

Specification for the Construction of Drilled Piers

Reported by ACI Committee 336

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This specification covers requirements for drilled pier construction. It includes delivery, handling, and storage of the casing, excavation, soil testing, placing of concrete and reinforcing steel, and inspection. Drilled piers are sometimes called drilled shafts, caissons, or bored piles.

Keywords: bored pile; caisson; concrete; drilled pier; foundation; placing; reinforced concrete; reinforcement; slurry; soil; specification; test; tolerance.

FOREWORD

F1. This foreword is included for explanatory purposes only. It does not form a part of Specification ACI 336.1.

F2. ACI Specification ACI 336.1 is a Reference Specification to be used by incorporation in its entirety in the project specifications. Individual sections, articles, or paragraphs shall not be copied into the Project Specifications, because taking them out of context may change their meanings. If sections or parts of ACI Specification 336.1 are copied into project specifications or any other document, they shall not be referred to as ACI Specifications, because the specification has been altered.

F3. A statement such as the following will serve to make ACI Specification 336.1 a part of the Project Specifications:

Work on (Project Title) shall conform to all requirements of ACI 336.1-00 published by the American Concrete Institute, Farmington Hills, Mich., except as modified by these Contract Documents.

F4. Responsibilities for project participants must be defined in the project specifications. ACI Specification 336.1 defines responsibilities solely for the Contractor and defines specific conditions when the Contractor is to take direction from the Owner's Representative-Geotechnical Engineer.

F5. Each technical section of ACI Specification 336.1 is written in the Three-Part Section Format of the Construction Specifications Institute, as adapted for ACI requirements. The language is imperative and terse.

F6. Checklists do not form a part of Reference Specification ACI 336.1. Checklists are to assist the specifier in properly choosing and specifying any necessary requirements for the Project Specifications.

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SECTION 1—GENERAL REQUIREMENTS

1.1—Scope

1.1.1 This Reference Specification covers requirements for drilled pier construction and applies to drilled piers of 30 in. (750 mm) diameter and larger. The Contractor shall submit proposed installation methods to the Owner's Representative-Geotechnical Engineer. Methods compatible with the design intent, as determined by the Owner's Representative-Geotechnical Engineer, will be accepted. Methods that are not compatible with the design intent will be rejected.

1.1.2 The provisions of this Specification shall govern, unless otherwise specified in the Contract Documents. In case of conflicting requirements, the Contract Documents shall govern. Conflicting requirements shall be submitted to the Owner's Representative for resolution.

1.2—Definitions

The following definitions cover the meanings of certain words and terms used in this Reference Specification.

Accept, accepted, acceptable, acceptability—Adequate or satisfactory as determined by the Owner's Representative or Owner's Representative-Geotechnical Engineer.

Anchorage embedment—Embedment of the anchorage system, such as anchor bolts or threaded rods, used to fasten structural components to the piers.

Bearing stratum—The soil or rock stratum that carries the load transferred to it by a drilled pier.

Bell—An enlargement at the bottom of the pier for the purpose of spreading the load over a larger area.

Casing—A permanent or temporary steel cylinder used to resist earth and water pressures, to serve as a concrete form, and to protect personnel.

Contract Documents—Documents, including the Project Drawings and Project Specifications, covering the required Work.

Contractor—The person, firm, or corporation with whom the Owner enters into an agreement for construction of the Work.

Controlled slurry—Slurry that is controlled to conform to specified properties.

Cut-off—The top of a pier, a level surface at the elevation shown on the Contract Drawings.

Drilled pier—A foundation element, with or without an enlarged bearing area, extended downward by drilling through earth materials, water, or both, to an acceptable design depth and filled with structural concrete.

Dry method—Method of pier installation in which concrete is placed in the dry and where casing may be used to maintain sidewall stability.

End bearing—Where load is supported at the bottom of the pier.

Inspection—Observation of construction, equipment, and materials used therein, and actual subsurface conditions that, along with related construction engineering decisions made by the Owner's Representative-Geotechnical Engineer, enables the Owner's Representative-Geotechnical Engineer to render a professional opinion on expected foundation performance and the Contractor's conformance with the Contract Documents.

Liner—A cylindrical form of pier design diameter having the tensile strength to withstand internal concrete pressures and not designed for external earth and water pressures; used inside an oversized temporary casing to prevent possible concrete contamination when temporary casing is removed.

Owner—Corporation, association, partnership, individual, public body, or authority with whom the Contractor enters into agreement and for whom the Work is provided.

Owner's Representative—Architect, Structural Engineer, or Geotechnical Engineer authorized to act on behalf of the Owner.

Owner's Representative-Geotechnical Engineer—Geotechnical engineer specifically authorized to carry out the responsibilities defined in this Reference Specification.

Pig—Device inserted into a tremie or pump pipe to separate the concrete from the pier excavation fluid inside the pipe.

Probe hole—A 1.6 to 2.5 in. (40 to 63 mm) diameter hole usually drilled by air percussion methods to a required depth below the pier bottom. The geotechnical engineer feels the probe hole wall by lowering and raising a hooked rod. The size and amount of seams found enables the determination of the soundness of the soil formation.

Project Drawings—The drawings that, along with Project Specifications, complete the descriptive information for constructing the Work required or referred to in the Contract Documents.

Project Specifications—The written documents that specify requirements for a project in accordance with the service parameters and other specific criteria established by the Owner.

Reference Specification—A specification that, by citing in the Contract Documents, becomes a reference standard for the Contractor to use in the construction of a project together with other project requirements.

Side-resistance—Friction developed along the side of a drilled pier that transmits vertical forces to the surrounding soil or rock.

Slurry displacement method—Method of drilling, concreting, or drilling and concreting in which controlled slurry consisting of water, with or without additives such as bentonite, attapulgit, or polymer, is used to stabilize the hole; the slurry may be used to maintain the stability of the uncased drilled pier hole to allow concrete placement when water seepage into a drilled pier hole is too severe to permit concreting in the dry, or both.

Submitted—Given to the Owner's Representative for appropriate action.

Testing agency—Person, firm, or corporation retained to perform required tests on the contract construction materials

and to document conformance with the Contract Documents and with the construction engineering decisions made by the Owner's Representative-Geotechnical Engineer.

Tremie method—Procedure for placing concrete underwater or slurry using a watertight steel pipe or tube to place concrete without washing out cement fines.

Work—The entire construction or separately identifiable parts thereof that are required to be furnished under the Contract Documents. Work is the result of performing services, furnishing labor, and furnishing and incorporating materials and equipment into the construction in accordance with the Contract Documents.

1.3—Reference standards

1.3.1 General—Standards of ACI, ASTM, AWS, and API referred to in this Reference Specification are listed with their serial designation, including year of adoption or revision, and are part of this Reference Specification.

1.3.1.1 ACI standards

ACI 117-90	Standard Specifications for Tolerances for Concrete Construction and Materials
ACI 301-99	Specifications for Structural Concrete

1.3.1.2 ASTM standards

A 36/A 36M-97a	Specification for Carbon Structural Steel
A 283/A 283M-97	Specification for Low and Intermediate Strength Carbon Steel Plates
A 615/A 615M-96a	Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement
A 616/A 616M-96a	Specification for Rail-Steel Deformed and Plain Bars for Concrete Reinforcement
A 617/A 617M-96a	Specification for Axle-Steel Deformed and Plain Bars for Concrete Reinforcement
A 706/A 706M-96b	Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement
A 929/A 929M-97	Specification for Steel Sheet, Metallic Coated by the Hot-Dip Process for Corrugated Steel Pipe
C 31/C 31M-00	Standard Practice for Making and Curing Concrete Test Specimens in the Field
C 39-96	Test Method for Compressive Strength of Cylindrical Concrete Specimens
C 94/C 94M-98c	Specification for Ready-Mixed Concrete
C 143/C 143M-98	Test Method for Slump of Hydraulic Cement Concrete
C 150-98	Specification for Portland Cement

C 494-98a	Specification for Chemical Admixtures for Concrete
C 1017/C 1017M-98	Specification for Chemical Admixtures for Use in Producing Flowing Concrete
C 1064-86	Test Method for Temperature of (Revised 1993) Freshly Mixed Portland Cement Concrete
D 4380-84 (Revised 1993)	Test Method for Density of Bentonite Slurries
D 4381-84 (Revised 1993)	Test Method for Sand Content by Volume of Bentonite Slurries
D 4972-95a	Test Method for pH of Soils

1.3.1.3 API standards

RP13 B-1(1990)	Standard Procedures for Field Testing Water-Based Drilling Fluids
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1.3.1.4 AWS standards

D1.1-96	Structural Welding Code—Steel
D1.4-92	Structural Welding Code—Reinforcing Steel

1.4—Standards-producing organizations

Abbreviations for and complete names and addresses of organizations issuing documents referred to in this Reference Specification are listed:

American Concrete Institute (ACI)
P.O. Box 9094
Farmington Hills, Mich. 48333-9094

American Petroleum Institute (API)
Production Department
211 N. Ervay, Suite 1700
Dallas, Tex. 75201

American Society for Testing and Materials (ASTM)
100 Barr Harbor Drive
West Conshohocken, Pa. 19428

American Welding Society (AWS)
550 NW LeJeune Road
Miami, Fla. 33126

1.5—Standard units

The values stated in inch-pound units are to be regarded as the standard. SI units given in parenthesis are for informational purposes only.

1.6—Project conditions

The Contractor shall perform the following items listed in 1.6.1 through 1.6.4.

1.6.1 Examination of site

Determine any constraints to the work presented by the existing surface conditions and report them to the Owner's Representative.

1.6.2 Subsurface data

Review the subsurface investigation results. Discover and document any substantial difference between actual sub-sur-

face conditions and those reported. Notify the Owner's Representative in writing within 48 hours of such discovery.

1.6.3 Existing underground utilities

Locate in the field all existing underground structures and utilities. Determine if there are conflicts with the Work. Report any conflicts to the Owner's Representative. Cease work in this area until the conflicts are resolved.

1.6.4 Preconstruction conferences

Attend all preconstruction conferences required by the Contract Documents.

1.7—Quality assurance

1.7.1 Owner's Representative-Geotechnical Engineer

The Owner's Representative-Geotechnical Engineer will provide inspection of the drilled-pier construction. This Specification provides that construction engineering decisions will be made by the Owner's Representative-Geotechnical Engineer during the course of the Work as unknown or unforeseen conditions are encountered. At the completion of the Work, the Owner's Representative-Geotechnical Engineer will determine the acceptability of the pier installation within the terms and conditions of the Contract Documents and his or her construction engineering decisions.

1.7.2 Contractor

The Contractor shall:

- a. Provide site supervisor and drillers, each with a minimum of 3 years of acceptable experience in installing similar types of drilled piers. If an installation method is specified, experience with this method is required;
- b. Schedule and provide time and means for the Owner's Representative-Geotechnical Engineer to inspect each drilled pier before concreting;
- c. Provide the Testing Agency the means and opportunity to take samples and make tests;
- d. Submit a program to the Owner for quality control;
- e. Submit a detailed description of field procedures for pier construction, whether a wet or dry method is to be used, including procedures for excavation, dewatering, slurry type, and source and casing withdrawal, if applicable; and
- f. Perform all excavation or concrete work in the presence of the Owner's Representative.

1.7.3 Testing Agency

1.7.3.1 The Testing Agency will perform required tests on construction materials to check conformance with the Contract Documents. Required tests on concrete include slump and temperature on site in accordance with ASTM C 143/C 143M and ASTM C 1064, and compressive strength of standard-cured cylinders prepared in accordance with ASTM C 31/C 31M and tested in accordance with ASTM C 39.

1.7.3.2 The testing agency and its representatives are not authorized to revoke, alter, relax, enlarge, or release the requirements of the Contract Documents, nor to make any construction engineering decisions during the course of the Work, nor to accept any portion of the Work.

1.8—Submittals by the Contractor

1.8.1 Submit to the Owner's Representative before starting the Work:

1.8.1.1 Experience record of supervisory personnel and drillers. (1.7.2.a)

1.8.1.2 List of equipment and equipment operating procedures.

1.8.1.3 Shop drawings showing location and size of reinforcing steel. (3.4.4)

1.8.1.4 Proposed concrete materials and mixture proportions conforming to the requirements of ACI 301. (2.4.1)

1.8.1.5 Detailed field procedures for pier construction, including excavation, concreting, and casing withdrawal, if applicable. (1.7.2.e)

1.8.1.6 If spoil, drilling fluid, or both are to be disposed of off site, submit letters of approval from all governmental agencies with jurisdiction over proposed disposal sites. (3.7.4.5)

1.8.1.7 Welding procedures for permanent casing. (2.2.2)

1.8.1.8 AWS welder certification for permanent casing. (2.2.2)

1.8.1.9 Welding procedures for reinforcement. (2.3.1)

1.8.1.10 AWS welder certification for reinforcement.

1.8.1.11 Quality-control program. (1.7.2.d)

1.8.1.12 Test report from the supplier giving the slurry type and admixtures and the physical and chemical properties of the mixed slurry to the Owner's Representative-Geotechnical Engineer. (3.7.2.3)

1.8.1.13 Size, wall thickness, type of steel, and length of permanent and temporary steel casing. (2.2.3)

1.8.1.14 Size, length, material, and strength of liner. (2.2.4)

1.8.1.15 Any splice requirements other than those in the Contract Documents. (3.4.7)

1.8.2 Submit the following to the Owner's Representative during construction:

1.8.2.1 Notification to the Owner's Representative-Geotechnical Engineer in time to permit in-place inspection of the completed excavation before placement of reinforcing steel and before placing concrete. (3.5.4)

1.8.2.2 Reports of material quantities such as concrete, reinforcement, and slurry.

1.8.2.3 Certified mill test reports for reinforcing steel, including bar markings. (2.3.1)

1.8.2.4 Reports of in-hole slurry tests during construction in accordance with Section 3.7. (3.7.2.3, 3.7.2.5, 3.7.6.2)

1.8.2.5 Concrete batch-plant tickets containing the information required by ASTM C 94.

1.8.2.6 Reports of as-built location, alignment, elevations, and dimensions of drilled piers, specifically identifying those piers that are not in accordance with the Contract Documents.

1.8.2.7 Graphical plot of theoretical concrete volume and actual measured volume versus depth or elevation for each drilled pier constructed by the slurry displacement method. (3.7.5.10)

SECTION 2—PRODUCTS

2.1—General

This Section covers requirements for materials and products in connection with construction of drilled piers.

2.2—Steel casing and liner

2.2.1 Steel casing liner shall conform to the requirements of ASTM A 283, Grade C; ASTM A 36; or ASTM A 929.

2.2.2 Full-penetration welds shall meet AWS D1.1 requirements for joints in noncorrugated permanent casings and be welded by AWS-certified welders. Welding procedures and welder certifications shall be submitted to the Owner's Representative for acceptance.

2.2.3 Casing shall be of sufficient strength to withstand handling stresses, drilling stresses, concrete pressures, and surrounding earth and water pressures, to protect personnel as required, and to permit advancement of the pier through caving ground. Size and length of casing shall be submitted to the Owner's Representative-Geotechnical Engineer for acceptance.

2.2.4 Liner shall be of sufficient strength to withstand internal concrete pressures. Size, length, material type, and strength of liner shall be submitted to the Owner's Representative-Geotechnical Engineer for acceptance.

2.3—Reinforcing steel

2.3.1 Reinforcing steel shall conform to ASTM A 615, A 616, A 617, or A 706. ASTM A 616 bars (rail steel) shall meet the bend-test requirements of axle-steel reinforcing bars, ASTM A 617, Grade 60, and the bar markings rolled into the surface of the bars shall include the letter "R" to designate rail steel. Bars to be welded shall conform to ASTM A 706. Shop drawings and mill test reports on reinforcing steel shall be submitted. Welding procedures shall be submitted, if applicable.

2.3.2 Reinforcement shall be spliced in conformance with the Contract Documents.

2.4—Concrete

2.4.1 Concrete and concrete work shall conform to ACI 301. Concrete materials and mixture proportion information shall be submitted in accordance with ACI 301.

2.4.2 Concrete of the specified slump and strength shall be provided and placed. Concrete for use in the slurry displacement method ([Section 3.7](#)) shall have a maximum nominal aggregate size of 3/4 in. (19 mm).

2.4.3 Concrete shall meet the slump requirements given in Table 2.4.3 until placement is complete.

2.4.4 Water-reducing, set-retarding admixtures shall conform to ASTM C 494, Type D, to meet slump requirements and to delay concrete setting.

2.4.5 High-range, water-reducing, and set-retarding admixtures shall conform to ASTM C 494, Type G or ASTM C 1017, Type II only with the acceptance of the Owner's Representative-Geotechnical Engineer.

2.4.6 Cement shall conform to ASTM C 150 Type I or Type II.

2.4.7 Calcium chloride or any admixture containing chloride ions shall not be used.

2.5—Sand-cement grout

Sand-cement grout suitable to fill annular void outside permanent casing or permanent liner shall be provided and placed in a manner acceptable to the Owner's Representative-Geotechnical Engineer. The mixture shall consist of a mini-

Table 2.4.3—Concrete slump requirements during placement

Slump		Drill method
in.	mm	
4 to 6	100 to 150	Dry, uncased, or permanent casing
6 to 8	150 to 200	Temporary casing
7 to 9	180 to 230	Slurry displacement

imum of 188 lb/yd³ (112 kg/m³) of Type II cement, an acceptable sand, and shall have a water-cementitious materials ratio (*w/cm*) less than 1.0.

2.6—Controlled slurry

2.6.1 Slurry shall consist of a stable colloidal suspension of various pulverized clays or polymers thoroughly mixed with water and having the properties given in Table 2.6 or as accepted by the Owner's Representative-Geotechnical Engineer.

2.6.2 Water used to mix slurry shall be obtained from sources accepted by the Owner's Representative-Geotechnical Engineer.

SECTION 3—EXECUTION

3.1—Tolerances

Tolerances shall be in accordance with ACI 117, except as follows:

3.1.1 General

3.1.2 Location tolerance at cut-off shall be no greater than 1/24 of the specified shaft diameter or 3 in. (75 mm), whichever is greater. If the as-installed shaft is larger than specified, the center of the shaft may be taken as the center of a circle having the specified area that lies within the as-installed shaft.

3.1.3 Out-of-plumbness of piers shall not exceed 1.5%. If the cross-sectional area of the as-installed shaft is larger than specified at both cut-off and bottom, the out-of-plumbness shall be measured by:

a. The center at cut-off shall be the center as permitted in Section 3.1.2; and

b. The center at the bottom shall be determined in the same manner as for the center at cut-off.

3.1.4 Bottom area

Provide bottom area not less than that shown on the Project Drawings, or as unless otherwise acceptable to the Owner's Representative-Geotechnical Engineer.

3.1.5 Bottom slope

Excavate the bottom of the pier to a level plane within a tolerance of 1 vertical to 12 horizontal, or as acceptable to the Owner's Representative-Geotechnical Engineer.

3.1.6 Pier shaft diameter

Provide pier shaft diameter shown on the Project Drawings, or as accepted by the Owner's Representative-Geotechnical Engineer. Maximum diameter shall be as accepted by the Owner's Representative.

3.1.7 Anchorage embedment tolerance

Limit the vertical and horizontal deviations of individual anchorage components from the specified location to ±0.5 in. (15 mm).

Table 2.6—Required slurry properties

Item to be measured	Range of results at 68 F (20 C)	Test methods
1. Density before concreting lb/ft ³ (kg/m ³) for slurry 1 ft (300 mm) from pier bottom		(Mud balance) ASTM D 4380
a. Mineral slurries (bentonite/attapulgate)		
1. No end bearing	85 max (1.4 × 10 ³)	
2. With end bearing	70 max (1.0 × 10 ³)	
b. Polymer slurry		
1. No end bearing	64 max (1.0 × 10 ³)	
2. With end bearing	64 max (1.0 × 10 ³)	(Marsh funnel) API— RP13B—Section 2
2. Marsh funnel viscosity for entry, s/qt (s/L)		
a. Bentonite/attapulgate	26 to 50	
b. Polymer slurry	40 to 90*	(Sand screen set) ASTM D 4381
3. Sand content in slurry, immediately before concreting, 1 ft. (300 mm) from bottom, by volume, %		
a. Mineral slurries (bentonite/attapulgate)		
1. With end bearing	4 max	
2. No end bearing	20 max	
b. Polymer slurry		
1. With end bearing	1 max	
2. No end bearing	1 max	
4. pH during excavation	7 to 12	ASTM D 4972

*Or as recommended by manufacturer and accepted by the Owner's Representative-Geotechnical Engineer.

3.2—Dry method

3.2.1 Excavate drilled piers to dimensions and required elevations shown on the Project Drawings. Clear all obstructions encountered during excavation.

3.2.2 Maintain sidewall stability during drilling and extend excavation to the stratum specified by the Owner's Representative-Geotechnical Engineer.

3.2.3 The Owner's Representative-Geotechnical Engineer will determine actual final bearing levels during excavation based on suitability of bearing stratum.

3.2.3.1 For end-bearing piers, explore bearing stratum with a probe hole to a minimum depth equal to the diameter of the bearing area below the bottom of each drilled pier, unless otherwise directed by the Owner's Representative-Geotechnical Engineer.

3.2.3.2 Provide a safe method for personnel access to inspect the bottom of the drilled pier. Alternatives to direct downhole inspection shall be approved by the Owner's Representative-Geotechnical Engineer.

3.2.3.3 Excavate for drilled pier bells, if applicable, immediately upon confirmation of the acceptability of the bearing stratum by the Owner's Representative-Geotechnical Engineer.

3.2.3.4 Determine bell dimensions.

3.2.4 Check each drilled pier for toxic and explosive gas before personnel enters and while personnel are in-hole. If

gas is found, ventilate with forced air until safe for entry, or follow alternative procedures acceptable to the Owner's Representative. During hand belling or other operations necessitating entry into the shaft, provide gas-testing equipment and a protective cage, or temporary casing of proper diameter, length, and thickness, plus other safety equipment called for by federal, state, and local laws for inspection and testing of drilled piers and protection of workers.

3.2.5 Remove loose material and free water from bottom of drilled piers, unless otherwise directed by the Owner's Representative-Geotechnical Engineer. If the bottom is sloping rock, excavate to either a level plane (see 3.1.5) or step the bottom with one step whose rise is less than 1/4 the diameter of the bearing area.

3.2.6 Excavate rock sockets as specified by the Contract Documents. Provide the socket roughness specified. Drill a probe hole to a maximum depth of one pier diameter, unless otherwise directed by the Owner's Representative-Geotechnical Engineer.

3.2.7 Keep all excavated materials an acceptable distance away from each open pier excavation.

3.3—Steel casing and liner

3.3.1 *Delivery, handling, and storage of casing*

3.3.1.1 Deliver casing to the site in an undamaged condition.

3.3.1.2 Handle and protect casing to maintain diameter within ±2% of the specified diameter.

3.3.2 Casing shall be continuously joined and have the strength and rigidity needed to maintain the required excavation dimensions against earth, drilling, and water pressures. If an inner permanent liner is used to permit casing withdrawal, it shall have the strength and rigidity to contain the concrete during placement.

3.3.2.1 Provide steel casing for shaft excavation where required. Make diameter of excavation such that the void space outside any temporary casing is minimized.

3.3.2.2 Withdrawal of temporary casing is the Contractor's option, provided the requirements in Section 3.6 are met.

3.4—Reinforcing steel

3.4.1 Reinforce drilled piers as specified in the Contract Documents.

3.4.2 Place reinforcement for drilled piers, as shown on the Contract Documents, after acceptance of the drilled pier excavation.

3.4.3 Reinforcement shall be free of mud, oil, other surface contamination, and excessive corrosion at time of concrete placement, in accordance with ACI 301.

3.4.4 The sizes and configuration of vertical reinforcing and tie steel shall be as shown on the Project Drawings. Maintain proper dimension and location of reinforcing steel during concreting operations.

3.4.5 Straighten or repair bars with kinks or unspecified bends in a manner acceptable to the Owner's Representative that will not damage the bars and will maintain the required cover.

3.4.6 Reinforcement cover shall be not less than 3 in. (75 mm) where exposed to soil and not less than 4 in. (100 mm) in cased piers where the casing is to be withdrawn. Provide spacer rollers acceptable to the Owner's Representative to maintain cover.

3.4.7 Splice vertical reinforcing steel in accordance with ACI 318 for compression or tension. Submit splice details.

3.4.8 Weld reinforcing bars in accordance with AWS D1.4. Use AWS-certified welders.

3.4.9 The minimum clear distances between reinforcement, including lapped bars, shall be 4 in. (100 mm) or four times the maximum aggregate size, whichever is larger.

3.4.10 Place reinforcement before pier concreting begins, unless otherwise directed by the Owner's Representative-Geotechnical Engineer.

3.4.11 Limit reinforcing-steel vertical movement during casing withdrawal to 6 in. (150 mm).

3.5—Concrete

Concrete work shall conform to ACI 301.

3.5.1 Dewater drilled pier excavation before placing concrete. Dewater in a manner that will not create subsidence or ground loss that might adversely affect the Work or existing adjacent structures.

3.5.2 If water inflow or sidewall instability encountered exceeds an amount acceptable to the Owner's Representative-Geotechnical Engineer, use alternative means to reduce inflow, such as extending casing, installing outside deep wells, grouting, or other acceptable means.

3.5.3 If water seepage or sidewall instability is still considered excessive by the Owner's Representative-Geotechnical Engineer, follow the procedure specified in Section 3.7.

3.5.4 Place concrete as soon as practical after completion of excavation and the bottom condition has been accepted. Notify the Owner's Representative-Geotechnical Engineer of concrete placement at least 24 hours in advance.

3.5.5 Complete placement of concrete in uncased or belled excavations during 1 work day.

3.5.6 Guide placement of free-fall concrete so as not to hit the reinforcement, hole sides, or anchor bolt assemblies. Vibration of concrete free falling more than 20 ft is not required.

3.5.7 Place concrete in pier in one continuous operation, unless otherwise directed by the Owner's Representative-Geotechnical Engineer. Level, roughen, and clean the surface of construction joints to the satisfaction of the Owner's Representative-Geotechnical Engineer before recommencement of concrete placement. Provide reinforcing dowels or shear key when directed by the Owner's Representative-Geotechnical Engineer.

3.5.8 Place concrete underwater in accordance with Section 3.7.

3.5.9 Concrete tests

3.5.9.1 The Testing Agency will take and test a minimum of one set of four concrete cylinders per drilled pier but not more than one set per truckload for quality assurance. The Testing Agency will perform a compression test on cylinders at 28 days.

The Contractor shall cooperate with the testing agency in the field testing and storage of test specimens, and shall perform testing for quality control or to supplement the testing agency testing, or accept the furnished testing agency testing. Submit batch plant tickets with mixture proportion information and provide open time and drum revolutions since batching.

3.5.10 Cure and protect tops of piers to prevent moisture loss and temperature extremes in accordance with ACI 301.

3.6—Casing withdrawal

3.6.1 Provide means and opportunity for the Owner's Representative-Geotechnical Engineer to inspect the operation during the withdrawal of casing and placing of concrete.

3.6.2 Coordinate casing withdrawal with concrete placement so that the concrete pressure head exceeds the anticipated outside soil and water pressure above the bottom of the casing at all times during casing withdrawal.

3.6.3 Do not withdraw casing after concrete has attained initial set as determined by Owner's Representative. Where casing is withdrawn, provide concrete with a minimum slump of 6 to 8 in. (150 to 200 mm) (see [Table 2.4.3](#)) and with a retarder to ensure minimum slump requirement is maintained during casing withdrawal. Check the concrete level before, during, and after withdrawing casing to confirm that separation of shaft concrete has not occurred. Do not vibrate concrete internally before the casing is withdrawn. A casing vibratory extractor is permitted.

3.6.4 Vibrate top 5 ft (1.5 m) of concrete after temporary casing has been withdrawn or when casing is permanent and concrete slump is less than 6 in. (150 mm).

3.6.5 Fill void space between permanent casing and shaft excavation or between permanent liner and temporary casing with an accepted fluid grout or other accepted material.

3.7—Slurry displacement method

3.7.1 General

This Section covers the special requirements for the slurry displacement method of installation. Materials and execution related to steel casing, reinforcing steel, and concrete shall be in accordance with [Sections 3.3, 3.4, and 3.5](#), respectively, except as noted. The installation and slurry materials shall be in accordance with this Section.

3.7.2 Installation procedure

3.7.2.1 Use slurry, unless the water, in combination with colloidal fines from soil being excavated, stabilizes the hole and is acceptable to the Owner's Representative-Geotechnical Engineer.

3.7.2.2 Obtain slurry from sources acceptable to the Owner's Representative-Geotechnical Engineer. Mix, store, and transport slurry using equipment made for these purposes.

3.7.2.3 Submit plans and test results for any physical or chemical treatment of the water or slurry necessary to meet the requirements of [Table 2.6](#) that are acceptable to the Owner's Representative-Geotechnical Engineer.

3.7.2.4 Set temporary surface casing to contain the slurry, unless otherwise specified by the Owner's Representative.

Use slurry to stabilize the excavation. Where drilled piers are installed below groundwater or in caving soils, maintain the slurry level in the excavation not less than 5 ft (1.5 m) above the groundwater level to provide a stable hole. Maintain the slurry level above any unstable zones a sufficient distance to prevent caving or sloughing of those zones. Demonstrate to the satisfaction of the Owner's Representative-Geotechnical Engineer that stable conditions are being maintained.

3.7.2.5 The in-hole slurry shall meet the specified properties, as given in [Table 2.6](#), before concreting. Recycling of slurry is permitted provided that the recycled slurry satisfies the [Table 2.6](#) requirements. Clean, recirculate, remove sand from, or replace the slurry to maintain the required slurry properties. Submit to the Owner's Representative-Geotechnical Engineer a written record of results for the [Table 2.6](#) tests for each drilled pier installed.

3.7.2.6 Complete concreting the drilled pier the same day that the excavation is completed. If this is not possible, redrill, clean, and test the slurry in the excavation before concreting.

3.7.3 *Excavation*

3.7.3.1 Use excavation methods that leave the sides and bottom of the hole free of loose material that would prevent intimate contact of the concrete with firm, undisturbed soil or rock. If loose or unacceptable material is present, reclean the hole to the satisfaction of the Owner's Representative-Geotechnical Engineer.

3.7.3.2 For piers designed without end bearing, the accumulated sediment at the bottom of the pier, measured just before concreting, shall be less than 6 in. (150 mm). If greater, reclean the hole.

3.7.3.3 Remove all soil and excavated materials and store them a sufficient distance from each open pier excavation to avoid contamination of the excavation after final clean out.

3.7.3.4 Use drilling tools and excavation procedures that minimize negative pressure and avoid disturbance of the surrounding material in the excavation. Raise and lower the drilling tool in the hole at a rate that does not swirl the slurry and affect the stability of the hole.

3.7.3.5 At the completion of excavation and also before the start of concrete placement, clean the drilled-pier bottom with an air-lift, recirculation system, or a cleanout bucket equipped with a one-way flap gate that prevents soil in the bucket from reentering the pier.

3.7.4 *Concrete and reinforcing steel*

3.7.4.1 Place reinforcing steel in accordance with the Contract Documents.

3.7.4.2 Use concrete in the slurry displacement method that satisfies the requirements of [Section 2.4](#).

3.7.4.3 Do not start concrete placement until a concrete supply adequate to fill the pier is assured. Place concrete within the time limit during which the excavation remains clean and stable and the concrete maintains the required slump. If an unplanned cold joint occurs, see [Section 3.5.7](#).

3.7.4.4 During concrete placement, the displaced slurry shall be pumped to holding tanks. Do not spill onto or contaminate the site. Do not use excavated slurry pits, unless accepted by the Owner's Representative.

3.7.4.5 Dispose of the slurry off site in a legally acceptable manner. Submit approval of governing agencies with jurisdiction.

3.7.5 *Concreting methods*

3.7.5.1 Place concrete by tremie methods or by pumping.

3.7.5.2 Tremie or pump pipe shall be made of steel and have watertight joints. Tremie pipe shall have a minimum diameter of 8 in. (200 mm), and pump pipe shall have a minimum diameter of 4 in. (100 mm).

3.7.5.3 A capped or pig-plugged tremie or pump pipe shall be inserted and seated in the excavation at the bottom of the pier before the commencement of concrete placement.

3.7.5.4 The bottom of a capped pipe or tremie shall be tightly closed with a bottom plate or other acceptable device. Place enough concrete in the pipe or tremie to prevent the flow of slurry into it.

3.7.5.5 If a pig is used, set the open tremie pipe loosely on the bottom. Insert the pig at the top and then place concrete pushing the pig ahead, separating the concrete from the drilled pier excavation fluid. Take care to ensure that the pig is properly sized to fit in the pipe, and keep the concrete separate from the slurry so that all slurry is expelled from the pipe during the initial charging process. When the pipe is filled with concrete, lift the pipe off the bottom the minimum amount needed to start the concrete flowing. Once concrete flow has started, place concrete into tremie at a fast enough rate to maintain a positive head of concrete inside the pipe relative to slurry level outside pipe.

3.7.5.6 Embed tremie or pump pipe a minimum of 10 ft (3 m) in the concrete to maintain a seal throughout concrete placement to prevent reentry of slurry suspension into the pipe. If the seal is lost (see [Section 3.7.5.4](#)), withdraw pipe, recreate the seal by embedding a capped tremie or pump pipe 10 ft into the existing concrete, and restart the tremie operation.

3.7.5.7 Displace out of the pier or remove from the pier the first portion of concrete that comes to the top of the pier that contains concrete contaminated with slurry until uncontaminated concrete is visible. Add or remove concrete to the specified cutoff level.

3.7.5.8 Raise or lower the tremie pipe in a manner that does not break the seal and does not cause pier defects, such as vertical bleed channels or piping, or segregation.

3.7.5.9 Do not use aluminum pipe or equipment for placing concrete.

3.7.5.10 Report in graphical format the theoretical and actual volume of concrete placed versus depth at elevation intervals not exceeding the shaft diameter.

3.7.6 *Inspection and testing*

3.7.6.1 The Owner's Representative-Geotechnical Engineer will inspect drilled pier installations and determine the actual final bearing level. Inspection and testing will be done using the criteria set forth in the Contract Documents.

3.7.6.2 Perform slurry testing by the test methods in [Table 2.6](#). The Owner's Representative-Geotechnical Engineer will inspect the Contractor's testing. Provide all test equipment required for the tests specified in [Section 2.6](#). Have

available at the site a slurry sampler capable of obtaining slurry samples at any depth within the drilled pier excavation.

3.7.6.3 The testing agency will sample and test concrete in accordance with **Section 3.5.9**.

3.8—Placement of anchorage embedments

3.8.1 Before placement, all anchorage components shall be free of contaminating material or unacceptable corrosion.

3.8.2 Place anchorage components either by pushing into the fresh concrete or by setting in the open shaft. If the anchorage components are not easily pushed into the fresh concrete, the concrete shall be vibrated to ensure full contact between anchorages and concrete.

PREFACE TO SPECIFICATION CHECKLISTS

P1. Checklists do not form a part of ACI Specification 336.1. Checklists assist the specifier in selecting and specifying project requirements in the Project Specifications.

P2. Building codes set minimum requirements necessary to protect the public. ACI Specification 336.1 may stipulate requirements more or less restrictive than the minimum. The specifier shall make adjustments to the needs of a particular project by reviewing each of the items in the checklists and including those the specifier selects as mandatory requirements in the Project Specification.

P3. The mandatory checklist requirements indicate Work requirements regarding specific qualities, procedures, materials, and performance criteria that are not defined in the ACI Specification 336.1.

P4. The optional checklists identify specifier choices and alternatives. The checklists identify the sections, parts, and articles of the reference specification and the action required or available to the specifier.

P5. Recommended references

The documents of the various standards-producing organizations and publications referred to in the Checklists to Specification ACI 336.1 are listed below with their serial designation. These references are intended to provide guidance to the Specifier and are not considered to be part of Reference Specification ACI 336.1. Standards referred to in this Specification and considered to part of Reference Specification ACI 336.1 can be found in Section 1.3 Reference standards.

American Concrete Institute (ACI)

ACI 311.5	Batch Plant Inspection and Field Testing of Ready-Mixed Concrete
ACI 336.3	Design and Construction of Drilled Piers

Deep Foundations Institute (DFI)

DFI-ADSC	Drilled Shaft Inspectors Manual
DFI	100 Day Document
ADSC	The International Association of Foundation Drilling
DFI-ADSC	Drilled Shaft Inspectors Manual
ADSC	Downhole Entry Manual
ADSC-FHWA	The Effects of Free-Fall Concrete in Drilled Shafts

Federal Highway Administration (FHWA)

FHWA-RD-92-004	Drilled Shafts for Bridge Foundations.
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The above publications can be obtained from the following organizations (additional references can be found in Section 1.3 of the Specification):

American Concrete Institute
P.O. Box 9094
Farmington Hills, Mich. 48333-9094

ADSC: The International Association of Foundation Drilling
9696 Skillman Street
Suite 280
Dallas, Tex. 75243

American Petroleum Institute
1220 L Street, NW
Washington, D.C. 20005

Deep Foundations Institute
120 Charlotte Place, 3rd Floor
Englewood Cliffs, N.J. 07632

Federal Highway Administration
Turner Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Va. 22101-2296

MANDATORY REQUIREMENTS CHECKLIST	
Section/ Part/ Article	Notes to Owner's Representative
1.1.1	<p>Specify which installation methods are compatible with the design and exclude methods that are not compatible.</p> <p>Installation methods can adversely affect design parameters such as end bearing and side resistance. Examples of this would be the effect of using temporary or permanent casing on design-side resistance, and in-hole dewatering's effect on loosening the bearing soil and its resulting reduction in end-bearing capacity.</p> <p>Designers sometimes take into account the effects of different installation methods on their design parameters, such as reducing the allowable end bearing to allow for bottom loosening. If a designer does not feel that appropriate reductions can be determined, however, those installation methods that can adversely affect the design assumptions should be excluded.</p>
1.6	<p>Include in the qualification requirements for bidders certain specific actions.</p> <p>Because drilled piers require that Contractors have specific knowledge and expertise, the following actions should be required of all bidders:</p> <ol style="list-style-type: none"> 1. Visit the site; 2. Attend all prebid conferences; and 3. Submit and have accepted a written résumé of drilled pier experience including quantity, depth, diameter, installation method, owner, engineer, and references. Any general contractor desiring to subcontract the drilled pier work should ensure that the proposed subcontractor has fulfilled those requirements. Failure to do so is ample cause for disapproval of the subcontractor.
2.2	<p>Specify size, wall thickness, type of steel, and length of required permanent casing or liner.</p> <p>Permanent casing, when part of the design, should be specified and shown on the Contract Documents. Permanent casing is normally of two types: smooth-wall steel casing strong enough to resist all imposed pressures and thin-walled metal liner for use as an economical concrete form when not subject to soil and water pressure. An example of the latter case would be when used inside temporary casing that is later withdrawn after concrete has been placed and has taken initial set within the metal liner. Normally this liner is a corrugated steel pipe.</p> <p>When a permanent casing is used to carry part of the design load, all joints should have full-penetration welds or a mechanical alternative.</p>
2.3.2	Specify splice details not covered in Contract Documents.
2.4	<p>Specify the minimum 28-day strength, maximum aggregate size, and concrete characteristics.</p> <p>Drilled pier concrete characteristics are vital for successful pier installation and are different from those needed to build above-ground structures. In addition to strength, the other principal characteristics are fluidity, nominal maximum aggregate size, and setting time. The amount of time the concrete remains fluid is especially important for piers installed by the slurry displacement method. The concrete mixture should maintain minimum slump requirements throughout the concrete placement time and extraction of any temporary casing in contact with the concrete. Combinations of retarders and high-range water-reducing admixtures used to extend fluid properties should be tested in advance of construction and should meet requirements of ACI 212.4R and ASTM C 494. The selection of the concrete characteristics and construction method should be consistent with Table 2.4.3 and based on an intimate knowledge of the installation process, subsurface conditions, and design objectives. The geotechnical engineer's guidance in design and construction is a prerequisite to successful construction.</p>

MANDATORY REQUIREMENTS CHECKLIST (continued)	
Section/ Part/ Article	Notes to Owner's Representative
3.2.6	Specify method of constructing socket. The required roughness of the socket should be determined by the Design Geotechnical Engineer. If the socket requires a specific groove width, depth, and spacing, this should be specified.
3.5.7	Specify splice or dowel requirements at cold joints.

OPTIONAL REQUIREMENTS CHECKLIST	
Section/ Part/ Article	Notes to Owner's Representative
1.1.1	If some pier diameters are less than 30 in. (750 mm), review the Specification and modify. If pier diameters are less than 30 in. (750 mm), certain elements of the Specification can be inappropriate, such as the permitted use of free-fall concrete and any requirements for physical down-hole inspection. The risk of free-fall concrete scraping the sides of the shaft while falling increases dramatically as the shaft diameter decreases below 30 in. (750 mm), and physical bottom inspection of pier diameters less than 30 in. (750 mm) is impractical.
1.2	Modify definitions. Owner's Representative —At different times, different persons are authorized to act as the Owner's Representative. The decision as to which person is acting on behalf of the owner at a specific time or under a specific circumstance rests with the Owner and should be established in the Contract Documents. The Design Structural Engineer and the Design Geotechnical Engineer should be retained for construction inspection and construction engineering because design decisions will be required during construction of the foundations. Owner's Representative—Geotechnical Engineer —Generally, the Owner's Representative could be any one of a number of qualified persons. Under specific circumstances, however, only a qualified Geotechnical Engineer should act. These specific circumstances are set forth in this Reference Specification. The Geotechnical Engineer is also known as a Soils Engineer, Soils and Foundations Engineer, or Earthwork and Foundation Engineer. The Design Geotechnical Engineer also should be the Inspecting Geotechnical Engineer. When the Inspecting Geotechnical Engineer is not the Design Geotechnical Engineer, the Inspecting Geotechnical Engineer will have the responsibilities and authority of the Design Geotechnical Engineer and should be knowledgeable of and in agreement with the design assumptions. Pig —Also called a rabbit or go-devil. Testing Agency —The contractual relationship between the Testing Agency and the Owner should be established in the Contract Documents. The Testing Agency should be retained by the Owner.

OPTIONAL REQUIREMENTS CHECKLIST (continued)	
Section/ Part/ Article	Notes to Owner's Representative
1.6.2	<p>Supply subsurface investigation reports, if not included in bid documents.</p> <p>Logs of borings and test data are available for the Contractor's information and for the Contractor's interpretation. Logs and test data are not represented as a complete description of the site subsurface condition, but only display what was found in borings at the indicated locations on the day the holes were drilled. The earth and groundwater conditions may be different from those described in the subsurface investigation. This information, however, serves as a baseline from which significant variations that affect the contractor's work and costs can be noted. Procedures for a changed or unexpected conditions claim should be established in the Contract Documents and should include procedures for dispute resolution that reduce the likelihood and cost of litigation. The most common alternative dispute-resolution procedures involve mediation, arbitration, or dispute review boards. Appropriate alternative dispute-resolution procedures are available from the following organizations:</p> <p>Deep Foundations Institute 120 Charlotte Place, 3rd Floor Englewood Cliffs, N.J. 07632</p> <p>The American Arbitration Association 140 West 51st Street New York, N.Y. 10020-1203</p> <p>ASFE/The Association of Engineering Firms Practicing in the Geosciences 8811 Colesville Road Suite 6106 Silver Springs, Md. 20901</p>
1.6.4	<p>Specify if Prebid or Preconstruction conferences <u>are not</u> required.</p> <p>Requirements for prebid conference attendance by Contractors are important on large and complex projects to explain any unusual aspects of the foundation system that can significantly affect the Contractor's costs before bidding. A preconstruction conference with the successful bidder is recommended, except for small or routine projects.</p> <p>The preconstruction conference is normally organized by the general Contractor and is attended by the drilled pier subcontractor, Owner's Representative, and Testing Agency. The purpose of the preconstruction meeting is to establish or confirm lines of communication and roles of the parties involved, review construction procedures and schedule to be followed, and answer any questions that the parties involved might raise.</p>

OPTIONAL REQUIREMENTS CHECKLIST (continued)	
Section/ Part/ Article	Notes to Owner's Representative
1.7	<p>Review Quality-Assurance Program</p> <p>Construction of drilled piers involves an inherent risk of defects. This risk becomes greater when using the slurry displacement method. The probability of some defects occurring during construction is recognized in design by the relatively low values of allowable stress permitted in the concrete compared to above-ground construction. The role of quality assurance is to reduce the probability of defects in the drilled piers.</p> <p>No simple post-construction method is available to conclusively determine the absence or presence of a pier defect. Nondestructive test methods, such as the sonic echo or the impulse test, when performed and interpreted by trained and experienced personnel, can be useful as part of an overall quality assurance program. Cross-hole sonic logging using preplaced access tubes attached to the reinforcing bar cage offers the most reliable nondestructive indication of defects in the concrete zone between the tubes.</p> <p>Interpretation of nondestructive test information is required by the Owner's Representative-Geotechnical Engineer in assessing the acceptability of a given pier having a suspected defect.</p>
1.7.1	<p>Review role of Owner's Representative-Geotechnical Engineer</p> <p>The Geotechnical Engineer who performed the subsurface exploration and prepared the geotechnical engineering report that forms the basis of the foundation design should review, modify, or accept the Project Documents and is also best qualified to provide the necessary inspection of drilled pier construction and determine the suitability of the bearing stratum actually encountered in the field. Field tests and observations should be interpreted and correlated with design assumptions and the experience level of the Geotechnical Engineer. This is particularly true in variable soil and rock deposits, and where isolated individual tests can be misleading. For example, a low unconfined compression test result in an otherwise hard glacial clay deposit may be due to a sand and silt seam and thus not be indicative of the actual confined compressive strength of the soil.</p> <p>If the Inspecting Geotechnical Engineer is not the Design Geotechnical Engineer, the experience level of the Inspecting Geotechnical Engineer is even more critical. The Inspecting Geotechnical Engineer should be particularly knowledgeable of the local conditions and understand and agree with the Design Geotechnical Engineer's report and design parameters. If not in agreement, the Inspecting Geotechnical Engineer should either turn down the assignment or recommend new design parameters and a new basis for the design with the agreement of the Design Structural Engineer.</p>

OPTIONAL REQUIREMENTS CHECKLIST (continued)	
Section/ Part/ Article	Notes to Owner's Representative
1.7.2	<p>Modify Contractor requirements.</p> <p>The experience and equipment requirements of contractors for acceptance as bidders will vary with the size and complexity of a project. The default of "three years of acceptable experience in installing similar types of drilled piers" should be adequate for most projects. These requirements can be adjusted as determined by the Geotechnical Engineer, particularly when working with complex or variable soil formations, deep and large diameter piers, pier construction involving casing withdrawal, or the slurry displacement method.</p> <p>The requirement that the Contractor "shall provide means for the Owner's Representative-Geotechnical Engineer to inspect each drilled pier before concreting" can mean down-hole inspection. In such cases, the ADSC down-hole entry manual procedures should be required. There is a growing trend to find alternatives to down-hole entry for safety reasons. In this case, procedures for providing topside inspection are described in the DFI-ADSC <i>Drilled Pier Inspector's Manual</i>.</p> <p>The Contractor's quality-control program normally involves retaining a testing agency to design the concrete mixture or to work with a supplier who already has an approved mixture, based on ACI 301 requirements. The concrete supplier provides quality control of the mixture sent to the site, making periodic cylinders for strength testing. The Contractor normally relies on the Owner's testing agency for the confirmation of concrete mixture strength results. In this case, close cooperation between the Contractor and the testing agency is essential. The Contractor's quality-control program should have one person designated to work with the testing agency with the authority to make certain that proper cooperation is achieved.</p> <p>Under conditions acceptable to the Owner's Representative-Geotechnical Engineer, the Contractor can perform partial excavation without the presence of the Owner's Representative-Geotechnical Engineer. An example is drilling and setting top temporary casing in open areas not adjacent to sensitive property.</p>
1.7.3	<p>Modify quality-assurance tests.</p> <p>The testing agency normally performs all of the quality-assurance, concrete-related activities (slump, air yield, cylinder preparation and storage, and compressive strength). The quality-assurance, soil-related tests (primarily strength and penetration) are performed by the Geotechnical Engineer. The Geotechnical Engineer and testing agency may be the same organization or may be different entities.</p>

OPTIONAL REQUIREMENTS CHECKLIST (continued)	
Section/ Part/ Article	Notes to Owner's Representative
2.2	<p>Review temporary casing requirements.</p> <p>Temporary casing required by field conditions is usually not shown on the Contract Documents. Some field conditions, however, such as nearby existing structures, require special treatment. Use of temporary casing should be consistent with slump requirements (minimum slump of 6 in. [150 mm]) and zero or reduced side-resistance design.</p> <p>Temporary casings should have sufficient wall thickness and strength for handling stresses and to resist all soil and water pressures. A table of minimum casing wall thicknesses for various diameters and hydrostatic pressure differentials is shown in the DFI-ADSC <i>Drilled Shaft Inspector's Manual</i>.</p>
2.3	<p>Review reinforcing steel requirements. Specify Grade of reinforcement.</p> <p>The ASTM grade of reinforcing steel can affect constructibility. For piers with high bending moments, increasing the steel grade reduces the number of bars, increases the space between bars, and thereby improves the concrete flow.</p>
2.4	<p>Review ACI 301 Optional Checklist</p> <p>In general, the applicable items of the ACI 301 checklists have been incorporated into this checklist; however, other items can apply. For example, if water-soluble sulfate exists in the soil or groundwater at the project site, specify a cement meeting criteria set forth in Table 4.3.1 of ACI 318.</p>
2.5	<p>Specify mixture proportions or required properties of sand-cement grout.</p> <p>An annular void space requires filling in two cases. One is when a permanent steel casing has been inserted in an oversized hole that might cave and collapse against the casing so that the amount of void space cannot be observed. The other is an annular space between a permanent form liner and an oversized temporary casing installed during excavation. The temporary casing is removed after concrete has been placed to cut-off in the permanent form liner and initial set has occurred. In the first case, a cement-mix-fluid grout that can be pumped under pressure through a 1 to 2 in. diameter grout pipe is required to ensure the grout reaches all possible void zones. In the second case, the entire void space can be seen so that a gravity flowable grout can be acceptable, depending on depth and lateral restraint assumptions. See Optional Checklist 3.6.5. The Design Geotechnical Engineer, in consultation with the Design Structural Engineer, should recommend the minimum grout properties.</p>

OPTIONAL REQUIREMENTS CHECKLIST (continued)	
Section/ Part/ Article	Notes to Owner's Representative
2.6	<p>Specify slurry materials and properties and suitability of polymer slurry. Specify variations from slurry properties given in Table 2.6</p> <p>The use of slurries to maintain open shafts is now relatively common throughout the drilled-pier industry. In recent years, the use of polymers has increased dramatically because of ease of use and disposal compared to traditional bentonite slurries. Table 2.6 indicates the normal working range of slurry properties for proper construction. Variations from this range may be permissible and even necessary for certain situations. When working in permeable sand and gravel deposits, it may be desirable or necessary to increase the polymer viscosity above 90 s/qt (95 s/L).</p> <p>When working with mineral slurry, in some caving situations, it may be necessary to permit the density of the slurry to increase above 70 lb/ft³ (1120 kg/m³) in the case of end-bearing piers. Working with an experienced contractor with prior experience in such caving soils is helpful in making necessary modest adjustments to the table values.</p> <p>In addition, when working with piers designed for side-resistance and without end bearing where Table 2.6 permits up to 20% sand content by volume, the specification writer should consult with the Geotechnical Engineer with respect to local experience and practices to see if this limit should be lowered.</p> <p>Because high sand content in the slurry can be the cause of pier defects if the sand settles out of the slurry during concreting, some researchers recommend maintaining the same maximum sand content requirements for both side-resistance and end-bearing designed piers.</p>
3.1.2	<p>Determine if the location tolerances are compatible with the design. Specify location variation if different from specification.</p> <p>The location tolerances given in the Specification are the national consensus standards. The designer should check to see that the stress induced by the maximum eccentricity permitted is within code-allowable values. If a tighter tolerance is required (particularly with small diameter shafts), it should be specified.</p>
3.1.3	<p>Specify out-of-plumb tolerance requirement if different from the specification.</p> <p>For most piers with partial-length reinforcement, 1.5% is satisfactory.</p> <p>The out-of-plumb tolerance for shafts that are reinforced full length depends on the structural design. It may be increased to 2% by increasing the reinforcement.</p> <p>For unreinforced piers extending through materials offering minimal or no lateral restraint (water, normally consolidated organic soils, and soils that might liquefy during an earthquake)—12.5% of the pier diameter but not more than 1.0% of the pier length should be used.</p> <p>For unreinforced piers extending through materials offering lateral restraint (soils other than those indicated above)—not more than 1.5% of the pier length should be used.</p>

OPTIONAL REQUIREMENTS CHECKLIST (continued)	
Section/ Part/ Article	Notes to Owner's Representative
3.1.4	<p>Specify conditions when bottom area or levelness can vary from that specified.</p> <p>Mechanical drilling equipment will normally excavate a relatively flat bottom; exceptions may include stratified sloping rock or broken rock soil interfaces. In these situations, stepped bottoms and even sloping bottoms may be acceptable, depending on the degree of lateral confinement of the pier. Adequate lateral confinement is particularly critical when working in karst (cavernous limestone) topography where adjacent cavities in the limestone are possible.</p> <p>A bottom area less than design is unlikely because the normal method of excavation uses drilling tools equal to the design pier diameter. Bearing areas measured to be slightly smaller than design, however, may be acceptable to the Geotechnical Engineer if the actual bearing capacity exceeds that called for in the design.</p>
3.1.5	<p>Specify conditions when the pier diameter can vary from that specified.</p> <p>Normally, the constructed pier diameter will equal or exceed the design pier diameter because the drill tools typically drill a slightly oversized shaft due to minor scraping as the tools come in and out of the pier. There may be occasions, however, where slow ground squeeze is occurring and the measured pier diameter is slightly below design pier diameter. In this situation, the Owner's representative can accept the reduced pier diameter based on the reserve structural capacity in the pier design. Piers designed to carry the load primarily in side-resistance often have reserve capacity.</p> <p>There are situations where obstructions require downsizing the shaft below the initial design diameter. A significant reduction in shaft diameter will usually require an increase in the concrete strength to maintain stresses below code-allowable values.</p> <p>A maximum pier diameter is rarely specified and is self-constraining due to the increased volume of concrete and subsequent expense borne by the Contractor as the excavated diameter exceeds the design diameter. There are instances, however, when a maximum diameter should be specified in the Contract Documents due to adjacent obstructions or existing construction.</p>
3.1.6	<p>Specify conditions when the anchorage embedment tolerance can vary from that specified.</p> <p>If the element to be anchored to the drilled pier is structural steel or precast concrete, the allowable tolerance is usually tight. Due to the crowded conditions, it is often advisable during placement of the drilled-pier concrete to stop the concrete in the pier below the anchorage embedment location. The anchorage can then be set under more closely controlled conditions.</p> <p>If the element to be anchored is cast-in-place concrete, the tolerance is usually less tight.</p>

OPTIONAL REQUIREMENTS CHECKLIST (continued)	
Section/ Part/ Article	Notes to Owner's Representative
3.2.3	<p>Specify provisions for compensation if the Owner's Representative-Geotechnical Engineer requires piers to extend below the specified depth or to stop short of the design depth or to change the dimension of the bell.</p> <p>Inspection and testing at the bottom and side of each pier will be by the Owner's Representative-Geotechnical Engineer. If test results indicate the stratum is not capable of providing the required allowable service load-bearing pressure, the Owner's Representative-Geotechnical Engineer will determine what adjustments need to be made. Additional borings, in-place and laboratory testing, and verification of the design loads are usually performed before determining what adjustments are appropriate. The adjustments may include, but are not limited to, advancing the shaft length or enlarging the bell diameter for the appropriate bearing pressure.</p> <p>For side-resistance piers, the level of bearing stratum and material type are confirmed by observation of soil or rock from cuttings and rate of penetration.</p> <p>Bottom elevation of drilled piers shown on project drawings are taken from the design geotechnical report and are estimated depths for bid purposes. Provision should be made in the Contract Documents to compensate the Contractor when required by the Owner's Representative-Geotechnical Engineer to deepen the drilled pier beyond the design depth. This can be done based on a unit add and deduct price for above and below design depth. Compensation for changing the size of the bell, if required, can be based on an add or deduct price for the bell volume difference.</p>
3.2.3.1	<p>Specify minimum number or minimum percent of piers to be probed. Specify depth of probe if different than specification.</p> <p>Whether and what percent of piers need to be probed should be specified. Probing depends on the level of knowledge of the local geology and the extent of the prior subsurface exploration program. Probing is desirable when there is a distinct possibility of encountering voids or soft zones below the pier within the zone of significant influence. In fissured or cavity-prone rock, more than one probe per pier and deeper probes are sometimes required. The extent of probing specified should be determined by the Design Geotechnical Engineer. Compensation should be established based on unit bid prices for added probes and deeper probes.</p>
3.2.3.4	<p>Specify method of checking bell diameter.</p> <p>If down-hole inspection is precluded, either because of the presence of gas or other safety issues, or excavation is occurring under slurry, indirect measurements taken from the top of the shaft will be required. Examples of methods of measurement are described in the DFI-ADSC <i>Drilled Pier Inspector's Manual</i>.</p>

OPTIONAL REQUIREMENTS CHECKLIST (continued)	
Section/ Part/ Article	Notes to Owner's Representative
3.2.5	<p>Specify amount of loose material or water permitted in-hole at time of concrete placement.</p> <p>The amount of loose material or water permissible in the drilled pier shaft at the time of concrete placement depends on the rate of water inflow, the amount of settlement tolerable, and the amount of excess concrete strength.</p> <p>For end-bearing piers, the thickness of loose material acceptable at the base of the pier should not exceed twice the tolerable differential settlement, that is, an average of 1 in. (25 mm) of loose material for an allowable 0.5 in. (15 mm) differential settlement.</p> <p>Up to 2 in. (50 mm) of water is usually considered acceptable, provided there is at least 10% reserve concrete strength. This allows for some strength reduction that is caused by this water mixing with the initial load of concrete. Free-fall concrete placed into as much as 6 in. (150 mm) of water has been reported without significant adverse effects, but this is not recommended. (Reference: ADSC report on "The Effects of Free-Fall Concrete in Drilled Shafts," [1994]).</p>
3.2.7	<p>Specify if on-site disposal is permissible or required.</p> <p>Disposal of excavated material offsite is usually specified in the Contract Documents as the responsibility of the Contractor. In situations where the excavated material is suitable for fill, the location of on-site disposal can be specified.</p>
3.3.2	<p>Specify requirements for permanent liners not designed for earth and water pressures.</p> <p>Permanent liners used as a concrete form inside a smooth-walled steel temporary casing are usually thin-walled corrugated metal of sufficient thickness to handle the tensile forces created by the pressure of fluid concrete. The corrugated permanent liner should meet the requirements of ASTM A 929.</p>
3.4.1	<p>Specify full-depth reinforcement.</p> <p>Full-depth reinforcement is usually required only for piers subjected to high-uplift or high-bending moments. Even in the case of high-bending moments, full-depth reinforcement may not be necessary depending on the depth of the pier and the soil profile. With high lateral soil resistance, the bending moment can reduce to zero at a point well above the base of the shaft. The extent of steel reinforcement required can be determined following the procedures outlined in ACI 336.3R.</p>
3.4.7	<p>Specify if all bars can be spliced at the same elevation.</p> <p>When there is a possibility that future adjacent construction could result in a lateral earth movement producing bending in the drilled pier, the possibility of tension in the vertical reinforcement should be considered by the Design Structural and Geotechnical Engineers. If there is a possibility of tension, the design and spacing or staggering of splices in the vertical reinforcing should be designed according to ACI 318. If there is no possibility of such an occurrence, all the vertical bars can be lap spliced at the same elevation provided this does not result in excessive congestion of steel at the splice.</p>

OPTIONAL REQUIREMENTS CHECKLIST (continued)	
Section/ Part/ Article	Notes to Owner's Representative
3.4.11	<p>Specify the tolerance of vertical movement of reinforcing steel if different than specification.</p> <p>There may be situations, such as a partial-depth reinforcing, where a tighter tolerance on reinforcing steel should be specified, and situations such as a full-depth reinforcing, where much greater movements can be specified. If movements greater than 6 in. (150 mm) are specified, other provisions may be necessary to ensure that the greater steel movement has not resulted in defective concrete through arching. For example, if the steel movement occurred as the temporary casing was being withdrawn, it may be a sign that the concrete is binding to the casing and arching concrete between the reinforcing cage and across the casing. In this case, there is the possibility that water and soil could inflow beneath the casing into the concrete below the arching. Thus, even where the steel is not required structurally, acceptance of greater than 6 in. (150 mm) of steel movement should be qualified, that is, acceptable only if concrete continuity and integrity is confirmed by testing (coring or nondestructive testing as described in FHWA-RD-92-004).</p>
3.5.4	<p>Specify maximum length of time that a pier excavation can remain open.</p> <p>The length of time that a pier excavation can safely remain open depends on the soil conditions and local code restrictions. Many local codes prohibit leaving a shaft open overnight unless cased full length. If the shaft is being constructed under slurry, and the size and depth of the shaft combined with local work-hour restrictions prevent completion in one day, however, leaving the uncompleted shaft open but full of slurry should be satisfactory provided the surface opening is adequately covered to meet safety requirements. Excluding local code restrictions, piers excavated in some dense and hard clay soil could safely remain open more than one day. In soft clays and wet silts, the hole stand-up time may only be minutes. The Design Geotechnical Engineer's input and local experience are necessary in setting time limitations.</p>
3.5.6	<p>Specify if free-fall concrete is not permitted or if the free-fall height is limited.</p> <p>Recent research on free-fall concrete has confirmed that free fall does not cause segregation, at least for fall heights up to 60 ft (18 m) and pier diameters as small as 3 ft (1 m) with 10 in. (750 mm) diameter cages. Even accidentally hitting the reinforcing bar cage does not appear to result in measurable segregation (ADSC-FHWA report on "The Effects of Free-Fall Concrete in Drilled Shafts," [1994]); however, hitting the reinforcing bar cage may displace the cage and should be avoided. Thus, free-fall limits may be desirable in small diameter shafts deeper than 60 ft (18 m).</p>
3.5.8	<p>Specify if tremie or concrete pumping may be used.</p> <p>Concrete pumping through a 4 or 5 in. (100 or 125 mm) diameter pipe offers certain advantages over tremie placement through a 10 or 12 in. (250 or 300 mm) diameter pipe, because a much smaller pig is needed to separate the concrete from the slurry or water. As a result, the pipe, upon initial discharge, can be closer to the bottom (4 in. [100 mm] rather than 10 in. [250 mm]) and still let the pig out. In this way, the potential for initial concrete contamination is reduced. This may be critical in short rock sockets having a high design socket friction of where end bearing has been assumed. In uncased holes, maintaining an accurate depth-versus-concrete volume plot to confirm absence of side wall caving during concreting is much simpler if concrete is pumped rather than gravity tremie placed. The volume of concrete pump stroke can be calculated and verified by a field test.</p>
3.5.9	<p>Specify if concrete compression tests are required at other than 28 days.</p> <p>In some cases, concrete samples have been taken from every truck but tested only if required.</p> <p>For very large piers, that is, over 50 yd³, consider sampling and testing one set of cylinders for every 50 yd³.</p>

OPTIONAL REQUIREMENTS CHECKLIST (continued)	
Section/ Part/ Article	Notes to Owner's Representative
3.6	<p>Specify alternative procedures.</p> <p>All aspects of the procedures outlined for withdrawing temporary casing are critically important whenever there is the potential for an excessive water or slurry pressure head outside of the casing. The procedures required to avoid contamination and defects are well-described.</p> <p>Many cases of defective drilled piers that have resulted in litigation have occurred because one or more of these specified procedures have not been followed.</p>
3.6.5	<p>Specify any requirements for filling of annular space.</p> <p>Annular void space between permanent liner and temporary casing should be backfilled before removing the outer temporary casing to avoid adjacent ground settlement because the soil will eventually collapse into any void space. Where high lateral restraint is not critical and where depths are shallow (less than 20 ft [6 m]), backfilling with sand may be acceptable. Where maximum lateral restraint is desired or where depths are greater than 20 ft (6 m) and arching of sand backfill is likely, filling with a cement grout is recommended. Grout specified to have a minimum 28-day strength of 150 psi (1000 kPa) is adequate for void filling. To ensure complete filling, the grout should be pumped through a pipe extending to the bottom of the annular void space. If sufficiently fluid grout is used, it may be acceptable to place the grout from a concrete truck using a chute and gravity flow. The level of grout in the annulus on the side opposite the grout discharge point should be monitored to assure uniform void filling.</p>
3.7.1	<p>Specify the slurry displacement method. Specify any unique installation details.</p> <p>Article 3.7 offers detailed minimum procedures to be followed when the slurry displacement method is permitted or required.</p> <p>In some piers, the design stresses may be at or close to the allowable code value. These piers need close attention because few, if any, defects can be tolerated. In these cases, additional specified procedures are advisable to minimize the likelihood of undetected defects of significant magnitude.</p> <p>Specifying sonic logging in two or more preplaced access tubes or pipes with 2 in. (50 mm) diameters attached to the reinforcing cage as described in FHWA-RD-92-004 can give an indication of the concrete integrity between the pipes.</p>
3.7.2.2	Specify if slurry must be obtained from specific sources.
3.7.2.4	<p>Specify deviations from Table 2.6.</p> <p>In some soil formations with a very high silt content and a high water table, it may be necessary to increase the allowable maximum slurry density or slurry viscosity to prevent cave-ins. Any deviations should be based on local experience with the soil formation and recommendation of the Design Geotechnical Engineer.</p>

OPTIONAL REQUIREMENTS CHECKLIST (continued)	
Section/ Part/ Article	Notes to Owner's Representative
3.7.3.2	<p>Specify if allowable accumulated sediment is different than specification.</p> <p>Although the requirements for cleaning the bottom of the excavation for side resistance piers is not as strict as that for end-bearing piers, small amounts of sediment, if mixed with the concrete, can result in a significant lowering of concrete strength. Contaminated concrete in rock sockets with high side-resistance values or long side-resistance soil piers can result in relatively high pure-shear stress levels in the concrete approaching ultimate shear-strength levels. In such cases, a much stricter bottom clean-out is required to minimize concrete contamination and potentially significant defects in the concrete. In such cases, bottom clean-out and desanding or desilting requirements similar to end-bearing piers should be specified to avoid the possibility of the bottom sediment mixing with the pier concrete.</p>
3.7.4.5	Specify submittal of documentation that legal requirements have been complied with.
3.7.6.1	<p>Review drilled pier acceptance criteria with the Design Geotechnical Engineer. Specify unique contract requirements.</p> <p>Acceptance of the drilled pier bearing stratum and drilled pier as-built installation is usually done by the Geotechnical Engineer. With regard to the bearing stratum, the type and number of tests performed and any specific acceptance criteria is determined by the Geotechnical Engineer. Because the design bearing value is based on certain assumptions with regard to strength and compressibility, the Design Geotechnical Engineer should decide the type and amount of testing necessary to satisfy the design assumptions. Because some subjectivity is unavoidable, it is strongly recommended that the Design Geotechnical Engineer be involved with the testing and inspection during construction. If there has been an adequate geotechnical investigation for design, and the geology is well known, only minimum testing is required in the field to confirm the bearing stratum. In cohesive soils, this typically is a single unconfined compression test performed on a sample taken from the bearing stratum. Judgment may be required in interpreting test results to account for sample disturbance and the presence of sand and silt seams in the cohesive stratum.</p> <p>In rock, acceptance of the bearing stratum will often depend on a predetermined seam criteria to be used in evaluating probe holes drilled to confirm rock stratum. The seam criteria will vary depending on whether seams are open or filled and on tolerance for foundation settlement.</p>

SUBMITTAL CHECKLIST	
Section/ Part/ Article	Notes to the Owner's Representative
1.7.2	Specify who accepts the quality control program. Specify any additional required submittals by Contractor and distribution thereof.