Section 2433. Concrete Drilled Shaft

2433.01 DESCRIPTION.

A. A concrete drilled shaft foundation consists of reinforced concrete placed in a drilled shaft seated in bedrock or soil and may encompass a rock socket as shown in the contract documents. References to “rock” and “rock socket” throughout this section are only applicable to shafts seated in bedrock with rock sockets as specified in the contract documents.

B. Ensure elevations, dimensions, and depth of the drilled shafts and rock sockets are as specified in the contract documents. If bearing strata are encountered at different elevations or are judged to be of a different quality, the Engineer may adjust the socket elevation.

2433.02 MATERIALS.

A. Slurry.

1. Use only mineral or polymer slurries in the drilling process unless the Engineer, in writing, approves other drilling fluids. Ensure the percentage and specific gravity of the material used to make the suspension is sufficient to maintain the stability of the excavation and to allow proper concrete placement. In the event of a sudden significant loss of slurry to the excavation, stop foundation construction until the Engineer has approved either: 1) methods to stop slurry loss; or 2) an alternate construction procedure.

2. Perform all tests at a slurry temperature of 40°F (4°C) or higher.

3. Thoroughly premix mineral slurry or polymer slurry with clean, fresh water. Mix for the adequate time (as prescribed by the manufacturer) allotted for hydration in slurry tanks. Adequate capacity slurry tanks are required for slurry circulation, storage, treatment, and disposal. No excavated slurry pits will be allowed. Prior to introduction into the shaft excavation, draw sample sets from the slurry tanks and test the samples for conformance with the specified material properties. A sample set consists of samples taken at mid-height and within 2 feet (0.6 m) of the bottom of the slurry tanks.

4. In the Engineer’s presence, sample and test all slurry, unless directed otherwise. Record the date, time, persons’ names sampling and testing the slurry, and the test results. Submit a copy of the recorded slurry test results to the Engineer at the completion of each shaft, and during construction of each shaft when the Engineer requests.

5. During shaft excavation, take and test sample sets of all slurry, composed of samples taken at mid-height and within 2 feet (0.6 m) of the bottom of the shaft, as necessary to verify the control of the slurry properties. As a minimum, take and test sample sets at least once every 2 hours after beginning slurry use. When the test results show consistent specified properties, take and test sample sets at least once

every 4 hours of slurry use. When tests show that the sample sets do not have consistent specified properties, either recirculate the slurry or agitate it with drilling equipment.

6. When samples are found to be unacceptable, either clean, recirculate, desand, or replace the slurry in order to maintain the required slurry properties. Do not begin cleaning the bottom of the excavation and placing concrete until after tests show that the sample sets have consistent specified properties.

7. Demonstrate to the Engineer's satisfaction that stable conditions are being maintained. If the Engineer determines that stable conditions are not being maintained, immediately take action to stabilize the shaft. Submit a revised installation plan which corrects the problem and prevents future instability. Do not continue with shaft construction until receiving the Engineer's approval of the revised shaft installation plan.

a. Mineral Slurry.

Ensure mineral slurry complies with Table 2433.02-1:

Table 2433.02-1: Mineral Slurry Requirements

Property	Test Method	Requirements
Density (lb/ft^3 (kg/m^3))	Slurry Density Materials I.M. 387	64 to 75 (1030 to 1200)
Viscosity (sec/gal (sec/L))	Marsh Funnel and Cup Materials I.M. 387	104 to 201 (27.5 to 53)
pH	pH Paper	8 to 11
Sand Content (%)	Sand Content Test Materials I.M. 387	*
* Sand content of mineral slurry prior to placing the reinforcing steel cage and immediately prior to placing concrete less than or equal to 4.0%.		

b. Polymer Slurry.

1) For polymer slurry use, comply with the manufacturer's recommendations and this specification. Submit to the Engineer the name and telephone number of the manufacturer's representative. The manufacturer's representative is to provide technical assistance in the use of the polymer slurry as needed.

2) Ensure polymer slurry complies with Table 2433.02-2:

Table 2433.02-2: Polymer Slurry Requirements

Property	Test Method	Requirements
Density (lb/ft^3 (kg/m^3))	Slurry Density Materials I.M. 387	62 to 63 (995 to 1010)
Viscosity (sec/gal (sec/L))	Marsh Funnel and Cup Materials I.M. 387	136 to 227 (36 to 60) 231 to 252 (61 to 66.5) (dry sand/gravel)

pH	pH Paper	8 to 11
Sand Content (%)	Sand Content Test Materials I.M. 387	*
* The sand content of polymer slurry prior to placing the reinforcing steel cage and immediately prior to placing concrete less than 2.0%.		

3) Wait 30 minutes after the last drilling and scouring to allow contaminants to settle out before taking and testing a sample set of slurry. After the reinforcing steel cage is placed in the excavation, take and test a sample set of slurry immediately prior to concrete placement.

B. Concrete.
Comply with the following:

1. All materials, proportioning, air entraining, mixing, slump, and transporting of PCC shall be according to Section 2403, except as modified herein.

2. Water/cement ratio: not to exceed 0.45.

3. Drilled shaft construction: use Class D PCC mixture with a slump of 8 inches ±1.5 inches (200 mm ±40mm).

4. Portland cement: meet the requirements of ASTM C 150 Type I / II and Section 4101.

5. Air entrainment: apply Section 2403.

6. Mid-range water reducer is required according to Materials I.M. 403.

7. Retarder is required according to Materials I.M. 403 to maintain workable concrete.

8. Do not use GGBFS.

C. Grout.
Apply Materials I.M. 388.

2433.03 CONSTRUCTION.

A. Construction Tolerances.
Drilled shaft excavations and completed shafts not constructed within the required tolerances will be considered unacceptable. Correct all unacceptable shaft excavations and completed shafts to the Engineer's satisfaction. Furnish materials and work necessary, including engineering analysis and redesign, to complete corrections for out of tolerance drilled shaft excavations (without either cost to the Contracting Authority or an extension of the completion dates of the project).

1. Ensure the drilled shaft is within 3 inches (75 mm) of plan position at the top of shaft.

2. Ensure the vertical alignment of shaft excavation does not vary from the plan alignment by more than 1/4 inch/foot (20 mm/m of depth).

3. Set full depth reinforcing steel cages at no less than 6 inches (150 mm) above the bottom of the excavated shaft prior to concrete placement.

4. Ensure that, after all the concrete is placed, the top of the reinforcing steel cage is no more than 6 inches (150 mm) above and no more than 2 3/4 inches (70 mm) below plan position.

5. Casing dimensions are subject to American Pipe Institute tolerances applicable to regular steel pipe.

6. The top elevation of the shaft may have a tolerance of plus 1 inch (25 mm) or minus 3 inches (75 mm) from the plan top of shaft elevation. Ensure sufficient reinforcement bar splice length for splices above the shaft.

7. Use excavation equipment and methods that ensure the completed shaft excavation will have a planar bottom. Ensure the excavation equipment cutting edges are normal to the equipment's vertical axis within a tolerance of 3/8 inch/foot (30 mm/m) of diameter.

B. Drilled Shaft Installation Plan.

1. Two weeks prior to the pre-construction conference, submit a list containing at least three drilled shaft projects, of similar diameter and length to those shown on the plans, completed in the last three years. In the list of projects include names and phone numbers of owner's representatives who can verify the Contractor's participation on those projects. In addition, submit a signed statement that the Contractor has inspected the project site and all the subsurface information made available in the contract documents.

2. No later than 1 month prior to constructing drilled shafts, submit a drilled shaft installation plan for the Engineer to review. In this plan provide the following information:
   - **a.** Name and experience record of firm(s) and associated personnel for the following:
     - **1)** Driller.
     - **2)** Drilled shaft superintendent.
     - **3)** Site exploration.
     - **4)** Confirmation boring.
     - **5)** Crosshole sonic logging (CSL).
     - **6)** Name of load cell testing firm, if applicable.
   - **b.** List of proposed equipment to be used, including cranes, drills, augers, bailing buckets, grooving equipment, scouring equipment, final cleaning equipment, core sampling equipment, confirmation

boring equipment, tremies or concrete pumps, casing, slurry equipment, airlift pumps, and so forth.

c. Details of overall construction operation sequence and the sequence of shaft construction in bents or groups.

d. Details of shaft excavation methods.

e. Details of casing and forms, including installation and removal.

f. Details of the type and methods to mix, circulate, desand, test, and dispose of slurry (if applicable). If polymer slurry is proposed, submit data on load transfer and manufacturer's requirements for slurry control.

g. Details of methods to clean the shaft excavation, including air lift methods and spin bucket methods as applicable.

h. Details of reinforcement placement, including support and cage centering methods.

i. Reinforcing steel cage splicing method, if proposed, including details of dimensions, installation, splice location, support and cage centering methods, and estimated time required for splicing.

j. Details of concrete placement including procedures for tremie or pumping methods and method to prevent slurry intrusion at the discharge end.

k. Concrete mix proposal.

l. Details of methods to control cuttings, water, slurry, and so forth with adjacent traffic conditions (vehicular or railroad if applicable).

m. Details of CSL testing, including location and attachment methods of the steel access pipes.

n. When a load cell test is specified, include details of the test equipment used in the load cell test, and description of load cell test procedures and program according to Materials I.M. 388.

o. Details of methods used to groove the sides of the drilled shaft length within the bedrock supporting stratum and methods of scouring and verification of grooving.

p. Details of final discharge of concrete at top of shaft, of removing contaminated concrete, and verifying concrete uniformity for site specific conditions.

q. When casing is required, include details on casing to be used, including:

- Specific length/depth of all casing proposed, and
- Specific evaluation and determination of casing (size, depth, etc.) required to prevent all shaft installation procedures from having an effect or impact on adjacent structures, railroads, and so forth.

3. The Engineer will evaluate the drilled shaft installation plan for conformance with the contract documents. Within 14 calendar days after receipt of the plan, the Engineer will notify the Contractor of additional information required or changes necessary to meet the contract requirements, or both. Field test the Engineer's procedural approvals. These approvals do not relieve the Contractor of the responsibility to satisfactorily complete the work as detailed in the contract documents.

4. A pre-drilling conference, in which the Contracting Authority, Contractor, and drilling staff discuss the anticipated shaft process, will be required for this work prior to the start of shaft excavation.

C. Control and Disposal of Materials.

Dispose of excavated material, as well as slurry and/or water removed from the shaft excavation. Collect and properly dispose off site all slurry and water displaced during final cleaning and concrete placement. Open pits for collection of materials will not be allowed. Control all excavated material, slurry, water, and other matter so that at no time it enters or encroaches upon the adjacent travel lanes, railroad, water ways, and so forth.

D. Shaft Excavation.

1. General.

a. Construct drilled shafts by either the wet, dry, or casing method as necessary to produce sound, durable concrete foundation shafts free of defects. These methods are described below.

b. Remove surface and subsurface obstructions. Special tools and/or procedures may be required. No separate payment will be made for removing obstructions.

c. If the Engineer determines that the material encountered during excavation and/or present at tip elevation is unsuitable and/or differs from that anticipated in the design of the drilled shaft, extend the drilled shaft tip elevations.

d. Maintain a drilling log during shaft and socket excavation. In the log, place information such as elevation, depth of penetration, drilling time in each of the strata, material description, and remarks. Furnish two copies of the log (signed by the Contractor) to the Engineer within 1 week after completion of the excavation.

e. After the shaft excavation has been completed, immediately proceed with shaft construction.

2. Wet Method.

a. The wet method consists of:

- Keeping the shaft filled with slurry a minimum of 4 feet (1.3 m) above the highest expected water table during drilling and excavation,
- Desanding of the slurry when required,
- Final cleaning of the excavation by means of a bailing bucket, air lift, pump or other approved device, and
- Placing shaft concrete which displaces the slurry.

b. In the event that layers susceptible to cave-ins are encountered which cannot be controlled by slurry, install temporary removable casing according to Article 2433.03, D, 3.

3. Dry Method.

a. The dry method consists of:

- Drilling the shaft excavation,
- Removing accumulated water and loose material from the excavation,

- Placing the reinforcing cage, and
- Concreting the shaft in a relatively dry excavation.

b. Use the dry method only at sites where:
- The ground water level and soil and rock conditions are suitable to permit construction of the shaft in a relatively dry excavation, and
- The Engineer can visually inspect the sides and bottom of the shaft prior to placing the concrete.

c. The Engineer will approve the dry method only if the shaft excavation demonstrates:
- Less than 12 inches (0.305 m) of water accumulates above the base over a 1 hour period when no pumping is permitted,
- The sides and bottom of the hole remain stable without detrimental caving, sloughing, or swelling between completion of excavation and concrete placement, and
- All loose material and water can be satisfactorily removed prior to inspection and concrete placement (less than 3 inches (75 mm) of water will be permitted in the bottom of the shaft excavation at the time of concrete placement).

d. Use the wet or casing method for shafts that do not meet the dry method requirements.

4. Casing Method.

a. The casing method is used to advance the hole through unstable material. Over-reaming to the outside diameter of the casing may be required. Before the casing is to be removed, the level of fresh concrete must be a minimum of 5 feet (1.5 m) above the bottom of the casing so that fluid trapped behind the casing is displaced upward. As the casing is withdrawn, maintain the concrete level so that fluid trapped behind the casing is displaced upward without contamination or displacing shaft concrete.

b. Determine the appropriate depth to terminate the temporary casing to ensure the stability of the shaft. The purpose of the temporary casing is to stabilize the shaft walls during drilling to prevent cave-ins as the result of potential vibrations. The purpose of the casing is also to prevent shaft installation procedures from having an impact on adjacent structures, railroads, and so forth.

c. Permanent casing, if required, will be specified in the contract documents.

E. Grooving and Brushing Sidewalls.

1. Groove sidewalls of drilled shaft within the rock socket to produce channels with approximate dimensions of 2 inch (50 mm) deep by 3 inch (75 mm) high at intervals of 1 foot (0.3 m).

2. Use a method approved by the Engineer to remove excessive smearing of soft material that may occur on rock socket wall.

3. Clean base of shaft by spin bucket and air lift. Perform grooving and/or brushing prior to final cleaning of base of shaft.

F. Final Cleaning.

1. If a slurry cake builds up on the shaft sidewalls, remove it prior to concrete placement (at no additional cost to the Contracting Authority). If mineral slurry is used, ream the shaft sidewalls above the rock socket reamed prior to placement of reinforcement. Adjust operations so that the maximum time that the slurry is allowed to remain in the shaft is 24 hours.

2. Clean the base of each shaft so that a minimum of 50% of the base will have less than 1/2 inch (15mm) of sediment at the time of concrete placement. Ensure the maximum sediment or debris depth at the base of the shaft does not exceed 1 inch (25mm).

3. The Engineer will visually inspect dry shafts.

4. Use an air lift to clean the bottom of slurry shafts. After a waiting period equal to the time to set the reinforcing steel cage and set up for concrete placement, measure the amount of sediment in the bottom of the shaft. If the amount of sediment meets the requirements in Paragraph 2 above, clean the base of the shaft a second time with the air lift and immediately proceed with shaft construction. If after the described wait period the amount of sediment exceeds the requirements of Paragraph 2, clean the shaft by air lift and repeat the above procedure until the sediment accumulation meets the requirements. The Engineer may approve an alternate method to clean the bottom of the shaft. The Contracting Authority will not provide additional compensation for alternate methods.

G. Excavation Inspection.

Provide equipment for checking the dimensions and alignment of each shaft excavation. Under the direction of the Engineer, verify the dimensions and alignment of the shaft under construction. After final cleaning, use a suitable weighted tape or other approved methods to measure final shaft depths.

H. Reinforcing Steel Cage Construction and Placement.

1. Assemble the reinforcing steel cage (consisting of longitudinal bars, ties, cage stiffener bars, spacers, cage centering devices, and other necessary appurtenances). Place the steel cage immediately after the shaft excavation has been inspected and accepted, and prior to concrete placement. If the Engineer approves, the reinforcing steel cage may be placed as two approximately equal units joined together in the shaft excavation.

2. Ensure the reinforcing steel in the shaft is tied at intersections and supported in such a way that the reinforcing steel will remain within allowable tolerances given in this specification. Use concrete spacers or other approved non-corrosive spacing devices at sufficient intervals near the top and bottom, and at intervals not exceeding 10 feet (3 m) along the shaft, to ensure concentric spacing for the entire cage length. Ensure spacers are:

- Constructed of approved material equal in quality and durability to the concrete specified for the shaft.
- Of adequate dimension to ensure a minimum distance of 3 inches (75 mm) between the cage and the excavated hole.

3. When a full depth reinforcing steel cage is used, support it at the bottom using approved cylindrical feet to ensure that the bottom of the cage is maintained at the proper distance above the base. When a partial depth reinforcing steel cage is used, design and furnish a support system.

4. Check the elevation of the top of the steel cage before and after the concrete is placed. If the reinforcing cage is not maintained within the specified tolerances, make necessary corrections to the satisfaction of the Engineer. Do not construct additional shafts until after modifying the reinforcing cage support in a manner satisfactory to the Engineer.

I. Concrete Placement.

1. General.

a. Place shaft concrete within 24 hours of the start of excavation of the rock socket. Place concrete as soon as possible after placing reinforcing steel.

b. Coordinate concrete batching and delivery with the batch plant the time limits, as stated in the contract documents, between batching and delivery are not exceeded.

c. Place concrete in a continuous manner. Continue concrete placement after the shaft excavation is full until good quality concrete is evident at the top of shaft.

d. Before continuing with column construction, remove a sufficient volume of concrete to ensure elimination of all contaminated concrete at the top of shaft.

e. Place concrete through either a tremie or a concrete pump.

f. Complete placement of the concrete in the shaft within 3 hours. Adjust admixtures, when approved for use, for the conditions encountered on the job so the concrete remains in a workable plastic state throughout the 3 hour placement limit.

g. For construction of shafts larger than 6 feet (2 m) in diameter, the Contractor may propose a placement time in excess of 3 hours provided the Contractor submits trial mix documentation that all concrete in the shaft will retain a minimum 4 inch (100 mm) slump for the entire placement period.

h. Remove all temporary casing.

2. Concrete Placement by Tremie:

a. For the tremie, comply with the following:

- Constructed so that it is watertight and will readily discharge concrete.
- No more than 12 inches (300 mm) in diameter.
- No aluminum parts in contact with concrete.

- Discharge end of the tremie constructed to prevent water or slurry intrusion and permit the free flow of concrete during placement operations.
- Sufficient mass so that it will rest on the shaft bottom before start of concrete placement.
- Sufficient length to extend to the bottom of the shaft.

b. Maintain the discharge orifice between 5 feet and 10 feet (1.5 m and 3.0 m) below the surface of the fluid concrete.

c. Support the tremie so that it can be raised to increase the discharge of concrete and lowered to reduce the discharge of concrete.

d. Maintain a continuous flow of concrete. Ensure the concrete in the tremie maintains a positive pressure differential at all times to prevent introduction of air pockets or contaminants into the concrete.

3. Concrete Placement by Pump.

a. Concrete pumps and lines may be used for concrete placement. Use minimum 4 inch (100 mm) diameter pump lines constructed with watertight joints. Do not begin concrete placement until the pump line discharge orifice is at the shaft base elevation.

b. Use a plug or similar device to separate the concrete from the fluid in the hole until pumping begins. Either remove the plug from the excavation, or use a plug of a material approved by the Engineer which will not be a detriment to the shaft if not removed.

c. Maintain the discharge orifice between 5 feet and 10 feet (1.5 m and 3.0 m) below the surface of the fluid concrete. When lifting the pump line during concreting, temporarily reduce the line pressure until the orifice has been repositioned at a higher level in the excavation.

d. Perform the pumping operation in a manner that prevents introduction of air pockets into the concrete. If breaking the pump line is required, temporarily position the discharge orifice 3 feet to 5 feet (1.0 m to 1.5 m) below the surface of the fluid concrete in the hole. The Contractor may propose additional methods to eliminate introduction of air into the concrete.

J. Crosshole Sonic Log (CSL) Testing.

1. Coordinate with an independent testing agency to perform CSL testing according to ASTM D 6760. Provide analysis and interpretation on each completed shaft.

2. The procedure in ASTM D 6760 will be followed with the exceptions listed below:

a. Plastic access ducts and drilled boreholes will not be allowed unless the Engineer approves.

b. A minimum of 4 access ducts are required.

c. Perform CSL testing after the shaft concrete has cured at least 48 hours but no later than 7 calendar days.

d. Grout the access ducts after the Engineer’s approval of the testing results.

e. Include the waterfall diagram (which is a nesting of ultrasonic pulses in an ultrasonic profile) in the report.

3. Furnish and install one access pipe per 1 foot (0.3 m) of shaft diameter, but no less than four per shaft, with external couplings for CSL testing. Furnish access pipes complying with the following:

- 2 inch (51 mm) diameter, Schedule 40 pipe conforming to ASTM A 53, Grade A or B, Type E, F, or S.
- Round, regular inside diameter free of defects and obstructions, including all pipe joints, in order to permit the unobstructed passage of 1 3/8 inch (35 mm) maximum diameter source and receiver probes used for the CSL tests.
- Watertight and free from corrosion with clean internal and external faces to ensure a good bond between the concrete and the access pipes.
- Fitted with a watertight cap on the bottom and a removable, watertight cap on the top to prevent debris from entering the pipes.
- Watertight joints to achieve the specified length.

4. Securely attach the access pipes to the interior of the reinforcing cage such that each pipe is equally spaced within the reinforcing cage. If a partial depth reinforcing cage is specified, design and furnish a support system to secure and properly align the CSL access pipes.

5. Install the access pipes in straight alignment and parallel to the vertical axis of the reinforcing cage. Access pipes shall have 2 inches (50 mm) concrete cover at the bottom of the shaft or extend to the top plate of a load cell placed at the bottom of the shaft. When a load cell is located above the bottom of the shaft, fit the access pipes with watertight slip joints between the load cell bearing plates. Extend the access pipe at least 2 feet (600 mm) above either the top of the continuous concrete placement operation or the top of the shaft. Do not damage the access pipes during the reinforcing steel cage installation.

6. Fill the access pipes with clean water prior to concrete placement. To prevent debris from entering the pipe, reseal each access pipe immediately after water placement. Prior to CSL testing, flush all access pipes containing debris, refill with water of similar temperature, and reseal. Use water of similar temperature to avoid debonding of access pipes with surrounding concrete. Dewater all access pipes and fill with grout after the tests are completed, and the shaft has been accepted by the Engineer. Use grout meeting the requirements of Materials I.M. 388.

7. Submit the test results, analysis, and interpretation for the shafts to the Engineer within 7 calendar days of testing. The Engineer will:

- Determine final acceptance of each shaft, based on the CSL test results and analysis for the tested shafts, and
- Provide a response within 5 working days after receiving the test results and analysis submittal.

8. Do not commence subsequent shaft excavations until receiving the Engineer's approval and acceptance of the first shaft based on the results, analysis, and interpretation of the CSL testing.

9. Do not commence subsequent construction of the structure until receiving the Engineer's approval and acceptance of the supporting shaft based on the results, analysis, and interpretation of the CSL testing.

10. For all shafts determined to be unacceptable, submit a plan for remedial action, including correction procedures and designs, to the Engineer for approval. Do not begin repair operations until receiving the Engineer's approval of the remedial action plan.

K. Demonstration Shaft.

1. Demonstrate equipment and methods, prior to construction of the first production drilled shaft, by installing a non-production drilled shaft. Install on site at a location the Engineer determines.

2. Construct the demonstration shaft in soil as shown in the contract documents or a minimum of 3 feet (1 m) into bedrock. A reinforcing steel cage, designed by the Contractor, to adequately support the CSL tubes will be required.

3. Construct the demonstration shaft according to the requirements of this specification with special emphasis on slurry control and disposal, method of scouring, air lift pump usage, concrete delivery and coordination with the batch plant, concrete slump at the point of delivery, and concrete placement. Include one break of the concrete pump line.

4. If the demonstration shaft installation demonstrates the equipment and methods used to construct drilled shafts to the requirements of this specification are inadequate, the Engineer will require appropriate alterations in equipment or methods, or both, to eliminate the unsatisfactory results. The Contractor may be required to perform additional demonstration shafts until an adequate procedure is demonstrated and approved by the Engineer.

5. Do not begin constructing production drilled shafts until the Engineer approves the methodology and reviews the CSL report. The Engineer will complete the review process within 5 working days.

6. The Demonstration Shaft item will be deleted from the contract if:

- The Contractor has demonstrated sufficient experience in the construction of drilled shaft foundations in soil/rock and under conditions similar to those at this site, and
- Other applicable factors indicate it to be acceptable.

L. Test Shaft.

1. When required in the contract documents, install a test shaft at the location indicated in the plans. Base the final selected depth of the test shaft on the confirmation boring.

a. Confirmation Boring and Sampling.

1) Prior to installation of the test shaft, complete a confirmation boring at the test shaft location to a depth 10 feet (3 m) below the bottom elevation as shown in the contract document or a minimum of 30 feet (10 m) into the bedrock, whichever is greater.

2) Perform standard penetration tests according to ASTM D 1586 in the soil overlying bedrock. Perform the tests on 5 foot (1.5 m) centers.

3) Determine moisture contents on the soil samples. Continue soil sampling and testing with split barrel (spoon) sampling, according to ASTM D 1586, until the top of bedrock is encountered.

4) Core the rock using double barrel diamond coring methods producing a minimum 1.75 inch (44.4 mm) core according to ASTM D 2113, or other approved sampling method. Keep records, including Percent Core Recovery and Rock Quality Designation, according to ASTM D 2113 and D 6032. Preserve rock samples at their natural moisture content and condition. Transport them to the laboratory for classification by a Professional Engineer licensed in the State of Iowa.

5) Test representative samples of intact rock for unconfined compressive strength according to ASTM D 2938, except record stress and strain according to ASTM D 2166, up to 20% strain or failure, whichever occurs first. Prepare a stress-strain plot. In addition, list the unconfined compressive strength.

6) Perform one unconfined compression test for every 3 feet (1.0 m) of rock core. The Engineer will select test samples.

7) Do not install test shafts until the results of the confirmation boring have been submitted and reviewed and incorporated in the proposed load test program to be submitted according to Materials I.M. 388.

8) The Engineer will complete the review of the confirmation boring report within 7 calendar days after submittal and the proposed load cell test program report within 7 calendar days after submittal.

b. Load Cell Test.

1) When required by the contract documents, furnish all materials and labor necessary to conduct a load cell test according to Materials I.M. 388.

2) Install telltale casings to allow measurement of shaft movement during load cell test.

3) Use the utmost care in handling the rebar cage/test equipment assembly so as not to damage the load cell and instrumentation during installation.

4) After the CSL test has been approved and the concrete has reached a minimum required strength of 3500 psi (24 MPa),

internally pressurize the load cell creating an upward force on the shaft and an equal, but downward force. The total load for a given internal pressure is found from the load cell's calibration. Ensure this is performed prior to load cell's shipment to the site. During the period required to perform the load cell test, no casings may be vibrated into place or steel piles installed within 200 feet (60 m) of the load test.

5) If the test shaft is a production shaft, monitor the load/deflection curve and halt testing so that the capacity of the shaft is not compromised. Then unload the load cell and reload it to verify that the test shaft has at least the design capacity. If the test shaft is not a production shaft, continue the load cell test until ultimate capacity is reached or the capacity of the load cell is reached.

6) If the test shaft is a production shaft, grout the hydraulic lines and load cell cavities after completion of the load cell test. Use a grout meeting the requirements of Materials I.M. 388.

7) Within 14 calendar days of the test completion, supply four printed copies and one electronic copy of the report for each load cell test, as prepared by the approved firm in Materials I.M. 388. Provide field results after completion of the test. In the report include, at a minimum, the following:

- **a)** Load distributions, skin friction, and end bearing for the various strata instrumented by the strain gauges.
- **b)** Summary of drilled shaft's dimensions, elevations, areas, and masses.
- **c)** Boring logs, test data, and other relevant information from the confirmation boring.
- **d)** Log of the Contractor's installation along with actual mapping of the shaft profile.
- **e)** Load movement for end bearing and upward shear.
- **f)** Equivalent top load movement curve.
- **g)** Side shear creep limit curve.
- **h)** End bearing creep limit curve.
- **i)** Side shear load transfer for each zone/layer identified in the confirmation boring report, where strain gauges were installed, or as modified by the Engineer and the approved firm in Materials I.M. 388.
- **j)** Plots of mobilized side shear load transfer versus vertical displacement for each zone/layer identified in the confirmation boring report, where strain gauges were installed. Layers may be modified in final load test design, if approved of by the Engineer.
- **k)** Tables with test data.

2. If the Engineer determines the test shaft to be unacceptable, submit a plan for remedial action to the Engineer for approval. The Engineer may require another load cell test on another shaft.

3. Do not begin construction of the production shafts until the Engineer approves the methodology, reviews CSL report, and reviews load cell test results.

4. Prior to commencement of the load cell test, repair all cavities or inclusions. Obtain the Engineer's approval for the repairs.

5. The Engineer will complete the review process within 14 calendar days of the load test report submittal.

6. The load test results will be used to evaluate the shaft capacities within the bedrock and to define the final bottom elevation of the remaining productions shafts. The final bottom elevation of the remaining production shafts may vary from what is shown on the plans.

7. Once the load cell test has been completed and the Engineer has approved it, clean up the test shaft site. If the test shaft is a production shaft, clean up the site using whatever measures are required to incorporate the test shaft into the foundation, subject to the Engineer's approval. If the test shaft is not a production shaft, remove it to 3 feet (1 m) below final ground level and clean the area according to Article 1104.08.

2433.04 METHOD OF MEASUREMENT.

Measurement will be as follows:

A. Concrete Drilled Shaft.
Feet (meters), to the nearest 6 inches (0.15 m), constructed.

B. Reinforcing Steel.
Section 2404 applies.

C. Load Cell Test.
By count.

D. Demonstration Shaft
Feet (meters), to the nearest 6 inches (0.15 m), constructed and approved.

2433.05 BASIS OF PAYMENT.

Payment will be the contract unit price as follows:

A. Concrete Drilled Shaft.

1. Per foot (meter).

2. Payment is full compensation for all equipment, labor, and materials (except reinforcing steel) necessary to satisfactorily construct the shafts including:
   - Drilling and excavation of shaft and possible rock socket,
   - Casing,
   - Installation and removal of temporary casing,
   - Furnishing and placing concrete,
   - CSL pipe and testing, shaft inspection, and
   - Disposal of excavated materials and water, and all other materials.

B. Reinforcing Steel.
Section 2404 applies.

C. Load Cell Test.

1. Each.

2. Payment is full compensation for:
- Performing confirmation boring and testing and all costs incurred during the procurement,
- Installation,
- Instrumentation with strain gauges and telltales,
- Conducting of the test,
- Subsequent removal of test apparatus, appurtenances, grouting cell tubes, and
- Reporting.

D. Demonstration Shaft.

1. Per foot (meter).

2. Payment is full compensation for all equipment, labor, and materials necessary to satisfactorily construct the approved shaft including:
- Drilling and excavation of drilled shaft and rock socket,
- Installation and removal of temporary casing,
- Furnishing and placing reinforcing bars,
- Furnishing and placing concrete,
- CSL pipe and testing,
- Shaft inspection, and
- Disposal of excavated materials and water, and all other materials.