PIP STE02465
Augered Cast-in-Place Piles Design Guide
PURPOSE AND USE OF PROCESS INDUSTRY PRACTICES

In an effort to minimize the cost of process industry facilities, this Practice has been prepared from the technical requirements in the existing standards of major industrial users, contractors, or standards organizations. By harmonizing these technical requirements into a single set of Practices, administrative, application, and engineering costs to both the purchaser and the manufacturer should be reduced. While this Practice is expected to incorporate the majority of requirements of most users, individual applications may involve requirements that will be appended to and take precedence over this Practice. Determinations concerning fitness for purpose and particular matters or application of the Practice to particular project or engineering situations should not be made solely on information contained in these materials. The use of trade names from time to time should not be viewed as an expression of preference but rather recognized as normal usage in the trade. Other brands having the same specifications are equally correct and may be substituted for those named. All Practices or guidelines are intended to be consistent with applicable laws and regulations including OSHA requirements. To the extent these Practices or guidelines should conflict with OSHA or other applicable laws or regulations, such laws or regulations must be followed. Consult an appropriate professional before applying or acting on any material contained in or suggested by the Practice.

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# PIP STE02465
## Augered Cast-in-Place Piles Design Guide

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1. **Scope**

This Practice complements *PIP STS02465* and assists the engineer in preparation of contract documents for furnishing and installing augered cast-in-place (ACIP) piles.

This Practice is modeled on *DFI TM-ACIP-4* (Augered Cast-in-Place Piles Manual). For additional information, refer to that manual, *FHWA-HIF-07-03* (Geotechnical Engineering Circular No. 8), *DFI TM-ACIP-2* (Augered Cast-in-Place Piles Inspector’s Guide), and *DFI TM-ACIP-3* (Guideline for Interpretation of Nondestructive Integrity Testing of Augered Cast-in-Place and Drilled Displacement Piles).

2. **References**

Applicable parts of the following Practices, industry codes and standards, and other references shall be considered an integral part of this Practice. The edition in effect on the date of contract award shall be used, except as otherwise noted. Short titles are used herein where appropriate.

2.1 **Process Industry Practices (PIP)**

- PIP STS02465 - Augered Cast-in-Place Piles Installation Specification
- PIP STS03001 - Plain and Reinforced Concrete Specification

2.2 **Industry Codes and Standards**

- American Concrete Institute (ACI)
  - ACI 212.3R - Report on Chemical Admixtures for Concrete
  - ACI 301 - Specifications for Structural Concrete
  - ACI 301M - Specifications for Structural Concrete (Metric)
- American Society of Civil Engineers (ASCE)
  - ASCE/SEI 7 - Minimum Design Loads and Associated Criteria for Buildings and Other Structures
- ASTM International (ASTM)
  - ASTM A615/A615M - Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement
  - ASTM A706/A706M - Standard Specification for Deformed and Plain Low-Alloy Steel Bars for Concrete Reinforcement
  - ASTM A722/A722M - Standard Specification for High-Strength Steel Bars for Prestressed Concrete
  - ASTM D6760 - Standard Test Method for Integrity Testing of Concrete Deep Foundations by Ultrasonic Crosshole Testing
- ASTM D7949 - *Standard Test Methods for Thermal Integrity Profiling of Concrete Deep Foundations*

- **Deep Foundations Institute (DFI)**
  - TM-ACIP-2 - *Augered Cast-in-Place Piles Inspector’s Guide*
  - TM-ACIP-3 - *Guideline for Interpretation of Nondestructive Integrity Testing of Augered Cast-in-Place and Drilled Displacement Piles*
  - TM-ACIP-4 - *Augered Cast-in-Place Piles Manual*

- **Federal Highway Administration (FHWA)**
  - FHWA-HIF-07-03 - *Geotechnical Engineering Circular No. 8 – Design and Construction of Continuous Flight Auger (CFA) Piles*

### 2.3 Technical Papers


### 3. Definitions

**constructor:** Party responsible for supplying materials, equipment, tools, supervision, and labor for installation of ACIP piles in accordance with contract documents. The term constructor applies also to constructor’s subcontractor(s) and vendor(s).

**contract documents:** Any and all documents, including codes, studies, design drawings, specifications, sketches, practices, and data sheets, that purchaser or engineer of record has transmitted or otherwise communicated, either by incorporation or reference, and made part of the legal contract agreement or purchase order between purchaser and constructor.

**engineer of record:** Purchaser’s authorized representative with overall authority and responsibility for engineering design, quality, and performance of civil works, structure, foundations, materials, and appurtenances described in contract documents. Engineer of record is licensed as defined by laws of the locality in which the work is to be constructed and is qualified to practice in the specialty discipline required for the work described in contract documents.

**geotechnical engineer:** Professional engineer responsible for performing geotechnical investigation and/or geotechnical consulting during foundation design, construction of civil works, installation of piling and foundations.

**owner:** Party who has authority through ownership, lease, or other legal agreement over site, facility, structure or project wherein ACIP piles will be installed.

**professional engineer:** A licensed engineer, other than engineer of record, qualified to practice in the specialty discipline required for the work described in contract documents.

**purchaser:** Party who awards contract to constructor. Purchaser may be owner or owner’s authorized agent.

**qualified geotechnical representative:** Graduate geotechnical engineer, graduate geologist, or geotechnical technician, provided technician has at least ten years of relevant field exploration and
logging experience and works under supervision of geotechnical engineer. Geotechnical engineer may also fulfill this role.

**Quality Assurance (QA) representative:** Party retained by purchaser responsible for review of submissions by QC inspector as well as direct observation of the work. Role may be fulfilled by qualified geotechnical representative or geotechnical engineer.

**Quality Control (QC) inspector:** Party responsible for verifying quality of all materials, installations, and workmanship furnished by constructor. QC inspector is qualified by training and experience and holds certifications or documentation of their qualifications. Unless otherwise specified in contract documents, QC inspector is an independent party retained by constructor.

4. **General**

4.1 **System Description**

4.1.1 ACIP piles are installed using a continuous flight auger with a hollow stem. During the drilling phase, the flights are filled with soil, maintaining the stability of the hole. When the design depth is reached, grout or concrete is forced down the hollow stem as the auger is gradually withdrawn.

4.1.2 Reinforcing is installed in the fluid grout or concrete immediately after removal of the auger; commonly the cage is installed only to partial depth for constructability reasons, as required by design for bending. Typically, a single center bar is installed full depth at the pile centerline. This single bar is often sufficient for uplift and provides some physical verification of pile continuity to design depth.

4.1.3 ACIP piles typically have diameters from 12 to 36 inches (300 to 900 mm) and lengths commonly up to 100 ft (30 m). Whereas in the past ACIP piles have been commonly used in relatively small sizes and depths, the trend is towards higher capacities, with 24 inch (600 mm) up to 42 inch (1100 mm) diameters and depths as great as 100 ft (30 m) or occasionally up to 150 ft (45 m). European practice has included up to 60 inch (1500 mm) diameter piles. Aspect (depth:diameter) ratios of more than 30 are considered to require extra care, though there have been successful installations with aspect ratios of 50 or more.

4.1.4 Compared with drilled shafts, ACIP piles offer potential advantages of faster cycle times. In ideal cohesive soil, either system would work well but ACIP piles should have a faster cycle time. Where soil conditions would require casings for drilled shafts, there is a greater potential ACIP piles have time and cost advantages. In some soils, the pressure injection of the grout may provide somewhat greater pile load capacity compared to a similar size drilled shaft. Compared with driven piles, ACIP piles have the advantage in noise and vibration where these are considerations.

4.1.5 The main disadvantage of ACIP piles is that the result is highly dependent on operator skill. In addition, it is most critical that the correct equipment is used with sufficient downward thrust (“crowd”), power and torque as needed for the pile size and geotechnical conditions. It is very critical that “soil mining” due to excessive rotation without sufficient corresponding auger penetration be avoided. ACIP pile systems cannot readily be used either in very soft and organic soils or
in mixed soil with cobbles and boulders; however, ACIP piles have been used in soft rock and weathered limestone.

4.1.6 Where clearances are limited, a variation of the ACIP piles system is low-headroom equipment. In this system, segmental augers are used. It can be competitive with micropiles, particularly to resist higher shear and bending loads. Size and depth of piles may be limited both by clearance considerations and by the size and power of the drilling equipment.

4.1.7 A variation of ACIP piles are drilled displacement (DD) piles together with hybrid systems called partial displacement piles. In these systems, the drilling tool is designed to force all or part of the soil outward, compressing the soil. These systems may offer particular advantages in sands and average to weak soil conditions. For a given size, depth and soil, DD systems require more crowd, power and torque than conventional systems. DD piles are often used in weaker soil and to depths that are more limited. For a given size, depth and soil, DD piles may develop greater capacities and will reduce or eliminate spoils. Most systems of drilled displacement or partial displacement piles include proprietary technology. See Table 6.1 in FHWA-HIF-07-03 for comparisons of relatively favorable and unfavorable conditions for various deep foundation types.

4.1.8 For DD piles see further discussion in Section 5.1 and 6.1 below regarding modifications (overlays) needed in order to use PIP STS02465.

4.2 Design of ACIP Piles

For convenience in following sections of this Guide, where comparisons are made between DD piles and conventional ACIP piles, the latter will be referred to as continuous flight auger (CFA) piles.

4.2.1 Capacity of an ACIP pile, like that of other deep foundations, includes side friction and end bearing components. In general the compression capacity of ACIP piles for a given geometry and soil will fall between that of a drilled shaft and a driven pile, with CFA piles closer in capacity to drilled shafts and DD piles closer to driven piles. Pile testing should provide load-strain curves defining displacement as a function of load.

4.2.2 ACIP piles have uplift and lateral capacity similar to that of drilled shafts. However there may be practical limitations on the quantity of reinforcing bars that can successfully be placed in ACIP piles. CFA piles are subject to the same group effect considerations (both vertical and lateral) as drilled shafts; DD piles may achieve somewhat increased axial capacities when installed in groups.

4.2.3 Engineers are directed to FHWA-HIF-07-03 for a comprehensive review of design methods for ACIP piles. This reference also provides a basis for preliminary estimation of capacity for conventional ACIP piles and DD piles in both cohesive and cohesionless subgrade material. Estimated capacities may be calculated from geotechnical data such as standard penetration tests (SPT) or cone penetrometer tests (CPT).

4.2.4 Geotechnical engineer normally determines minimum grout volume for soil stratigraphy. Typically, a minimum of 115% of theoretical grout volume is placed in each increment of pile. In some very stiff soils or soft rock, unit volume could be reduced to as little as 100%. In soft soils or soils with voids, unit grout
volume can be significantly larger. In some instances, grout head can exceed the shear capacity of soil resulting in very large grout unit volumes. In such instances, ACIP piles may not be suitable.

4.2.5 Design loads for ACIP piles should be determined in accordance with minimum load requirements described in *ASCE/SEI 7*. As for some other types of deep foundations installed through unconsolidated material, downdrag may be a load consideration.

4.2.6 Reinforcing

4.2.6.1 Normally, ACIP piles are reinforced only as required for compression, bending and uplift. Geotechnical engineer should provide p-y analysis for piles subject to bending. Piles subject to uplift often have a single full-length reinforcing bar. See *ASCE/SEI 7* for instances where full-length reinforcing cages are required in high seismic areas.

4.2.6.2 Typically, *ASTM A615/A615M* Grade 60 (420) reinforcing bars should be used. If reinforcing bars need to be welded, then *ASTM A706/A706M* Grade 60 (420) reinforcing bars should be used.

4.2.6.3 *ASTM A722/A722M* reinforcing bars should be used if high-strength is required.

4.2.6.4 Typically, ACIP pile reinforcing steel cages are designed using bars of the same length. Ideally, cages should be kept to 15 to 25 ft (4.5 to 8 m). Shortening the reinforcing steel cage to this length can help reduce construction problems and increase pile installation rates.

4.2.6.5 Cage design should consider the need for grout to freely flow between the bars. Multi-layer cages are very difficult to install and pose significant risk of defects in the form of voids between bars due to bridging of the grout or concrete. Consider using larger diameter piles with single-layer cages composed of larger diameter bars.

4.2.6.6 Normally reinforcing cover is 3 inches (75 mm), though larger cover could be considered if necessitated by poor soil conditions.

4.2.6.7 Reinforcing cages longer than 20 to 25 ft (6 to 8 m) and multi-layered cages can be difficult or impossible to install properly. If longer cages are required, structural engineer and geotechnical engineer should review the soil profile and revise minimum grout quantity and diameter to ensure proper placement.

4.2.6.8 Sufficient spacing should be provided between reinforcing bars to permit free flow of grout. If reinforcing spacing is less than five times the maximum diameter of (concrete) aggregate, bar size should be adjusted, or a larger diameter pile should be specified.

4.2.6.9 Tension piles typically use a single full-length reinforcement bar.

4.2.6.10 Longitudinal reinforcement and spiral confining steel (or suitable alternative reinforcement) can be used to withstand seismic pile-soil interaction loading/distortion conditions, particularly if these piles derive a significant share of their support in end bearing resistance during and immediately after a major earthquake.
4.2.6.11 Cage design should facilitate installation of full-length cages (e.g., bending reinforcement bars inward at bottom of cage to reduce likelihood that it will catch on sides of pile grout hole).

4.2.6.12 Constructor should provide a plan to assure that a full-length cage can be installed.

4.2.6.13 Full-length reinforcing cages can preclude the use of ACIP piles as deep piles in some soil conditions.

4.2.6.14 Requirements for hooks on reinforcing cages should be carefully evaluated as hooks can cause difficulty in placement. Pre-assembled cages with hooked bars can be difficult to fabricate, place efficiently on delivery trucks, and handle in the field.

4.2.6.15 Often, top of the pile is below ground, and hooks are field bent. Field bending of reinforcing bars is essentially limited to # 7 bars (#22 metric bars) or less. Larger bars bend more slowly and require special procedures. If limiting bar size to #7 (#22 metric) reduces clearance unacceptably, diameter of pile may need to be increased.

4.2.6.16 Bar bends should be limited to 90-degree bends.

4.2.7 Governing building codes should be checked for limitations that are more restrictive than those in PIP STS02465. Some building codes place specific limits on design stresses and/or maximum loads for ACIP piles. Local codes may also restrict spacing between piles constructed within 24 hours of one another, reinforcing cover, length to diameter ratio, limitations on work below the water table, etc.

5. Contract Documents

5.1 Scope

5.1.1 Contract scope-of-work documents should specify party responsible for all tasks. “Split” contracting is not advisable. Generally, constructor should be responsible for all phases of constructing ACIP piles including safety, construction permits, sourcing of materials, suitable equipment, experienced manpower, installation schedule, load testing, and other items required for successful installation. Specifically, constructor of the ACIP piles should be responsible for safety, drilling, automated monitoring, grout procurement and placement, reinforcing assembly procurement and installation, monitoring ACIP piles for grout settlement, maintaining grout level in ACIP piles, protection of ACIP piles during curing, and pile load testing.

5.1.2 The basis for PIP STS02465 is that design of the piles, geotechnical report, and quality assurance are all tasks performed by parties engaged directly or indirectly by the Purchaser, separate from the ACIP pile installation contract. Constructor QA/QC responsibilities beyond those given in PIP STS02465 should be noted in contract documents, including pre-construction testing, monitoring during production and post-production integrity testing.

5.1.3 Particular attention should be given to roles and responsibilities in the case that QC inspector or QA representative informs the constructor of deficiencies in pile
installation but constructor decides to complete the pile anyway. Options for resolution of this situation include rejection by the geotechnical engineer (based on the installation record), proof-load testing, and integrity testing; the contract documents should address cost liabilities for this case.

5.1.4 Where DD piles are proposed, the constructor may assume design responsibility, effectively becoming the geotechnical engineer. In this case, the contract documents must specify the basis of design including relevant governing codes, owner requirements, and load cases. Reporting, submittals, and approvals by the engineer of record should be clearly specified.

5.1.5 PIP STS02465 may be used but will require significant modifications (overlays) for DD piles or other proprietary systems. These modifications should be agreed upon in the pre-award meeting review of exceptions (Spec item 5.2.1.t). These modifications include, but are not limited to, Design (5.3); Gear Box/Power Unit (5.6.2); Augering Equipment (5.6.3) and Installation Procedures (5.7.4) especially auger operations.

5.1.6 Interfaces with other contractors and material suppliers should be covered in contract documents.

5.2 Design Drawings

Design drawings should include scale piling plans showing pile locations, cap locations, known existing obstructions such as foundations and underground pipes. A pile numbering system should be provided for reference during construction. Details and/or schedules should provide elevations for pile tip, cutoff and grade; as well as reinforcing details. Piles are often numbered using the drawing sheet or sequence number followed by a column and row designation. Numbering should be determined early enough that it can be used for reinforcing steel to reduce confusion in the field. The numbering should also accommodate replacement or additional piles as may be required due to installation issues.

5.3 Schedule and Submittal Review

5.3.1 Desired schedule of work should be laid out in contract documents, accounting for any plans for pre- and post-production testing, as well as requirements related to limitations on adjacent piles and movement of equipment.

5.3.2 Timing of constructor submittals (if different from PIP STS02465) and timing of purchaser submittal reviews should be included with contract documents.

5.3.3 Requirements for progress reporting should be covered in contract documents.

5.4 Geotechnical Report

5.4.1 A geotechnical report based on a subsurface investigation is required. As for any project, geotechnical report requisition should include reasonable preliminary structural loads, locations, elevations, etc. Cone penetrometer testing can be used to supplement geotechnical soil boring program to correlate conditions across an extended site. Data requirements are essentially the same as for any similar project where deep foundations are proposed, with specific recommendations for ACIP piles.

5.4.2 Engineer of record and design engineer should review subsurface investigation and structural load report before design of piles and foundations.
5.4.3 Data from subsurface investigation(s) must be reviewed by constructor. Constructor should understand soil conditions at the site in order to provide suitable equipment to function under conditions at the site. Additional investigations may be performed at constructor’s own discretion and expense with owner’s approval.

5.5 Surveying

5.5.1 Contract documents should specify party responsible for survey laying out the piles and marking cut-off elevations.

5.5.2 Location of benchmarks and description of datum plane should be provided, if appropriate.

5.5.3 Contract documents should specify party responsible for survey locating as-built pile locations and elevations.

5.6 Underground Utility Location

5.6.1 Contract documents should include plans showing underground utilities nearby or adjacent to proposed foundations.

5.6.2 Contract documents should specify party responsible for identifying, locating, and marking underground utilities.

5.7 Construction Permits

5.7.1 Contract documents should specify party responsible for providing construction permits.

5.7.2 Obtaining construction permits from regulatory agencies should typically be the responsibility of constructor.

5.7.3 Construction permits that the owner/purchaser furnishes to constructor should be clearly and completely described in contract documents.

6. Specification Commentary

This Section provides a commentary on PIP STS02465. Section numbering generally follows the sequence of the Specification.

6.1 Specification Scope

PIP STS02465 is intended to cover conventional augered cast-in-place (ACIP) piles. Besides continuous flight auger, drilled displacement and screw piles, other terms mentioned in DFI TM-ACIP-4 include augered cast in situ, Auger Cast Piles, Intruded Mortar Piles, Augerpress Piles, Augered Pressure Grouted Piles, AugerPile Foundations, Continuous Flight Auger (CFA) Piles, Grouted Bored Piles, Augered Grout-Injected Piles, Drilled or Augered Uncased Piles, and Uncased Cast-in-Place Concrete Piles. A number of proprietary types of ACIP piles have been developed, for which the piles are known by trade names. Some of these include partial displacement piles. As mentioned above, the extent to which overlays are required for a specific system needs to be addressed on a case-by-case basis.
6.2 Specification Definitions
Definitions in PIP STS02465 are identical to this Practice. Geotechnical engineer is to be licensed according to laws of the locality in which work is to be constructed. QC inspector is to be an independent party retained by constructor. QA representative is retained by purchaser for review of the work.

With the use of overlays, other contractual arrangements are possible while still utilizing PIP STS02465. For one example, if the QC inspector is not an independent third party, responsibilities should be reviewed, possibly reassigning certain items to the QA representative.

6.3 Specification Quality Control/Assurance

PIP specifications normally locate quality requirements in Section 4. One aspect of ACIP pile installation is the need for detailed quality control and quality assurance at all stages of work, especially during actual drilling and grouting. For PIP STS02465, therefore, Section 4 provides a cross-reference to the many quality requirements found throughout.

6.4 Specification Requirements

6.4.1 General

6.4.1.1 PIP STS02465 provides suggested minimum requirements for prior experience in similar work by the constructor, constructor’s personnel and QC inspector. These requirements may be modified by judgment of purchaser.

6.4.1.2 Constructor is required to evaluate whether proposed equipment is fit for purpose based on soil conditions. Some soil material may require heavier-duty equipment than minimums given in PIP STS02465. The primary concern with underpowered equipment is “soil mining” which can occur where vertical advance of the auger does not keep up with auger rotation. Undersized equipment will also struggle to maintain production rates, often leading to schedule delays and/or cost overruns.

6.4.1.3 Constructor is required to evaluate the site to verify physical clearances for proposed equipment. Access route widths, turning radii, and overhead clearances may restrict installation sequence and require additional work to navigate. Where work by others may impact clearances (e.g. pipe bridge erection), it is important to provide as much detail as practical.

6.4.1.4 PIP STS02465 requires a pile load test to be performed. Testing can be used to confirm or modify adequacy of equipment and drilling procedures as well as compression, tension and lateral performance. Section 5.1.12 of PIP STS02465 provides a related requirement to follow approved installation procedures and provide notification of any change.

6.4.1.5 PIP STS02465 provides general requirements for monitoring of work by engineer of record, geotechnical engineer and QC inspector; and requirement for notification and correction of defective work.

6.4.1.6 PIP STS02465 enumerates general requirements for QC inspector to become familiar with all aspects of the ACIP pile installation program.
Although *PIP STS02465* covers areas for cognizance by QC inspector, these areas are likewise important to the QA representative.

6.4.1.7 *PIP STS02465* is set up in such a way that it can be used with various project organizational structures. On projects of any size, it will be necessary to set up a distribution matrix to ensure appropriate review and approval of each type of document.

6.4.2 Meetings

6.4.2.1 *PIP STS02465* includes a topic outline for required initial coordination meetings. The pre-award meeting list could be easily adapted for use for pre-bid meetings as well. The pre-construction meeting, held with the personnel responsible for the field work, covers the same basic topics. The level of detail may vary.

6.4.2.2 Two changes were made from the previous version of *PIP STS02465*: an added requirement for constructor to clarify any proposed specification modifications and exceptions; and deletion of the essentially identical separate topic list for the pre-construction meeting. It may be prudent to revisit many of these topics during the pre-construction meeting using the original listing; as a minimum, any changes or new information since the pre-award meeting should be highlighted.

*Comment:* See *DFI TM-ACIP-2* for more information and commentary on the pre-construction meeting.

6.4.2.3 Safety topics may include, but not limited to, crane safety inspections, operating procedures, operator experience and qualifications, special hazards, etc.

6.4.2.4 It is recommended to hold discussion of schedule to the end of the meetings to ensure all the technical topics are properly covered.

6.4.3 Design

*PIP STS02465* states that design will be furnished to constructor; therefore, no design requirements are provided. See Section 4.2 above and *FHWA-HIF-07-03* for design procedures. In the case of constructor providing the design, loads and load cases will need to be developed; and the reference above may be used as a basis for review by the geotechnical engineer.

6.4.4 Submittals

6.4.4.1 Pre-construction Submittals

*PIP STS02465* provides a list of submittals to pin down the equipment, procedures and materials to be used. The submittals should help confirm constructor’s mastery of the specific task and provide the basis for a detailed execution plan. A couple of items may be of particular interest. Item (i.) is a complete pile installation procedure, spelling out expectations for auger rotation speed, drilling penetration rate, torque and dead weight, grout pressure and grout volume factor. Item (n.) includes automated monitoring parameters and a sample of the printed output.
6.4.4.2 Construction Submittals

*PIP STS02465* provides requirements for record keeping by QC inspector for each individual pile, and provides US and metric data forms suitable for this purpose. Requirements are provided for distribution of the collected information. As an option, purchaser could elect not to require collection of certain “incremental data” (e.g. grout volume in each 5 ft (1.5m)) that is captured by the automated monitoring equipment, if it is judged that QC inspector’s attention is best focused otherwise.

6.4.4.3 Automated Instrumentation and Monitoring Submittals

Requirements are found in several places in *PIP STS02465*. Section 5.4.3 establishes the content and format of automated instrumentation and monitoring submittals. Section 5.4.2.4 and related sections provide for the pile-by-pile data collection and dissemination of information, including automated monitoring data. Section 5.6.1 provides technical requirements for the automated data recording equipment, including minimum data collection requirements (described in its corresponding section of this guide). Ideally, the automation facilitates on-the-fly adjustments during drilling and grouting.

6.4.5 Materials

6.4.5.1 Grout Materials

1. Chemical admixtures are often used to improve performance of grout. See *ACI 212.3R* for use of admixtures. Air entraining admixture as a substitute for fluidifier or other admixtures should be prohibited due to potential for causing poor grout strength and/or excessive grout settlement. Required grout strength should be specified in contract documents if other than 4,000 psi (28 MPa) 28-day default strength specified in *PIP STS02465*. Commonly strength is specified as 4000 psi (28 MPa) to 5000 psi (35 MPa) based on cube testing. Note that cube strength may be somewhat higher than cylinder strength.

2. If concrete (in lieu of grout) is proposed and accepted by engineer of record, specification requirements for concrete should be provided in contract documents since concrete is not covered in *PIP STS02465*. *PIP STS03001* can be used as a reference for concrete specification requirements. Many of the requirements for concrete may be similar to grout as specified in *PIP STS02465*, although target slump for concrete should be 8 inches +/- 1 inch (200 mm +/- 25 mm) and test cylinders for concrete should be collected, prepared and tested in accordance with *ACI 301 / ACI 301M*.

3. Since adding water or admixtures on site could potentially result in decreased grout strength, advance approval of procedures and contingencies (including permissible quantities) is required by *PIP STS02465*. 


4. Allowable maximum grout temperature and holding time stated in PIP STS02465, Section 5.5.7.6, are the same as temperatures and holding times given in DFI TM-ACIP-4. Opinions differ about allowable maximum grout temperature, and some think that 90°F (32°C) should be the maximum. DFI TM-ACIP-4 warns that excessive mixing time and temperature can be detrimental to grout strength. Initial mixing time after final addition of all ingredients is typically one minute for the first cubic yard (0.75 m³) and additional 15 seconds for each cubic yard (0.75 m³) thereafter.

Typically, a grout with cementitious materials of 750 lb (340 kg) of portland cement and 225 lb (102 kg) of fly ash per cubic yard (0.75 m³) with proper combination of admixtures can have a slow heat gain that permits placement at a greater temperature. Testing is necessary to ensure desired properties are maintained. Grout suppliers sometimes change admixtures and mix design without notice.

5. Requirements in PIP STS02465 are based on 100°F (38°C) allowable maximum temperature and 70°F (21°C) minimum delivery temperature. At 100°F (38°C), the maximum delivery time is two hours. Minimum grout temperature at placement is 40°F (4°C); mixing time for temperatures below 70°F (21°C) is two and a half hours.

6. Grout mix is assigned a mix number for identification purposes so QC inspector can verify that correct mix was delivered and placed in production piles. It is also important that the mix identification number be changed when the mix is changed — whether proportioning, cement supply, or change (addition, subtraction, or substitution) of admixtures.

7. Greater or lower grout temperatures and/or extended holding times and/or addition of water on-site may be permitted with approval of engineer of record and grout supplier. Note that in hot weather, grout is placed in a drilled hole whose temperature can be significantly less than ambient. Additional strength test cubes should be made that represent grout as-placed (typically taken from the discharge hopper). To prepare for an occurrence of low strength test results, definitions of remedial actions and assignment of responsibility for the actions should be made and agreed upon beforehand.

Cubes are used for sand grout with a maximum size aggregate of #16 sieve (1.18 mm). Cylinders are used for concrete with larger aggregate. Ensure that equipment used is sized appropriately for grout or concrete specified.

6.4.5.2 Reinforcing Bars

Materials for reinforcing bars should be specified in contract documents.
6.4.6 Equipment

6.4.6.1 Automated Instrumentation, Monitoring and Recording

1. Purchaser and engineer should require in contract documents, the use of automated monitoring equipment instrumentation to monitor pile installation.

2. Automatic monitoring equipment typically consists of:
   a. A display and monitoring unit providing immediate feedback especially during grouting
   b. A real-time clock
   c. A depth sensor to continuously monitor auger tip depth
   d. A magnetic flow meter to measure grout flow vs. real time
   e. A rotary head pressure sensor measuring hydraulic pressure to the gearbox, useful in calculating torque
   f. A rotation sensor, measuring rotation of the auger
   g. A pressure sensor for the grout line

3. Automated instrumentation and monitoring equipment should be provided for all pile installations except those installed using limited access/low-overhead equipment due to the need to remove auger segments during grouting.

Continuous pile installation electronic monitoring is recommended to provide good QA/QC evidence for each pile. Such monitoring will provide clear documentation of installation of the pile. Display can be arranged to provide immediate feedback to operator to adjust the installation. Many geotechnical engineers and agencies believe electronic monitoring should be required for all ACIP piles. See DFI TM-ACIP-4, Appendix A for more information.

6.4.6.2 Gear Box and Power Unit

1. PIP STS02465 requires gear box to be rated to provide a minimum of 20,000 ft-lb (27,100 Nm) of torque and to apply a minimum reaction of 4,000 lb (1,800 kg) of down-force (crowd). The down-force may be either dead weight of components or mechanical force. Power unit minimum is 200 hp (150 kW). Note that these requirements, which apply to conventional ACIP piles, are minimums and need to be confirmed as adequate by constructor. Engineer may need to require equipment with greater torque and crowd for difficult soil conditions or large diameter piles.

2. Equipment must be capable of advancing the auger of specified diameter to the specified embedment within the bearing strata. Constructor should be required to demonstrate to geotechnical engineer that equipment can and has been used to install similar piles in similar conditions to those specified. This becomes
particularly important for large diameter piles and stiff or dense subgrade. It may also be critical where a small crane or drill rig is being used for deep piles; the reaction from the auger may approach the resistance of the rig, increasing risk of unexpected rig movement and damage.

3. Because encountering subsurface obstructions can cause the unit to rotate and endanger personnel, constructor should provide procedures or information on restraining the unit.

6.4.6.3 Augering Equipment

1. Augers used are continuous flight, hollow stem types with a grout injection port at bottom of the auger head below the part of the head containing the teeth. The opening should be arranged or equipped to prevent the ingress of soil or water. Some use disposable plugs.

2. Auger flighting should be continuous single-helix types without gaps or breaks. In the case of segmental augers such as those used for low headroom installations, gaps at auger joints may be up to 1 inch (25 mm).

3. Augers should have a uniform outer diameter as specified. Diameter of the inner pipe should be chosen depending on soil characteristics and type of continuous flight auger pile desired. Diameter of the inner pipe is often the constructor’s decision. It may be desirable to displace some of the soil as auger passes through using the large diameter grout pipe. Soil displacement may reduce the problem of soil mining and may improve pile capacity. Direct displacement (DD) augers often use an oversize inner pipe.

4. Pitch of auger flighting is restricted to a spacing of about 9 inches (225 mm) in cohesionless soils to avoid soil mining. Cohesive soils such as clays may tolerate greater flight spacing to aid in moving the soils. Soils with mixed layers should use the tighter spacing.

5. Auger penetration rates should be steady to reduce potential for soil mining but may need to vary in mixed soil conditions. Normally penetration rates of 1.5 to 2 revolutions per flight are used in cohesionless soils and 2 to 3 revolutions per flight are used in cohesive soils. Soils with mixed layers should use higher rate of penetration (fewer revolutions) per flight. Refusal is normally defined as one ft (300 mm) per minute, but mining may occur well before this benchmark. Mining may be detectable based on increased spoil volume, formation of a cone-shaped depression at the surface, and/or – most importantly – significantly reduced pile capacity.

6. *PIP STS02465* requires marking leads for purposes of depth measurement during drilling and grouting; markings must be positioned for constant visibility by QC inspector. The QC
inspector monitors depth and rate of penetration by noting the position of the auger top or turn table relative to the markings on the mast.

7. Auger withdrawal is to be accomplished at a slow, continuous rate to maintain grout head pressure to avoid gaps or bulges in the pile.

8. *PIP STS02465* requires equipment capable of installing piles at least 10 ft (3 m) longer than that required for bid length piles; often the requirement is for 20% longer piles. It is also a good practice for constructor to provide auger sections on hand for at least 20% greater length than machine capacity; these additional sections serve as spares in case a damaged portion needs to be replaced.

9. *PIP STS02465* requires that if logs of soil borings indicate that minor obstructions may be encountered, a rock-cutting bit should be supplied and used. In highly variable soil conditions, some other type of foundation may be indicated.

### 6.4.6.4 Pumping Equipment

1. Positive displacement pump capable of at least 350-psi (2,400-kPa) displacement pressure at pump should be provided. Pump should be sized to assure smooth, continuous delivery of grout while limiting pressure fluctuations during auger withdrawal.

2. Pump pressure gauge should be provided in clear view of operator and readily accessible to QC inspector. Positive pressure should be maintained on grout at all times during withdrawal.

3. Pump should be calibrated on site, as described in *PIP STS02465*, prior to installation, under changed circumstances as noted or any time grout pump is suspected of not operating correctly. Pump should be capable of delivering grout volumes within 3% accuracy. A barrel test is described to facilitate computation of volume per pump stroke for manual recording. Because computed grout calibration would be low, grout should not be allowed to overflow container.

4. Constructor should position pump and leads such that QC inspector can clearly see lead marks, pressure gage, and stroke counter while standing on grout line near grout pump. QC inspector must remain close to the grout pump to count the number of grout pump strokes placed over each 5-ft (1.5-m) interval. Operator must have the same information available via monitor or direct observation.

### 6.4.6.5 Mixing and Transportation Equipment

1. *PIP STS02465* provides basic requirement for adequate mixing and transportation equipment to produce desired grout mix. Mixing plant may be central mix, transit mix or onsite plant.
2. Sufficient quantity of grout to complete a pile should be at the site before pile installation begins. This is for each pile in turn, not the whole day or job. Grout trucks are to be readily available at job site.

6.4.7 Execution

6.4.7.1 General

As stated above, to ensure continuous installation, sufficient quantity of grout should be at site before each pile installation begins. No open holes are permitted in ACIP pile work; otherwise, these become drilled shaft piers, which are governed by other practices. If grout is not readily available and constructor is forced to sit with the auger idle in the hole, there is an increased risk that the auger will become stuck. Rotating the auger without advancing or withdrawing while grouting is unacceptable as it leads to mining of material from the sidewalls that can result in reduced skin friction capacity of the pile.

6.4.7.2 Construction Tolerances

1. Pile centers are to be located within 3 inches (75 mm) of locations shown in contract documents. Structural engineer’s pile cap (or pedestal or grade beam) design should account for pile location tolerance.

2. Vertical piles should be plumb within 2% to avoid interference with each other and to assure uniform distribution of loads to soils below. In rocky conditions, requirements are sometimes set to as much as 4%.

3. Battered piles should be installed to within 4% of pile length based on specified batter for proper load transfer and reasons stated above. Structural engineer’s design should account for allowable variations in slope of vertical and battered piles.

4. Reinforcing cages or center bars should have a minimum of 3 inches (75 mm) clearance from wall of the augered hole to provide adequate grout flow and cover.

5. Finished top of pile should be no more than 1 inch (25 mm) above or 3 inches (75 mm) below elevation shown on approved working drawings.

6. Reinforcing should extend past pile cutoff as shown on drawings.

6.4.7.3 Adjacent Piles

1. PIP STS02465 requires that piles not be placed within 6 pile diameters of each other, center to center, within 12 hours. Some other specifications vary, requiring eight pile diameters for instance, or requiring a different time interval. Generally, soils that are more granular require greater care to ensure that pile drilling does not disturb previously grouted pile.
2. Structural engineer of record and geotechnical engineers should determine allowable spacing and set time before installation of adjacent piles. This determination should consider lateral strength of soil and initial set of grout.

3. Initial grout set for ACIP piles can be field determined using a grout sample taken in a set of disposable cups made when grout truck arrives on site. Field samples should be set in shade and checked by QC inspector to determine initial set. When QC inspector inverts cup and grout comes out as a cup-shaped block only slightly plastic, the grout has achieved initial set. QC inspector should record this information on pile report.

4. If a more precise characterization of set time is desired, the mortar component of the grout may be tested in accordance with ASTM C191.

5. Often, constructor will install piles on an alternating pattern to provide time for grout to set. This may take creativity to devise a pattern that installs piles without affecting adjacent piles and minimizing equipment movement.

6.4.7.4 Installation Procedures

1. PIP STS02465 provides a detailed installation procedure including contingencies for certain common difficulties in ACIP pile installation.

2. It is expected that pile parameters such as length, drilling criteria, grout factor and installation procedures of production piles will be modified by geotechnical engineer and engineer of record based on information obtained during pre-production test pile installation. This includes establishing the appropriate rates of auger penetration based on stratigraphy, auger pitch, applied crowd, and applied torque. Production piles should be installed with same equipment and identical procedures, with modifications as indicated above.

3. Oversight should be provided by an experienced QC inspector to prevent excessive rotation of the auger, which can cause loss of ground in sands particularly those classified as “running sands.” “Running sands” tend to have relatively uniform diameter with low plasticity.

4. Drilling should advance at a continuous rate appropriate for soil conditions until required depth or refusal is reached.

5. A plug should be provided in the hole at the bottom of the auger, or the line charged with compressed air, during drilling to prevent entry of soil or water into hollow stem of the auger.

6. When auger reaches specified depth, auger may be raised slightly and grout pumping should begin. When grout fills the pump line and auger tube, and the required 5 ft (1.5 m) of grout
head is developed at the auger tip, auger is re-drilled to the established tip elevation before auger withdrawal begins.

7. After grout is flowing from the auger bottom of the hollow stem, the rate of grout injection and auger withdrawal should be coordinated so that grout constantly flows from hollow stem and required volume is placed in each subsequent depth increment.

8. Grout head pressure of 5 ft (1.5 m) should be continuously maintained above injection point during withdrawal of auger. When grout first appears at grade, auger depth is known as “grout return depth”. Above this point, it is generally not possible to maintain grout head pressure; grout pumping and auger withdrawal should continue at the same steady rate.

9. Minimum theoretical grout volume (115%) as specified in PIP STS02465 should be increased as necessary in accordance with volume used in test piles and/or recommendations of geotechnical engineer, based on soil type encountered during soil borings.

10. Spoil that accumulates around auger during drilling and injection of the grout should be cleared promptly, because the reinforcing installation and cut-off need to be established. Cylinders can be used to adjust the cut-off elevation slightly below or above existing grade.

11. Reinforcing steel should be placed as soon as possible and while grout is still fluid (prior to initial set). Reinforcing should sink by its own weight or require only minor assistance in installation. When reinforcing cage is installed easily, there is a good chance that the pile is free of severe constrictions.

   a. Constructor should stiffen reinforcing cages for handling by tying all bar intersections tightly with wire. Bracing across the center of the cage should be avoided as it greatly increases penetration resistance.

   b. In hot weather, cages or bars should be sprayed with water just before insertion to cool reinforcing. This improves the bar to grout bond.

   c. Tops of piles should be carefully screened to fresh concrete before reinforcing is placed, as part of keeping bars clean for optimum concrete bond.

   d. Reinforcing steel should not be forced into the grout filled pile shaft using a backhoe or other mechanical equipment though slight mechanical assistance is acceptable. Pile Installation Records should note whether reinforcing steel was placed into the pile smoothly without encountering any obstructions.

   e. Separate crane to handle and install long reinforcing cages should be considered. A crane can improve cage
installation, reduce damage to the cage, reduce contamination of cage due to mud, and release drilling rig to continue work. Typically, few problems are experienced if cages are placed within 10 to 15 minutes of grout placement and pile top screening.

12. Drilling of nearby piles can cause settlement/subsidence of grout in previously completed piles. QC inspector and constructor should observe the tops of completed piles to note any grout subsidence for the period before initial set occurs.

13. Grout subsidence of about one ft (0.3 m) can generally be handled by topping off piles with additional grout if pile grout has not achieved initial set.

14. In case of greater grout subsidence, increase minimum pile spacing, alternate pile locations, and/or allow grout to set for a longer time. Adjacent piles can be placed after initial set occurs, but note that PIP STS02465 requires that 12 hours elapse.

### 6.4.7.5 Spoils Handling

1. The drilling process produces spoils in the form of excess grout and soil returned to surface by the augers.

2. Contract documents should clearly state which party is responsible for removing and disposing spoils, any restrictions on disposal, and location of a disposal area provided, if any.

   **Comment:** On some projects, general construction constructor may be responsible for removing spoils. This makes pile installation sequence more difficult to complete in an orderly sequence. Special efforts are required to coordinate the work between the general construction constructor and piling constructor.

3. If soil is contaminated, handling and disposal costs should be considered in determining the feasibility of ACIP pile system.

4. If contaminated spoil disposal is an issue, but drilled piles are preferred over driven piles, drilled displacement (DD) piles may be considered because of reduced or eliminated spoils. All types of DD piles do not necessarily eliminate spoils, but may significantly reduce amount of spoils. Various types of proprietary DD piles may be more or less suited for different soil conditions. Appropriate engineering, including geotechnical engineering, should be performed if considering DD piles.

### 6.4.7.6 Obstructions

1. If an obstruction is encountered and it does not allow pile to be completed in the planned location, constructor should notify geotechnical engineer and engineer of record in order for these parties to determine remedial action.
2. Geotechnical engineer will determine if pile is acceptable as installed or if remedial measures are required.

3. Normally, the most cost effective and time saving remedial measure is to re-drill and re-grout the pile if suspect conditions are observed.

6.4.7.7 Termination (Pile Cut-Off)

1. Constructor should cut off the tops of piles and square with pile axis at elevations indicated on the approved working drawings, by removing fresh grout or concrete from top of the pile or by cutting off hardened grout or concrete down to final cutoff point at any time after initial set has occurred.

2. Reinforcing should extend specified amount above the pile cut off elevation in order that reinforcing can be developed in pile cap. Often the cage must be temporarily supported in the fluid grout column to maintain the design elevation.

6.4.7.8 Low-Overhead ACIP Piles

1. Low headroom working conditions are best avoided. If it is necessary to use low headroom construction, use smaller piles [usually 18-inch (450-mm) diameter or less] and smaller working loads per pile to avoid installation problems with small lightweight rigs.

2. Low headroom equipment can be used effectively with ACIP piles and is often more cost effective than high strength micro-piles if ground conditions are favorable for ACIP pile installation.

3. Note that continuous placement of grout is not possible when the auger string must be broken during withdrawal. Therefore, this technique should only be used in favorable ground conditions and with close control to maintain grout pressure and volume during extraction.

4. Low headroom ACIP pile rigs avoid using a crane mast and utilize segmental auger sections to achieve the low headroom capability. Torque capacity and crowd for such rigs are limited to about 21,000 ft-lbs (28 kN-m) and 3,000 lbs (13 kN), respectively. Because of these limitations, low headroom equipment should only be used in the most favorable soil conditions for which minimal risk of soil mining exists. Based on engineering judgment, the minimum rig capacity specified in PIP STS02465 may be relaxed for light duty, low-headroom projects.

5. Spliced steel cages and/or coupled threaded bars are often necessary to install reinforcement in low headroom applications.

6. Low-headroom installation is slower to the extent auger sections must be spliced. Auger sections should be keyed to minimize the hazards of unscrewing sections. Use of pipe wrenches is
discouraged to potential breakage and incurring personnel injury or damage to equipment in tight conditions normally encountered in low-head room situations.

6.4.7.9 Drilled Displacement Piles

Drilled displacement (DD) pile applications are discussed in Section 4 above. While DD piles are a type of ACIP pile, normally DD pile installation involves proprietary equipment, especially auger configuration. PIP STS02465 provides minimum equipment size only, requiring constructor to demonstrate adequacy and applicability of system. Apart from equipment, other QA/QC requirements apply.

6.4.7.10 Probe, Reaction and Test Piles

PIP STS02465 defines functions of probe, reaction and test piles as part of pre-production program. These can be most useful in defining capacity of piles, proving adequacy of proposed equipment, and refining soil stratigraphy across project site. Such a program is highly recommended; actual extent must be defined elsewhere in contract documents.

6.5 Specification Inspection, Testing and Acceptance

6.5.1 Inspection

6.5.1.1 Inspection data requirements for ACIP piles during installation differ from the data typically obtained for driven piles or drilled shafts. Problems that are difficult to detect can occur, which can reduce the load carrying capacity of an ACIP pile. For this reason, careful, full-time, purchaser-retained on-site inspection by an experienced professional is considered essential; refer to the definition of the QA representative. Modifications should be made to inspection requirements to fit specific needs of each project.

6.5.1.2 Automated instrumentation and monitoring systems, as described elsewhere in this document, should be provided to enhance the inspection. This type of system should be used wherever feasible. Even if instrumentation is provided by the constructor, a qualified QC inspector should be present during ACIP pile work. The special instrumentation cannot typically be used for ACIP piles installed in areas having restricted headroom conditions, because low headroom ACIP piles have the auger installed and removed in segments. Grout pressure is released each time an auger section is removed.

6.5.1.3 For additional information on inspection criteria, installation procedures, inspection tools, common problems and the responsibilities of the parties for successful installation of these ACIP piles, see DFI TM-ACIP-2 and, Inspection and Quality Control of Augercast Piles by Piscsalko and White.

6.5.2 Integrity Verification

6.5.2.1 ACIP pile integrity testing is performed to assure there are no major defects in the ACIP piles. Type and frequency of tests should be defined in contract documents. The engineer normally specifies a number or percentage of production piles to be integrity tested, with an increase or
decrease in frequency based on results. Often 10 to 20 ACIP piles are tested to start the project and 10 to 20 more for every 200 ACIP piles. In some cases, purchaser may require 100% of piles to be tested with low strain pulse echo (LSPE); at the other extreme it may be required only where some aspect of installation was deemed to be questionable.

6.5.2.2 LSPE testing (in accordance with ASTM D5882) is the quickest and least expensive test method. It is basically a sonic echo test made with a hammer on the hardened pile surface (pile top is ground smooth). It is performed at least three to seven days after installation. It is generally limited to length-to-diameter ratio of 30 or less. It is less sensitive than other methods, detecting only major defects and often only the shallowest defect (if any is found). It cannot differentiate between a hairline crack and a large void.

6.5.2.3 Single-hole sonic logging (SSL) and cross-hole sonic logging (CSL) testing (in accordance with ASTM D6760) requires down-hole instrumentation in water-filled tubes installed into the wet grout (one or two tubes respectively). The tests are performed one to two days after pile installation. After three days, the pipe may de-bond and render the tests ineffective. (PVC pipe is commonly used but steel pipe has been shown to be better for bonding). These methods are more accurate but more expensive and time-consuming. Cross-hole sonic logging is suitable for larger piles; generally limited for cost reasons to piles with high bending moments and/or 30 inch (750) mm diameter and larger.

6.5.2.4 Thermal Integrity Profiling (in accordance with ASTM D7949) is another method that can be used. With this method, heat generated by curing cement is measured along the full length of the ACIP pile. This data is used to evaluate the grout/concrete quality of the entire cross-section, including outside the reinforcing cage along the full length of the pile, without maximum length limitations. Thermal Integrity Profiling is typically completed within 48 hours of installing the ACIP pile which can provide integrity evaluation earlier than some other methods. If this method is used, requirements for the ACIP pile constructor will need to be included in the contract documents.

6.5.2.5 Refer to DFI TM-ACIP-3 for Guideline for Interpretation of Nondestructive Integrity Testing of Augered Cast-in-Place and Drilled Displacement Piles.

6.5.3 Load Testing

6.5.3.1 Timing

1. Pile capacity verification may be performed on test ACIP piles at three different times depending on objectives:

   a. Before production installation begins, to determine if ACIP pile length or number can or should be modified to carry intended loads;

   b. As production installation begins, to determine if chosen ACIP pile installation method is developing adequate
strength and to allow modification of length and number of ACIP piles;

c. During and after production installation, to determine if ACIP piles are developing design strength. Normally load testing is carried out on a relatively small number of piles.

2. Capacity verification requires constructing test piles using equipment, methods and materials identical to production installation.

3. For pre-production testing, to assure validity, capacity verification should be performed on the portion of site where soils are expected to be weakest based on soil borings or CPT testing.

4. For early production testing, test piles should be among the first ten piles installed, to prove method of constructing and load capacity.

5. Tests should be conducted at least seven days after installation. Waiting for a longer period will allow grout to achieve greater strength.

6.5.3.2 Test Piles

1. Location, length, number, etc., of probe and/or test piles should be shown in contract documents.

2. Type of load tests (i.e., compression, tension, and lateral) should be specified in contract documents. Where two or more tests are to be performed on a pile, the sequence should be compression, tension, lateral.

3. If tension or lateral testing is required, the type of test loading procedure should be specified in contract documents.

4. Test pile(s) should be installed adjacent to an existing (or additional) soil boring or cone penetrometer (CPT) location such that soil conditions at test location are well defined. Test pile locations should be selected at locations where soil conditions are expected to be relatively weaker compared with rest of project site. Engineer can conclude that production piles at other locations will perform as well or better than the test pile.

5. Details of telltales or strain gauges for test piles should be provided. Telltale information can assist in resolving questions about structural integrity during load test and help estimate the side friction and end bearing capacity.

Comment: Telltale can easily be installed by tying a closed end small diameter casing of PVC or other material to the center reinforcing bar. After grout sets and prior to testing, a steel bar (rebar) is inserted, mounted with a dial deflection gauge and referenced to an independent reference beam to obtain pile tip deflections.
6. Test piles and reaction piles should be equipped with telltales and/or strain gauges to record pile movement at both top of pile and near pile tip.

7. Telltale data should be used to evaluate side soil friction support and end-bearing support, in addition to providing a confirmation that pile shaft was not damaged during testing. This is important for cast-in-place piles, which are typically tested before grout reaches full strength.

8. If test piles and reaction piles are equipped for telltales, PVC pipe should be large enough to permit sonic logging along length of piles to check pile integrity.

9. If approved by geotechnical engineer and engineer of record, test piles and reaction piles may be permitted to be incorporated as load bearing components of a foundation. If incorporation in foundation is permitted, a minimum of four reaction piles per test pile should be used.

10. In some cases, neither test piles nor reaction piles become a part of the permanent foundation system. However, if a pile integrity test indicates a pile is still sound after testing, that pile can be permitted to be part of a foundation.

**6.5.3.3 Pile Load Testing**

1. Capacity verification must be based on static load (compression) tests by ASTM D1143/D1143M as the standard. If different from PIP STS02465, type of test load procedure should be specified. Dynamic load tests must be calibrated to results of the static load test.

2. Constructor should design the test frame and select test equipment subject to the approval of geotechnical engineer and engineer of record.

3. Commonly in the US, the Davisson Offset Limit (DOL) is used as a criterion for determining failure for load test purposes. Failure using this method is defined as [elastic shortening of the pile] + [0.15 inch (3.8 mm)] + [pile diameter/120]. However, this criterion is now considered overly conservative for cast-in-place piles; there is some indication that the third term may be multiplied by a factor of 4 to estimate the true ultimate capacity. There are several possible alternative criteria (e.g., Brinch Hanson 90% Criterion, Butler-Hoy Criterion); geotechnical engineer should specify test method details and interpretation.

4. The “Quick” load test method should be used but the load hold times should be increased to ten minutes to permit sufficient time to take all readings and permit a safety inspection of test pile top and reaction pile connections before increasing test loads.

5. Dynamic Load Testing (DLT) in accordance with ASTM D4945 is a method to assess a pile’s bearing capacity by applying (a dropping mass) to a pile head. DLT can offer advantages of
speed and economy, compared to conventional static testing, where it has been calibrated to local soil conditions. On a larger project, it may be worth considering a single control static test supplemented with a large number of DLTs. If dynamic load testing is required, a written procedure for dynamic load testing should be provided in contract documents. The following should be considered in choosing to permit dynamic load testing and accounted for in selecting pile design capacities:

a. Viability of the testing
b. Applicability to a specific pile application
c. Assurance that testing cannot harm the structural integrity of the pile
d. Justified degree of confidence that can be assigned to the results

6.5.3.4 Rejected Piles
Engineer of record in consultation with geotechnical engineer will need to determine if any ACIP piles will be required to be removed and replaced at constructor’s expense, or other remedy required, in the circumstances listed in PIP STS02465.

7. Payment Guidelines

7.1 Basis of Payment

7.1.1 Basis for payment for pile installation should be specified in contract documents.

7.1.2 Typically, purchaser should request lump sum bids for entire installation of piles and unit pricing for over and under the bid quantity of piles.

7.1.3 Grout quantities in excess of 115% of the theoretical grout volume should be carefully documented by QA representative to permit verification of the volumes reported on the constructor’s installation record.

7.1.4 Unit pricing for changes before production commences (e.g., from test pile program results) is appropriate.

7.1.5 Constructors may limit the range for changes in pile length or diameter because of resulting requirements for larger equipment, which the lump sum bid and unit prices did not anticipate.

7.1.6 Payment for pile load tests should be based on furnishing and installing sufficient reaction materials including beams and jack to apply a minimum of three times the design load for the pile. Payment for use of equipment limiting the test to a lesser load should be reduced proportionately. Where more than one test is required, terms should address standby of test equipment between uses as well as delays to the work while waiting for arrival of test equipment.

7.1.7 Payment for pile integrity tests should include materials, equipment, personnel, field interpretation, and final report in hard copy, raw data, and electronic data file which can be analyzed by the engineer of record and geotechnical engineer.
7.2 Obstructions and Payment for Obstructed Piles

7.2.1 Equity and administrative law make underground obstructions an owner responsibility. Obstructions can cause constructor to incur downtime, potential equipment damage, and possible loss of grout.

7.2.2 Even with a rock bit, ACIP pile rigs cannot penetrate a significant distance into hard rock, and rock bits may not penetrate many obstructions. Extended drilling time at reduced penetration increases the risk of mining and may not produce an acceptable pile even if the target depth is eventually obtained.

7.2.3 Requirements should be provided in contract documents for handling piling installation obstructions if encountered.

7.2.4 Payment calculation method for piles terminated due to obstruction should be provided in contract documents.

7.2.5 If non-augerable material is encountered above the required tip elevation, pile should be grouted and completed. The intent is to backfill hole with grout, so side walls of hole do not slough in and adversely affect nearby piles. Engineer of record should be notified to determine if pile is acceptable as installed or if remedial measures are required.