or “H” pile, with connections that match both the drive cap system and the pile.
(10) Since the follower may absorb some of the energy of the hammer, the first pile in any location should be driven without the use of a follower so as to be able to make comparisons with operations that use a follower. In water, the first pile to be driven should be one sufficiently long 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 should 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, as the follower will likely reduce the efficiency of the pile driver. Underwater hammers and extensions to the leads can be used as 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 18-21 shows a typical drop hammer.
Figure 18-21: Drop Hammer

(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. An example of a power-driven hammer is the diesel hammer in figure 18-22.

Figure 18-22: Diesel Hammer
In addition to diesel, steam and compressed air are also used to power hammers. There are many factors that decrease efficiency of these hammers, including wear, improper 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 should comply with the manufacturer’s specifications. If any power-driven hammer does not operate properly, it should be shut down until adjusted or repaired.

Where steam or compressed air is used, a boiler inspection certificate and other safety items may be required to conform to safety regulations.

Single-acting hammers, often called Vulcan hammers, differ from drop hammers only in that the ram is raised by air or steam power rather than by a winch and cable. The ram or hammer falls by gravity. The striking parts of these hammers usually weigh approximately 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. Improper setting permits air or steam to enter the lower side of the cylinder, act as a cushion, and prevent a complete down-stroke. Improper setting can also cause the valve to cut off too soon, resulting in a short upstroke of the hammer.

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. Uniform pressure is required to ensure the rated capacity is achieved. The intake valve setting and the condition of the rings and cylinder walls directly affect the impact of the hammer.

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 desirable because of its compactness and simplicity. However, diesel hammers are noisier than other hammers, they tend to spew diesel-laden smoke, and they are often difficult to start.

Unlike hammers that are powered by air or steam, a diesel hammer is not self-starting. It must be raised and dropped to get it started and often requires some adjustment and several attempts before it will start.

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 is being driven, the stroke will increase 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.

Diesel hammers may be open-end or closed-end. Open-end hammers are single-acting. A closed-end hammer contains a bounce chamber at the upper end of the cylinder which effectively makes it a double-acting hammer. A closed-end hammer stroke is shorter than an open-end hammer stroke but it operates with more blows per minute than the open-end diesel hammer.

Vibratory hammers are used to extract and drive piles. They are most effective in granular soils, but they 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 (figure 18-23). As a result of this vibration, the soil next to the pile is mobilized causing it to liquefy. Soil in this state will not support the weight of the pile and hammer. Thus the pile is driven into the soil. Also, soil in this liquefied state offers little resistance from friction on the pile, so a vibrating pile can be easily lifted. Vibratory hammers come in various sizes. The larger, heavier hammers must be used when driving or extracting heavy piles.
Figure 18-23: Vibratory hammer

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 should be used. Only enough jetting should 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. The technique should only be used when allowed by the specifications or approved by the engineer.

The inspector’s responsibilities related to pile driving equipment include—
(i) Obtaining and studying the brochure printed by the hammer manufacturer in order to learn hammer capabilities and limitations.
(ii) Verifying the pile driving equipment is stable and of adequate capacity to lift the pile and to control both the pile and hammer during the driving.
(iii) Verifying the contractor possesses current boiler inspection certificate and other safety requirements where steam or compressed air is used.
(iv) Verifying that the drive cap system allows the energy from the hammer to be efficiently transmitted to the pile without damaging it.
(v) Verifying the cushioning material is of the proper strength, properly sized, and placed with the grain vertical.
(vi) Verifying the cushioning material is replaced when compressed to one-half its original size or when it begins to smoke.
(vii) Verifying the followers are used only when approved.
(viii) Verifying that double-acting hammers are operating at manufacturer’s rated speeds.
(ix) Verifying that the condition of the hammer is being checked for wear, improper adjustment, poor lubrication, long hose lengths, leaks, and drops in steam or air pressure.
(x) Verifying the water jetting equipment is of the type recommended for the soil.
(xi) Verifying that water flow is properly regulated.
(xii) Verifying that water jetting is not used for driving piles in coarse gravels.

J. Determining Bearing Capacity

(1) Bearing pile specifications require 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 will greatly increase. Continued driving after the bottom of the pile has reached the supporting strata is considered overdriving which may result in damage to the pile. Regardless of whether the pile is an end-bearing or friction pile, overdriving can damage piles and should 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 will be specified as a basis for determining the bearing capacity of each pile. NRCS Construction Specification 13, Piling (CS 13), 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, the Engineering News formula\(^1\) is preferred by NRCS to determine the bearing capacity of friction piles whenever the formula method is specified. This formula has three forms—

(i) For gravity (drop) hammers:
\[
R = \frac{2WH}{(S + 1.0)}
\]

(ii) For single-acting hammers:
\[
R = \frac{2WH}{(S + 0.1)}
\]

(iii) For double-acting hammers:
\[
R = \frac{2H(W + (A \times P))}{(S + 0.1)} \text{ or } R = \frac{2E}{(S + 0.1)}
\]

Where—

\[
\begin{align*}
R &= \text{Bearing capacity, in pounds or tons} \\
W &= \text{Weight of the striking parts of the hammer, in pounds or tons} \\
H &= \text{Height of fall (stroke), in feet} \\
A &= \text{Area of piston, in square inches} \\
P &= \text{Pressure of steam or air exerted on the hammer piston or ram, in pounds per square inch} \\
E &= \text{The manufacturer’s rating for foot pounds of energy developed by double-acting hammers, or 90 percent of the average equivalent energy, in foot-pounds, developed by diesel hammers with enclosed rams as evaluated by gauge and chart readings} \\
S &= \text{Average rate of penetration for the last 5 to 10 blows of a gravity hammer or the last 10 to 20 blows for steam, air, or diesel-powered hammers, in inches per blow}
\end{align*}
\]

(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—

(i) For gravity (drop) hammers:
\[
S = (2WH / R) - 1.0
\]

(ii) For single-acting hammers:
\[
S = (2WH / R) - 0.1
\]

(iii) For double-acting hammers:
\[
S = [2H(W + (A \times P)) / R] - 0.1 \text{ or } S = (2E / R) - 0.1
\]

\(^1\) Originally published in 1888 in Engineering News, 20:50-512. The formula has since been shown and discussed in many engineering textbooks.
(6) As an example, consider a pile with a required bearing capacity (R) of 70 tons being driven by a W=10-ton gravity hammer with a drop height (H) of 6 feet. S = \((2 \times 10 \times 6 / 70) - 1.0 = 0.71\) inches per blow. For this example, whenever the rate of penetration averages 0.71 inches per blow for the last 5 to 10 blows of the hammer, the required bearing capacity has been attained. Continued driving would be considered overdriving and should not be allowed.

(7) These formulas only apply when—
(i) The hammer falls freely.
(ii) The head of the pile is not crushed.
(iii) Penetration is reasonably quick and uniform.
(iv) A follower is not used.

(8) If there is hammer-bounce after the blow, twice the height of the bounce must be deducted from “H” to determine its value in the formula. If the hammer in the above problem bounced up one foot after impacting the drive-cap system, H would be reduced by 2 feet resulting in S being reduced to 0.14 inches per blow.

(9) 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 18.1 in appendix B can be used for this purpose.

(10) The inspector’s responsibilities related to verifying bearing capacity is attained include—
(i) Verifying that end-bearing piles are driven to the specified supporting strata, but not overdriven as to damage the pile.
(ii) Documenting test pile loading results whenever the test-pile method is used.
(iii) Documenting that all friction piles are driven to the depths determined from test-pile loading whenever the test-pile method is used.
(iv) Verifying that the required bearing capacity (R) is attained for each pile driven whenever the formula method is used by verifying—
- The hammer falls freely.
- The head of the pile is not crushed.
- Penetration is reasonably quick and uniform.
- A follower is not used.
- “H” is reduced by twice the amount of any after-blow bounce.
- The proper bearing capacity formula is used.
(v) Documenting all field driving data and bearing capacity calculations.

K. Preparing to Install Piling

(1) It is desirable to drive individual piles in one continuous operation. Any interruption should be brief so that the pile is not allowed to remain at one elevation for any length of time before driving is completed. Otherwise, the soil will tend to settle and pack around the pile resulting in harder driving than if the pile had been driven in one continuous operation. Interruptions can be avoided with proper planning and preparation.

(2) Where several piles are to be driven, a master plan and schedule showing the location of each pile relative to the structure should be provided in the design or required of the contractor. The schedule should 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 should be approved and on site in good working order prior to lifting the first pile into driving position.

(4) Sheet-piling is sometimes driven before all excavation is completed, but all excavation within the area to be occupied by bearing piles should be completed prior to driving. This is especially important for friction piles.

(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 should never be driven within 20 feet of concrete that is less than 7-days old. This includes concrete in cast-in-place piles with or without pre-driven shells or casings.

6. Potential damage from ground heave and vibration may adversely affect overhead utility poles, towers, and other supports. The danger of working around overhead power lines with driving equipment cannot be overstated. Utility owners should 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. It is important that the inspector review the specification requirements prior to driving and obtain any information needed to verify that the piles are—
   (i) Not overdriven as to damage the pile.
   (ii) Driven to the minimum specified depth.
   (iii) 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, it is rare to drive a pile in the same location where a boring was made. Thus, 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 should cease to avoid overdriving and damaging the pile. The average penetration per number of blows can be determined using the bearing capacity formula (see the previous section entitled “Determining Bearing Capacity”). In preparation for driving, the inspector should 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 should cease whenever the rate of penetration indicates that bearing strength has been attained according to the bearing formula. For end bearing piles, driving should cease whenever the rate of penetration slows to refusal. The inspector should 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 generally causes damage to the pile that may be difficult to detect if the damaged portion is not visible. The inspector must be aware of signs that point to overdriving and verify that it is avoided, but that the required bearing capacity is achieved. Prior to beginning the driving operation, it is advisable to check boring logs to get a feel for the 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 the pile lengths shown on the pile schedule be compared to that expected based on the boring logs. If possible, these test piles should 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. Load tests are often specified to verify that bearing piles will support the intended load. The inspector must be familiar with the specified requirements, such as the amount of test load to be applied, when the test can be started after the pile is driven, rate of loading, the frequency and accuracy at which settlement must be measured, and the length of time the load must remain on the pile to complete the test.

15. The inspector’s responsibilities when preparing to install piles are—
(i) Verifying coordination with utility company if utilities are present.

(ii) Reviewing 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.

(iii) Determining if piles are to be driven to refusal, a specified depth, or a bearing capacity based on specified formula.

(iv) Checking boring logs to have some idea of the driving resistances and types of materials to be expected.

(v) Verifying that all excavation within the area to be occupied by bearing piles is complete before driving begins.

(vi) Verifying piles are not driven within 20 feet of concrete less than seven days old.

(vii) Verifying that the pile locations marked conform to drawings and pile driving plan.

(viii) Verifying length and size of each pile is checked against plan and schedule.

(ix) Verifying boiler certificate is obtained from contractor if steam is to be used.

(x) Verifying engineer approval of jetting where jetting is planned.

(xi) Verifying that piles or leads are marked so that the penetration depth and rate can be determined quickly.

(xii) Verifying the accuracy of pile schedule and lengths by—

- Driving several piles adjacent to or at boring locations,
- Noting blows per foot of penetration, and
- Comparing driving resistance with that anticipated from boring logs.

(xiii) Verifying all equipment for performing required load tests, if applicable, is on site in working order prior to installing test piles.

L. Driving

(1) The process of pile driving can best be described by example. The following is an example of the process used to install steel piles.

(i) Mark the pile location correctly at the site.

(ii) If necessary, excavate the soil at the pile location to remove shallow obstructions, and then backfill.

(iii) Set up the pile driver.

(iv) Erect and drive the bottom section of pile into the ground.

(v) Extend the pile if necessary by welding on an additional section after the previous section has been installed.

(vi) Use a spirit level to periodically check and adjust the pile so that it remains plumb.

(vii) Continue driving until the pile has been driven to final depth.

(viii) Where the cutoff level is deep, use a follower to drive the pile to final depth.

(ix) If obstructions are found during pile driving, 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, the hammer, or both the pile and hammer. The pile driver must be securely anchored to avoid a shift in position. If the hammer shifts while driving, the blow of the hammer will be out of line with the axis of the pile and both the pile and hammer may be damaged.

(3) Pile drivers are typically equipped with leads, but there are drivers that are designed to operate without leads. A template like the one in figure 18-24 is a structure used for guiding piles that are 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.
(4) Piling tends to creep or move out of alignment during driving. To combat this tendency, the first pile should 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 should 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 should only be used when specified or approved by the engineer. The depth of jetting should be limited so that a portion of the pile is driven after jetting ceases. After all jetting in the immediate area ceases, friction piles should be redriven (retapped) to verify bearing capacity. End-bearing piles should also be retapped to verify that they have not been disturbed by jetting and are still resting on the bearing strata.

(7) Driving piles will result in ground vibration. The amount of ground vibration will depend on the resistance to driving and the driving effort. 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 that may occur due to vibration energy that is transferred to the structure. Vibration could cause damage to plumbing, windows, window seals, etc. Notify the responsible engineer of vibration-related 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 18-25 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 properly 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.

(9) An experienced inspector who studies the boring logs and observes the reaction of the pile during driving can make sound deductions about the material being penetrated and the condition of the pile during and after driving. The ground surface and the in-place piling should be observed for heaving. A bouncing hammer or kicking pile usually indicates refusal; if driving is continued, it 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 has not been squared off properly, or when the pile is not in line with the fall of the hammer. In all pile-driving operations, the fall of the hammer must be 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. However, it usually occurs when the butt of the pile has been crushed, when the pile has met an obstruction, or when the pile has penetrated to a solid footing. When a double-acting hammer is used, bouncing may result from too much steam or air pressure.

(11) Whenever the formula method is specified for determining bearing capacity, it is important that the pile driver be in good condition and the ram operating at full stroke, rated speed, and under the full recommended pressure. The movement of the hammer must be aligned with the axis of the pile. Cushioning materials must provide protection to the butt of the pile without absorbing too much energy. These materials become compressed and lose their ability to protect the butt of the pile; they must be replaced often. When piles are driven in groups or clusters, driving the inner piles last can force the outer piles out of alignment and reduce their bearing capacity.

(12) The inspector’s responsibilities related to driving piles include—
(i) Verifying proper handling of piles and insisting that lifting points be used.
(ii) Verifying that piles are installed at planned location and driven vertically, or if battered, on the axis they are to follow.
(iii) Verifying diameter and depth of pilot holes meets specifications and pile driving plan.
(iv) Verifying sequence of driving conforms to plan.
(v) Verifying that, where friction piles are clustered together, inner piles are driven first.
(vi) Recording penetration of pile immediately after setting and prior to driving.
(vii) Verifying hammer is centered over the pile.
(viii) When a template or timber bracing is used for guiding piles, checking for sturdiness and elevation.
(ix) Checking 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.

(x) If jetting is used, verifying—
- Existing structures are not being damaged.
- Previously driven piles are not being loosened.
- Depth of jetting does not exceed permitted depth.
- Pile remains plumb.
- Piles are retapped after jetting in the area is completed.

(xi) Verifying that pile driving is terminated if it becomes apparent that ground vibration may cause damage to adjacent structures.

(xii) Notifying engineer of ground vibration concerns.

(xiii) Checking the behavior of the pile during driving by—
- Comparing hardness of driving at various depths against that expected from boring logs.
- Watching for changes which indicate broken piles, obstructions, or driving irregularities.
- Checking when piles are driven in groups or clusters for heaving of the ground around the piles.

(xiv) Verifying that pile driving is terminated if observed ground heave could damage any structure.

(xv) Notifying engineer of heaving concerns.

(xvi) Checking uplift on piles by measuring pile grade immediately after installation and recheck later.

(xvii) Verifying that each pile is driven to the specified minimum depth.

(xviii) Verifying that end bearing piles are driven to the specified supporting strata by checking depths against boring logs.

(xix) Notifying 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.

(xx) When driving to refusal, verifying 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.

(xxi) Whenever the formula method is specified—
- Verifying the ram (hammer) is operating at full stroke, rated speed, and under full manufacturer-recommended pressure.
- Checking any evidence of reduced hammer speed.
- Verifying cushioning materials conform to resistance formula requirement.
- Verifying the recording of readings taken immediately after resumption of driving.
- Verifying that driving ceases when the average penetration (S) equals the value obtained by the bearing capacity formula.
- Verifying the required bearing capacity (R) is attained for each pile driven.

(xxii) To prevent overdriving—
- Verifying that contractor avoids overdriving when specific depths of penetration are unattainable due to some unforeseen underground condition.
- Observing sound and any vibration of the pile during driving for evidence of overdriving.
- Watching for indications of overdriving, such as bouncing of hammer; apparent loss of energy; bending, kinking, or butt damage of the pile, etc.
- Checking for signs of worn out or insufficient cushioning material during driving.
- If allowed by specifications, pulling an occasional pile to check for damage from overdriving.

(xxiii) Checking workmanship, materials, and line and grade of completed work.

(xxiv) Verifying permissible tolerances in alignment, plumbing, and grade are maintained.

(xxv) Verifying driving of each pile is continuous until required depth or penetration is attained.

(xxvi) If driving is suspended, noting the tip grade at the time of the suspension and the duration of the delay.

(xxvii) Verifying approval is obtained for relocation of piles or driving additional piles.
(xxviii) Notifying engineer of deviations from pile schedule.

M. Driving Steel Piles

(1) The great strength of steel combined with a small displacement of soil permits most of the energy from a hammer to be transmitted to the bottom of a pile. In spite of the great strength of these piles, sometimes it is necessary to drill pilot holes ahead of steel piles to obtain the specified penetration. By weld-splicing sections together, lengths in excess of 200 feet can be driven.

(2) H-piles and I-piles do not displace as much soil as do 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 the need of predrilling, thereby reducing the risk of excessive vibrations from drilling which might cause settlement of adjacent structures.

(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 commonly used to penetrate resistant layers and withstand hard driving.

(4) When large pile groups are to be driven at close spacing in granular soils, vibration from driving will result in compaction of 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 18-26). These short lengths of steel are designed to act as a footing to provide end bearing strength in sand.

Figure 18-26: Winged Pile

(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 can be 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 are manufactured in sizes from 1 to 6 feet outside diameter, and with wall thickness ranging from 1/4-inch to 1 inch. Hollow steel piles with thicker walls can be manufactured for increased strength or when corrosion is a concern.

(7) Hollow steel piles are typically filled with concrete after driving. Soil and debris must be removed from inside the tube before the concrete is placed. Water must be removed from inside the tube before the concrete is placed 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 should consist of a thicker wall 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 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 of steel tube piles is less likely. However, it should be assumed that in most soils the end will plug, thus, ground heave should be expected. Ground heave can be reduced by jetting, by predrilling (soil loosening), or precoring (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 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, known as 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. In this way a continuous wall is driven 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 consisting of a C-shaped (female) interlock on one side that gets clogged with soil as the sheet pile is being driven. Whenever possible, the sheets should be driven with the male interlock leading as seen in figure 18-27 to avoid soil plugging the female interlock. If the female interlock must lead, a bolt or other object may be inserted in the bottom of the female interlock to prevent filling with soil or the bottom of the female interlock could be crimped.
(16) It is necessary to drive sheet-piling within or against some type of guide frame or template. Horizontal templates at two levels are recommended 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 should be provided on both sides of the piling. The templates or guides must be close enough to the sheet-piling to provide the support needed for proper 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. Having the hammer be too heavy is more critical in driving lightweight sheets because of the increased danger of damage to the piling. A light single or double-acting hammer is usually adequate when driving one sheet at a time. A heavier hammer may be needed to drive more than one sheet at a time or for driving in highly resistant soil. 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. A rapid driving action is desirable for sand and gravel conditions. A heavier hammer and a slower driving action are usually required for clay soils. 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 be made to fit the shape of the piling and must 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 tend to draw adjacent piling out of line and out of plumb. Therefore, continual gradual adjustments to line and plumb must be made to avoid abrupt changes. As a general rule, every tenth piling should 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 whalers, tiebacks, and bracing where applicable (figure 18-28). Whalers should be installed in a manner that will allow the wall to expand and contract independent of the whaler. Anchors and tiebacks, if required, must be properly located and installed to prevent misalignment or failure of the structure. Bracing may be installed for rigidity. Bolting, welding, and deadman installation must be inspected to be sure that the structure is completed as shown on the drawings.
Figure 18-28 Steel Sheet Piling With Bracing

(21) A sheet-piling wall is typically capped with concrete, steel, or wood. All bracing, welding, walers, paint, etc. should be installed and inspected prior to installing the wall cap.

(22) The inspector’s responsibilities related to driving steel piles are to verify—
(i) Stiffening plates are installed on H or I-piles if required.
(ii) Wings are installed on wing piles.
(iii) Stiffening ring or steel shoe is installed on hollow steel piles where required or needed.
(iv) External stiffening rings are not used on friction bearing piles.
(v) Ends of hollow steel piles are closed when specified.
(vi) Insides of open-ended piles are cleaned of soil, water, and debris before filling with concrete.
(vii) Damaged butts are cut off.
(viii) The number of splices per pile are limited.
(ix) Cutoff elevations are within allowable tolerances.
(x) For sheet pile, interlocking groove (clutch) matches with adjacent sheet.
(xi) Guide form is accurately located and secured.
(xii) Initial pile is accurately located, aligned, and plumbed.
(xiii) Driving operations do not rupture sheet pile interlock.
(xiv) Splices are staggered.
(xv) Handling and pulling holes are provided if needed.
(xvi) Sheet-piling is left slightly higher than cutoff elevation.
(xvii) Every tenth sheet pile is pinned to prevent “walking” and to maintain plumb.
(xviii) Whaler installation will allow expansion and contraction of sheet-piling.
(xix) Caps are not placed on sheet-piling before bracing, welding, etc. is completed.

N. Driving Wooden Piles

(1) Wooden (timber) piles are typically installed using small hammers (1000 to 1500 pounds) to avoid splitting the piles. The butt of a pile should 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 should be fitted to protect the point of the pile during driving, unless the driving is wholly in soft soils.

(2) In easy driving conditions, the weight of the hammer should not be less than half the weight of the pile. In hard driving conditions, the hammer should 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 should 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 of the butt. Permanent softwood piles should be cut off below the lowest anticipated ground water level.

(4) Wakefield piling (refer to figure 18-6) is usually fabricated on site. The inspector must verify use of approved materials including grade and size of lumber, and size and length of nails, spikes or bolts used to fabricate the piling. Ensure that tongue-and-groove dimensions and nailing or fastening provide for a secure tight fit.

(5) The inspector’s responsibilities related to driving wooden piles include verifying—

(i) Use of tight steel or iron bands around butt.
(ii) The butt is recut to remove unsound material.
(iii) Pile length will allow for cutting off the butt.
(iv) Holes in treated piles are filled with hot creosote or other approved material and, where not used, tightly closed by a treated plug.
(v) Holes are not bored nor spikes driven to support scaffolding in treated piles.
(vi) Shoes are used where needed.
(vii) Painting of piles conforms to specified requirements.
(viii) Only approved materials are used for Wakefield piling.
(ix) For Wakefield piling, tongue-and-groove dimensions and nailing or fastening provide for 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. Precast concrete piles are commonly manufactured with square cross-sections ranging from about 10 to 18 inches across, with a maximum length of 60 feet. 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 can be produced either in the factory or on site. The quality of the pile is very much affected by the production process.

(2) Precast piles are most susceptible to damage when handling. Lifting points need to be specified by the designer or manufacturer and marked on the pile. The 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 may occur to a concrete pile and not be visible to the naked eye. Incidences of improper storage or handling should be reported to the responsible engineer. Piles that are improperly stored or handled should not be used until they have been cleared for use by the engineer.

(4) The length of pile sections is often dictated by practical considerations including 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. Good alignment of the pile sections is required to prevent excessive bending stresses at the joint during driving. Piles can also be 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 are more resistant to damage caused by mishandling and poor driving technique than nonprestressed concrete piles. However, they are more vulnerable to damage from striking obstructions during driving. They are also difficult to cut after installation, and special techniques have to be employed. 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 usually carried out 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 amount of boulders. Hard steel points (driving shoes) should be affixed to the tip of prestressed piles for protection when penetrating boulder-laden soils or weak rock.

(8) The inspector’s responsibilities related to driving concrete piles include—

(i) Verifying that specified lifting points are marked.
(ii) Verifying the piles are lifted at lifting points.
(iii) Verifying that stacked piles are supported near lifting points.
(iv) Notifying the engineer of mishandling.
(v) Obtaining approval from the engineer to use mishandled piles before installing them.
(vi) Verifying the pile is equipped with proper driving shoe when necessary to guard against tip damage.
(vii) Verifying provisions are made for proper splicing and that splicing conforms to design and plan.
(viii) Verifying good alignment of spliced pile sections before continued driving.
(ix) Verifying that warped, bent, or broken piles are rejected.
(x) For concrete sheet-piling, verifying tongue-and-groove interlocks are not chipped, cracked or broken.
(xi) For concrete sheet-piling, verifying sheet-piling interlocks are fully grouted, if required.

P. Installing Cast-in-Place Piles

(1) A cast-in-place concrete pile is typically constructed by driving a hollow steel shell into the ground and filling it with concrete. Hollow steel tubes that are used to form the shell are typically an integral part of the pile and bear a large portion of the load. Otherwise, the shell is treated as a form to hold open the hole 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 typically 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 inspector should 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 chapter 12 for details about concrete mixtures and proper 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 should 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 relatively low coarse aggregate content, relatively 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 will extend to the bottom of the hole must be used. The end of the vibrator should be lowered into the hole inside the reinforcing steel cage prior to beginning concrete placement. The vibrator should be operated and raised as the tremie or pump-line is raised. Overvibration is not as common as undervibration, so the vibrator should 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 nearly 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 additive (antiwashout admixture) to allow the mix to hold together while being placed in water. While not common, this may be allowed by the specification.

(9) The inspector’s responsibilities related to installing cast-in-place concrete piles include—
   (i) Checking the driven casing for ruptures and plumb before installing reinforcement or placing concrete.
   (ii) Checking that the driven casing is thoroughly cleaned.
   (iii) Checking for ground heave and conferring with the engineer when there is potential for problems related to ground heave.
   (iv) 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.
   (v) 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.
   (vi) Verifying the casing or prepared pile hole is free of water before placing concrete if the concrete mixture is not designed for placing in water.
   (vii) Checking to ensure that reinforcing steel is rigidly assembled, lowered into the shell or unlined hole, and adequately secured in proper position throughout the concrete placement operation.
   (viii) Verifying there are no loose reinforcement bars.
   (ix) Checking reinforcement for cleanliness.
   (x) Verifying an approved concrete mix is used and it conforms to specifications for temperature, slump, and air content.
   (xi) Verifying concrete is properly placed with by pump or with a tremie to limit segregation potential.
   (xii) Verifying that concrete is placed within the allotted time.
   (xiii) Verifying concrete cylinders are made and handled as specified.
   (xiv) Verifying concrete is consolidated by a method consistent with specified requirements.
   (xv) Verifying protection and curing of concrete is conducted as specified.
   (xvi) Verifying 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 capable of providing 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 usually accomplished using 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:
   (i) 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.
   (ii) Type B.—Neat cement grout is injected into the drill hole under pressure while withdrawing the temporary drill casing.
   (iii) Type C.—begins with type-A installation. After several minutes (typically 15 to 30 minutes) grout is injected through a sleeved grout pipe without a packer at pressures greater than 145 psi.
   (iv) Type D.—Installed in a similar manner to type C except that 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 1200 psi).

(v) 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 should outline allowable construction tolerances, such as the following:
   (i) Centerline of piling must not be more than 3 inches from the specified location.
   (ii) The pile must be plumb within 2 percent of the total length of the planned alignment.
   (iii) The top elevation of the pile must be plus 1 inch or minus 2 inches from the maximum vertical elevation indicated.
   (iv) 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 on a daily basis for signs of ground heave or subsidence and notify the inspector who, in turn, should 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 proper 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 likely require that the micropiles be grouted the same day that 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 1 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 inspector’s responsibilities related to micropile installation include checking to verify—

(i) The contractor has proven the specified minimum experience.
(ii) The specified minimum hole diameter is maintained throughout the grouting operation.
(iii) The centerline of the piling is where specified.
(iv) The pile is plumb to the degree specified.
(v) The top elevation is within the allowable tolerance.
(vi) There are no observable signs of ground heave or subsidence.
(vii) The reinforcing steel surface is free of deleterious substances such as soil, mud, grease, or oil.
(viii) The reinforcing steel is inserted to the desire depth without difficulty and not driven or forced.
(ix) Holes are redrilled if necessary to allow the reinforcing steel to be inserted with ease.
(x) Centralizers or spacers, if used, are of allowable materials and spaced correctly.
(xi) Centralizers or spacers keep the reinforcement in place without restricting the flow of grout.
(xii) The horizontal position of the reinforcing steel is within allowable tolerance.
(xiii) Micropiles are grouted the same day the holes are drilled.
(xiv) The approved grout is used.
(xv) The grout is well blended and free of lumps and undispersed cement.
(xvi) The grouting equipment has the required pressure monitoring gauges.
(xvii) The grouting pressure (if required) meets specification requirements.
(xviii) The grout is kept in agitation prior to placement.
(xix) The grout is placed within one hour of mixing.
(xx) Each micropile is grouted in one continuous operation.
(xxi) The tremie pipe or casing always extends below the level of the existing grout.
(xxii) Grout pressures are controlled to prevent excessive heave or fracturing of rock or soil formations.

R. Driving Vinyl, Fiber-Reinforced Polymer, and Aluminum Sheet Piles

(1) Vinyl, fiber reinforced polymer (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) Special care is required to install sheet piles made of polymer materials such as PVC or FRP. 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 18-29 shows a steel mandrel (green) used when driving vinyl sheet piling with a vibratory hammer. It is important that the shape of the mandrel be the same as the shape of the pile and that it remain in intimate contact with the pile at all times as the pile is being driven.

(3) Unlike PVC, FRP is strong enough that it most often can be driven without a mandrel. This allows FRP to be driven with much less driving energy than it takes to drive PVC with a mandrel because the thickness of the mandrel makes it hard to drive. Additionally, FRP acts more like steel when it comes to maintaining the interlock between piles. Historically, PVC sheet piling interlock has been 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 should 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 18-29 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.
Polymer materials are spliced by heat-bond butt-welding the ends of the piles. Aluminum may be spliced by welding or mechanical coupling. Sheet piles that are spliced should 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.

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.

Often, piles will be supported by horizontal walers that are connected to soldier piles as seen in figure 18-30 or that are anchored to the earthfill behind the sheet-pile wall. If the piling is to be supported by walers, these must be attached so as 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.
(9) The inspector’s responsibilities related to driving vinyl or FRP sheet-piling are to verify—
   (i) The accuracy of guide form alignment.
   (ii) The accurate location, alignment, and plumb of initial pile.
   (iii) That every tenth sheet pile is checked for alignment, location, and plumb.
   (iv) Each clutch matches and interlocks with the adjacent pile.
   (v) Driving operations do not rupture interlock.
   (vi) Piling is supported by a mandrel when necessary to prevent damage to the pile when driving.
   (vii) Splices are staggered.
   (viii) Sheet-piling is left slightly higher than cutoff elevation.
   (ix) Walers are installed as specified at the specified elevation with the specified hardware.
   (x) Whaler installation will allow expansion and contraction of sheet-piling.

645.1802 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 needed to complete the job.
   (2) The decision to drive test piles may be made by the designer or the contractor. 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 is done to verify that planned equipment and materials are adequate to do the job.

(4) Test piles should be driven without the use of jets if possible.

B. Load Testing

(1) Load testing of 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 when load tests are to be made should be specified in the piling construction specification. The process actually used to test load the piles, and the results, should be well documented.

(3) Tensile tests (figure 18-31), compression tests, or both can be performed to verify the capacity of micropiles.

Figure 18-31: Micropile Tensile Load Test

645.1803 Records and Reports

A. Daily Diary Entries

Daily diary entries should record the type, number, and length of piles driven, the driving operations, and other descriptions of the work performed. Checklist items that require the QA inspector’s intervention should be noted. Appendix C contains a sample entry for pile driving construction inspection.

B. Master Plan and Pile Schedule

It is important to prepare a master plan showing the location of each pile in the structure. A pile schedule should 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 should be clearly identified and made a part of the as-built plans.

C. Pile-Driving Record Using a Field Notebook

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 headings in the notebook should be compatible with the heading shown on worksheet 645 WS 18.1.

D. Pile Driving Record Using 645 WS 18.1

Worksheet 645 WS 18.1, “Pile Driving Record,” may be used in lieu of the field notebook. An example of a completed 645 WS 18.1 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.

645.1804 References


B. California Foundation Manual, State of California Department of Transportation Engineering Service Center Division of Structures, July 1997


