SECTION 511 - DRILLED SHAFTS

511.01 Description. This section describes installing drilled shafts, including reinforced or unreinforced concrete drilled shafts, with or without belled footings; and performing load tests as indicated.

511.02 Materials.

(A) Portland Cement Concrete. Portland cement concrete shall conform to Section 601 - Structural Concrete, except concrete shall have minimum 28-day compressive strength of 4,500 pounds per square inch.

Proportion concrete mix designs to yield properties of high workability, consolidation under self-weight, and resistance to segregation. Use aggregate with maximum nominal size of 3/4 inch. For concrete placed into a water-free borehole, slump range shall be 7 inches +/- 1 inch. For concrete placed under water, slump range shall be 8 inches +/- 1 inch. Minimum concrete slump shall be 4 inches within 4 hours of initial mixing. Superplasticizers will not be allowed.

(B) Reinforcing Steel. Reinforcing steel shall conform to Section 602 - Reinforcing Steel.

(C) Casing. Permanent casing shall conform to ASTM A 252, Grade 3.

(D) Cement Grout. Cement grout used for setting load cells and for filling load cells and voids at bottom of shaft following load test, shall be pumpable and shall have minimum 28-day compressive strength of 5,000 pounds per square inch.

(E) Crosshole Sonic Log (CSL) Test Access Tube. Access tube shall be at least 2-inch inside diameter, Schedule 40 pipe conforming to ASTM A 53, Grade A or B, Type E, F, or S.

Access tube shall have round, regular inside diameter, free of defects and obstructions, including all pipe joints, in order to permit free, unobstructed passage of 1.3-inch maximum diameter source and receiver probes used for crosshole sonic log testing. Access tube shall be watertight, free from corrosion, with clean internal and external faces that ensure good bond between concrete and access tube. Fit access tube with watertight caps on bottom and top.

When crosshole sonic log testing is indicated in the contract documents, submit manufacturer’s certificate of compliance for access tube acceptance.

511.03 Construction.

(A) Prequalification of Drilled Shaft Contractor. At the time of bid, meet requirements of Subsection 102.01 - Prequalification of Bidders and requirements of this subsection as follows:

(1) Experience Record. Submit experience record demonstrating the drilled shaft contractor has successfully completed at least three projects in the last three years, in which drilled shafts of diameter and length similar to those shown in the contract documents were installed. Include in list of projects, names and phone numbers of owner's representatives who can verify the drilled shaft contractor's participation on those projects. Drilled shaft contractor shall have on its payroll, supervisory personnel who have participated in drilled shaft construction, similar to the type proposed, for duration of at least three years within the last 10 years.

(2) Examination of Work Site. Submit signed statement that the drilled shaft contractor has inspected both project site and subsurface information, including soil or rock samples made available in the contract documents.

(B) Preconstruction Requirements.

(1) Installation Plan. No later than 30 days after contract award, submit installation plan that includes the following:

(a) Name and experience record of drilled shaft superintendent who will be in charge of drilled shaft operations for this project. Drilled shaft superintendent shall have minimum three years experience within the last 10 years in drilled shaft construction similar to type proposed.

(b) List of proposed equipment, including cranes, drills, augers, bailing buckets, final cleaning equipment, tremies, or concrete pumps, and casing.

(c) Details of construction operation sequence and shaft construction sequence in bents or groups.

(d) Details of shaft excavation methods, including proposed drilling and shaft cleanout methods, and excavated material disposal plan.

(e) Details of methods to ensure shaft stability, including prevention of caving or bottom heave using casings or other means accepted by the Engineer. If casings are to be used, submit dimensions and detailed installation and dewatering

procedures for permanent and temporary casings; and removal procedures for temporary casings.

(f) Details of reinforcement placement, including support and centralization methods.

(g) Details of concrete placement, including proposed operational procedures for free fall, tremie, or pumping methods.

(h) Details of required load tests, including equipment, procedures, and recent calibrations for jacks or load cells supplied by the Contractor.

(i) Proposed concrete mix design, including expected strengths at 3, 7, and 28 days. Submit test results of both a trial mix and a slump loss test, conducted by State-accepted testing laboratory using methods specified in Subsection 601.03(B) – Design and Designation of Concrete. Tests shall demonstrate that concrete meets 2-hour plasticity requirement at expected ground ambient temperature and at highest expected ambient air temperature (two separate slump loss tests required).

(j) Test results from laboratory measurements of the ultrasonic pulse velocity, performed in accordance with ASTM C 597, on 3-day, 7-day, and 28-day concrete trial mix samples described in Subsection 511.03(B)(1)(i).

The Engineer will evaluate drilled shaft installation plan for conformance with the contract documents. Within 21 days after plan receipt, the Engineer will notify the Contractor of additional information required, including if applicable, changes necessary to meet requirements of the contract documents. The Engineer will reject parts of installation plan that are unacceptable. Resubmit changes for re-evaluation. Procedural acceptance given by the Engineer shall be subject to trial in the field.

(2) Protection of Existing Structures. Prevent damage to existing structures and utilities. Include the following preventative measures:

(a) Select construction methods and procedures that will prevent caving of shaft excavation.

(b) Monitor and control vibrations from construction activities, such as driving casing or sheeting, or drilling shaft.

(3) Trial Shaft Installation. Demonstrate adequacy of proposed methods and equipment by successfully constructing an unreinforced trial shaft, of each shaft diameter to be installed, in accordance with contract documents. Position trial shaft away from production shafts, at location shown in the contract documents, or as ordered by the Engineer. Drill trial shaft to maximum depth shown in the contract documents. When belling is required in the contract documents, ream bells at specified trial shaft holes to establish feasibility of belling in a specific soil stratum.

If the Engineer rejects trial shaft due to deviation from requirements of the contract documents, alterations to proposed methods and equipment may be required. Drill additional trial holes to demonstrate adequacy of altered construction methods or equipment at no increase in contract price or contract time. Once the Engineer has accepted trial shaft and has authorized construction of production shafts, do not deviate from accepted methods or equipment without the Engineer's written approval.

Fill trial shaft hole with unreinforced concrete, using method proposed for production shaft construction. Cut off concreted trial shafts 2 feet below finished grade and leave in place. Restore disturbed areas at trial shaft sites to original condition, unless otherwise specified.

(C) Construction Requirements.

(1) Construction Sequence. Excavate for structure footings supported by drilled shafts and place embankment fills before drilling shaft. Do not cap drilled shafts before placing fills as near to final grade as possible. Leave ungraded only those areas needed to construct caps.

Before placing footing concrete, repair disturbances to footing area caused by shaft installation. Maintain minimum 12-feet, edge-to-edge separation between new shaft to be drilled and existing open shaft.

(2) Construction Methods. Construct drilled shafts and bell footings using the following methods, in accordance with the contract documents.

(a) Dry Construction Method. The dry method includes drilling shaft excavation, removing accumulated water and loose material from the excavation, placing reinforcing cage, and concreting shaft in a dry excavation. Dry excavation is defined as an excavation where maximum depth of water does not exceed 3 inches.

(b) Wet Construction Method. This method includes using water to maintain stability of shaft perimeter while advancing excavation to final depth, and placing reinforcing cage and shaft concrete.

Reuse drilling water only if permitted by the Engineer and contingent upon control of unit weight to no more than 62.5 pounds per cubic foot and Marsh funnel viscosity to not more than 27 seconds per quart, at the time drilling water is introduced into the borehole.

For drilled shafts in open water areas, extend exterior casings from above water elevation into the ground. Install exterior casing in a manner that will produce a positive seal at bottom of casing, such that no intrusion or extrusion of water or other materials occurs into or from shaft excavation.

(c) Casing Construction Method. The temporary casing method may be used when dry or wet construction methods are inadequate. Use permanent casing method only when required by the contract documents or authorized by the Engineer. Casing may be placed either in a predrilled hole or advanced by twisting, driving, or vibrating, before cleaning casing.

(3) Excavation.

(a) General. Excavate shafts at locations, and to dimensions shown in the contract documents. When material encountered during excavation differs from that anticipated in drilled shaft design, adjust shaft tip elevation, after acceptance by the Engineer.

1. Construction Method Log. Maintain construction method log during shaft excavation. Submit method log within 24 hours of shaft drilling completion. Include the following information:

a. Excavation diameters.

b. Equipment used, excavation rate, and difficulties encountered.

c. Description and approximate top and bottom elevations of each type of soil or rock material encountered.

d. Elevation and approximate rate of any seepage or groundwater.

e. Remarks.

2. Cofferdams. On projects with cofferdams, provide certified diver to inspect cofferdam conditions when the contract documents require a concrete seal. Before placing concrete seal, inspect cofferdam interior periphery. Inspect each sheeting indentation and around each drilled shaft.

3. Dispose of excavated material as specified in Section 203 - Excavation and Embankment.

4. When shown in the contract documents, excavate bells, by mechanical methods, to form bearing area of the size and shape in accordance with the contract documents.

5. Furnish drilled shaft concrete in excess of theoretical volume required to fill excavations for bells and shafts dimensioned in the contract documents.

6. Do not permit workers to enter shaft excavation unless the following conditions are met:

a. Suitable casing is in place.

b. Water level is lowered and stabilized.

c. Accepted safety equipment and procedures are provided and complied with.

(b) Excavation and Drilling Equipment. Furnish excavation and drilling equipment to excavate hole to maximum diameter and to a depth of ten feet or 20 percent beyond depths shown in the contract documents, whichever is greater.

1. Special Drilling Equipment. When conventional earth augers or underreaming tools cannot be used for drilling, provide special drilling equipment, including rock core barrels, rock tools, air tools, and blasting materials to construct shaft excavation to size and depth required. Blasting will be allowed only if specified in the contract documents.

2. Sidewall Overreaming. Overream sidewall when hole sidewall has softened due to excavation methods or swelled due to delays in concreting. Ensure minimum overreaming dimension of 1/2 inch and maximum of 3 inches. Overream with grooving tool or overreaming bucket. The dimension and elevation of sidewall overreaming shall be as ordered by the Engineer. Overream sidewall and place additional shaft concrete at no increase in contract price or contract time.

(c) Unclassified Excavation. When the contract documents specifies unclassified shaft excavation, provide necessary equipment to remove and dispose of materials encountered in drilled shaft excavation. The Engineer will not pay separately for excavation of materials of different densities and character, or for employment of special excavation tools and procedures. The Engineer will pay for obstruction separately.

(d) Coring Samples (Shaft Excavation). Take soil samples or rock cores when shown in the contract documents. Extract soil samples with split or undisturbed sample tube. Cut rock cores with double or triple-tube core barrel accepted by the Engineer.

When shaft excavation is near completion, core to minimum of 10 feet below bottom of drilled shaft excavation. When ordered by the Engineer, extend depth of coring up to total depth of 20 feet. Log exploratory borings, measure rock core and standard penetration test samples, identify visually, and describe in boring log. Place samples in containers identified by shaft location, elevation, and project number. Deliver samples and associated boring logs to the Engineer within 24 hours after completing exploration.

The Engineer will inspect samples or cores and determine required excavation depth. Furnish two copies of typed final boring log to the Engineer when shaft excavation is accepted.

(4) Casings.

(a) General. Furnish steel casings that are smooth, watertight, and of ample strength to withstand both handling and driving stresses, pressure of concrete during placement, and surrounding earth pressures. The inside diameter of casing shall be no less than specified shaft diameter. The

Engineer will not authorize extra compensation for concrete required to fill oversized casing or oversized excavation.

When shaft extends above ground or through a body of water, shaft may be formed with removable casing, unless permanent casing is specified. For permanent casing, after curing concrete, remove portion of metal casing between an elevation two feet below lowest water elevation and top of shaft elevation. Remove casing carefully so that process will not damage concrete. When casing needs to be removed after concrete cures in open water, design and submit special casing system for acceptance. When concrete attains sufficient strength, casing may be removed provided:

1. Concrete curing continues for the full 72-hour period.

2. Shaft concrete is not exposed to salt water or moving water for 7 days.

3. Concrete reaches compressive strength of at least 2,500 pounds per square inch.

(b) Temporary Casing. Remove temporary casing before completing drilled shaft concrete placement. Telescoping and overreaming to beyond outside casing diameter may be required to install casing.

When choosing to remove and replace casing with longer or larger diameter casing through caving soils, stabilize excavation with backfill before installing new casing.

Before withdrawing casing, ensure level of fresh concrete in casing is the higher of the following: 5 feet minimum above hydrostatic water level; or level of drilling fluid outside the casing.

While withdrawing casing, maintain adequate level of concrete within casing so that fluid trapped behind casing is displaced upward and discharged at ground surface without contaminating or displacing shaft concrete.

The Engineer will consider drilled shaft defective when temporary casing becomes bound or fouled during shaft construction and cannot be removed. Correct such defective shafts using methods accepted by the Engineer, including removing shaft concrete and extending shaft deeper; providing replacement shaft; or providing straddle shafts to compensate

for capacity loss. Perform corrective measures, including redesign of footings caused by defective shafts, at no increase in contract price or contract time. The Engineer will not pay for defective casing remaining in place.

(c) Permanent Casing. Ensure casing is continuous between top and bottom casing elevations. After completing installation, cut off permanent casing at prescribed elevation. Complete shaft by installing required reinforcing steel and concrete in casing.

When special temporary casings are in the contract documents or specified in writing by the Engineer, maintain temporary outer casing alignment with permanent inner casing. Provide watertight seal between the two casings during excavation and concreting operations.

(5) Slurry. Drilling slurry will not be allowed.

(6) Excavation Inspection. Provide equipment for checking dimensions and alignment of each permanent shaft excavation. After cleaning, measure final shaft depth with weighted tape.

Ensure a minimum of 50 percent of each shaft base has less than 1/2 inch of sediment at the time concrete is placed. Ensure maximum sediment depth or debris on shaft base does not exceed 1-1/2 inches. The Engineer will visually inspect dry shafts for cleanliness. For wet shafts, the Engineer will use inspection methods deemed appropriate.

(7) Reinforcing Steel Cage Construction and Placement. Assemble and place reinforcing steel cage immediately after the Engineer inspects and accepts shaft excavation and before placing concrete. Reinforcing steel cage includes longitudinal bars, ties, cage stiffener bars, spacers, centralizers, and other appurtenances necessary to complete cage.

Tie and support shaft reinforcing steel such that reinforcing steel placement conforms to allowable tolerances as specified in Subsection 511.03(C)(10) – Construction Tolerances. Use concrete spacers at sufficient intervals (near bottom and at intervals not exceeding 10 feet along shaft length) to ensure concentric spacing for entire cage length. Use minimum of four spacers, equally spaced around circumference, at each vertical interval. Construct spacers of material accepted by the Engineer, equal in quality and durability to concrete specified for the shaft. Furnish spacers of adequate dimension to ensure a minimum 3-inch space between outer portion of reinforcing cage and side of excavated hole or casing. Provide

cylindrical concrete bottom supports accepted by the Engineer to maintain proper distance between bottom of cage and base of shaft excavation.

Check top of steel cage elevation before and after placing concrete. When reinforcing steel placement does not meet specified tolerances, correct to required tolerances. Do not construct additional shafts until reinforcing steel cage support method has been modified and accepted.

When bottom of constructed shaft elevation is lower than shown in the contract documents, extend at least half of the longitudinal bars required in upper portion of shaft, to the shaft bottom. Continue tie bars for the extra depth, spaced 2 feet on center. Extend stiffener bars to final depth. Use lap splices or unspliced bars of proper length. Welding of reinforcing steel will not be allowed.

(8) CSL Test Access Tube Installation. When crosshole sonic log testing is specified in the contract documents, furnish and install access tubes in all drilled shafts, except those constructed in the dry or as otherwise indicated.

Securely attach access tubes to interior of shaft reinforcing steel cage. Place access tubes around shaft, inside spiral or hoop reinforcing steel and 3 inches clear of vertical reinforcing steel, at uniform spacing not exceeding 2 feet 9 inches, unless otherwise indicated in the contract documents, measured along circle passing through centers of access tubes. If vertical reinforcing steel is not bundled and each bar is not more than 1 inch in diameter, place access tubes 2 inches clear of vertical reinforcing steel. If minimum clearances as specified herein cannot be met due to close spacing of vertical reinforcing steel, bundle access tubes with vertical reinforcing steel.

Install access tubes in straight alignment and as near to parallel to vertical axis of reinforcing steel cage as possible. Access tubes shall extend from bottom of reinforcing steel cage to at least 2 feet above either top of continuous concrete placement operation or top of shaft, whichever is higher. Make splice joints in access tubes watertight if joints are required to achieve full-length access tubes. Clear access tubes of debris and extraneous materials before installing access tubes. Protect access tubes from damage during shaft reinforcing steel cage installation and concrete placement.

Fill access tubes with potable water as soon as possible after concrete placement (but no later than one day after). After filling, reinstall top watertight caps.

(9) Concrete Placement.

(a) General. Place concrete through a tremie, concrete pump, or drop chute, using methods as described below.

Unless otherwise authorized by the Engineer, place concrete immediately after placing reinforcing steel.

Place concrete in one continuous operation from bottom to top of shaft. Continue placing concrete after shaft excavation is full until concrete with no laitance or soil contamination is visible at top of shaft.

Elapsed time from beginning to completion of shaft concrete placement shall not exceed 2 hours. Adjust admixtures accepted by the Engineer so that concrete remains in a workable, plastic state throughout 2-hour placement limit.

(b) Monitoring Concrete Volume. For each drilled shaft, prepare and submit, the next working day after concrete placement has been completed, the following:

1. A chart made up after excavation has been completed and accepted by the Engineer and before concrete placement has commenced, indicating depth of hole plotted with theoretical volume of concrete required to fill hole. Plot concrete elevation (surface) along vertical axis and concrete volume along horizontal axis.

2. As concrete is being placed, measure concrete surface at an interval of approximately each cubic yard of concrete discharged, unless otherwise ordered by the Engineer. Plot concrete volume actually placed at each elevation point.

3. Keep records of steel and concrete movement to document the following conditions:

a. When removing temporary casing, elevation of the top of reinforcing cage did not rise more than 2 inches or drop more than 3 inches from its original elevation.

b. As casing is extracted, static level of fluid concrete did not rise.

(c) Concreting by Tremie. Tremie consists of a tube of

sufficient length, weight, and diameter to discharge concrete at the shaft base. Tremie shall not contain aluminum parts that will come in contact with concrete. Use tremie with inside diameter at least 6 times the maximum size of aggregate used in concrete mix and not less than 10 inches. Ensure that inside and outside surfaces of the tremie are clean and smooth. Tremie wall shall be thick enough to prevent crimping or sharp bends.

Use watertight tremie for wet excavation concrete placement. Begin underwater placement after placing tremie at shaft base elevation. Use valves, bottom plates, or plugs to separate drilling water from fluid concrete. Begin concrete discharge within one tremie diameter of the base.

Remove plugs from excavation or use plugs made from material accepted by the Engineer that will prevent shaft defect, if not removed.

Discharge end of tremie shall permit free radial flow of concrete during placement. After starting flow of concrete, keep tremie discharge end immersed at least 5 feet below fluid concrete surface. Place concrete in a continuous flow. Maintain a positive head of concrete in tremie at all times.

The Engineer will consider shaft defective and will reject shaft, if at any time during concrete placement, the tremie discharge end is removed from fluid concrete column and concrete is discharged onto rising concrete surface. If shaft is rejected, remove reinforcing cage, concrete, and portion of sidewall, as ordered by the Engineer, and reconstruct shaft. The Engineer will not pay for defective shaft or shaft removal.

(d) Concreting by Pump. Use pump and discharge line of sufficient capacity, length, weight, and diameter to discharge concrete at the shaft base elevation. Pump and discharge line shall not contain aluminum parts that will come in contact with concrete. Furnish discharge line with minimum diameter of 4 inches and watertight joints. Do not begin concrete placement until discharge line orifice is at shaft base elevation.

For wet excavations, use plug to separate concrete from fluid in the hole until pumping begins. Remove plugs from excavation or use plugs made from material accepted by the Engineer that will prevent shaft defect, if not removed.

Keep pump discharge line orifice at least five feet below fluid concrete surface. When lifting discharge line during concreting, reduce line pressure temporarily, until discharge orifice has been repositioned at a higher level in the excavation.

The Engineer will consider shaft defective and will reject shaft, if at any time during concrete placement, the discharge line is removed from fluid concrete column and concrete is discharged onto rising concrete surface. If shaft is rejected, remove reinforcing cage, concrete, and portion of sidewall, as ordered by the Engineer, and reconstruct shaft. The Engineer will not pay for defective shaft or shaft removal.

(e) Concreting by Drop Chute. Free-fall placement of concrete will be allowed in dry excavations only. Use drop chute to direct free-fall concrete placement. Drop chute consists of a smooth tube of one-piece construction or sections that may be added and removed. Drop chute shall not contain aluminum parts that will come in contact with concrete. Place concrete through a hopper at top of tube or through side openings, as drop chute is removed from shaft during concrete placement. Support drop chute so that free-fall of concrete, measured from bottom of chute, is less than 25 feet.

Ensure concrete placed by drop chute falls directly to base without contacting reinforcing steel cage or shaft sidewall. When concrete placement causes shaft excavation to cave or slough, or when concrete strikes reinforcing steel cage or sidewall, reduce height of free fall or reduce rate of concrete flow into excavation. When concrete placement exceeds 25-foot free fall height limit, use tremie or concrete pump to place concrete.

(10) Construction Tolerances. Apply the following construction tolerances to drilled shafts:

(a) Construct drilled shaft within 1/12 of shaft diameter or 3 inches, whichever is less, of Plan location, measured in a horizontal plane at Plan top of shaft elevation.

(b) Limit alignment variation of vertical shaft excavation from alignment indicated in the contract documents to no more than 1/4 inch per foot of depth. Limit alignment variation of battered shaft excavation from the prescribed batter to no more than 1/2 inch per foot of depth.

(c) After placing concrete, ensure top of reinforcing steel cage is no more than 6.0 inches above and no more than 3.0 inches below position indicated in the contract documents, unless otherwise accepted by the Engineer.

(d) Casing diameters shown in the contract documents refer to outside diameter (OD) dimensions. When accepted by the Engineer, a casing larger in diameter than shown in the contract documents may be provided to facilitate meeting this requirement. When using a series of telescoping casings, size casing to maintain specified shaft diameters.

(e) Excavate bearing area of bells to bearing area indicated in the contract documents, as a minimum. Limit maximum bell diameter to three times specified shaft diameter. When accepted by the Engineer, other dimensions indicated in the contract documents for bells may vary.

(f) Ensure top of shaft elevation is within 1.0 inch of top of shaft elevation indicated in the contract documents.

(g) Use American Pipe Institute tolerances applicable to regular steel pipe for casing dimension tolerances.

(h) Use excavation equipment and methods to ensure that completed shaft excavation will have a flat bottom. Make cutting edges of excavation equipment normal to vertical axis of the shaft, within a tolerance of ±3/8 inch per foot of diameter. Supply as-built drawings.

The Engineer will reject drilled shaft excavations that cannot be completed within required tolerances. Correct unacceptable drilled shaft excavations by using a combination of the following methods: overdrill shaft excavation to a larger diameter to permit accurate placement of reinforcing steel cage with required minimum concrete cover; increase number, size, or length of reinforcing steel bars; enlarge bearing area of bell excavation within allowed tolerances.

Acceptance of correction procedures will be based on an analysis of the effect of misalignment and improper positioning. Submit redesign drawings and computations signed by a Hawaii Licensed Professional Structural Engineer and Hawaii Licensed Professional Civil Engineer who specializes in Geotechnical Engineering. Correct out-of-tolerance drilled shaft excavations, including engineering analysis and redesign, at no increase in contract price or contract time.

(11) Drilled Shaft Load Tests.

(a) General. When indicated in the contract documents, the Contractor shall perform load tests in the presence of the Engineer. Notify the Engineer of the load-testing schedule within 30 days of contract award.

Complete load tests before constructing production drilled shafts. Allow 10 working days after completing last load test for the Engineer to provide estimated drilled shaft tip elevations for production shafts.

Load cells will be required for drilled shaft load tests. Ensure load cells are sized to measure maximum load applied to shaft. Equip load cell with readout device. Before load testing begins, submit certificate from certified testing laboratory that shows load cell calibration within the preceding six months, for stages of loading and unloading. Load cell accuracy shall be within 1 percent of the true load.

After completing tests, cut off test and reaction shafts at an elevation 2 feet below finished ground surface. The removed portions of the shafts shall remain property of the Contractor.

(b) Static Load Tests. Obtain services of a Hawaii Licensed Professional Engineer with satisfactory load test experience to conduct static load test in accordance with the contract documents; record data; and submit reports of test results.

Load test shaft to maximum test load equal to three times the design service load, or to plunging failure, whichever occurs first. Plunging failure is defined as shaft head deflection equal to 5 percent of shaft diameter.

Begin static load testing only after concrete has attained a compressive strength of 3,400 pounds per square inch. Load test drilled shafts in the order specified by the Engineer. Complete static load tests as described in ASTM D 1143 (Compression Test) quick test method, and ASTM D 3966 (Lateral Test), or as otherwise modified. Supply equipment necessary to conduct static test. Design loading frame apparatus to carry maximum load plus adequate safety factor.

(c) Bi-directional Load Tests.

1. Instrumentation. Furnish instrumentation including strain gages, extensometers, load cells, and other equipment specified in the contract documents to measure movement of load cell top and bottom plates, top of shaft, and strain at indicated locations within shaft.

Instrument load test shafts with strain gages (either sister bars or embedment strain gages), two each side at top, bottom, and 10-foot intervals along test shaft length; and rod extensometers at same intervals as strain gages and as indicated in the contract documents.

Extensometers shall be minimum 1/4-inch diameter stainless steel solid rods that couple solidly by screw joints and consist of straight, unbent, undamaged sections. Rods shall be positively fixed at extensometer tips by an anchor that is grouted or otherwise firmly fixed to shaft or load cell. Extensometers shall be attached to anchor by reversed threaded screws, bayonet, or other means that allow recovery and reuse of most of the rods. Extensometers shall be encased in 1/2-inch PVC conduit and be free to move independently of shaft throughout their full length. Tie conduit to reinforcing steel or pressure pipe at maximum 5-foot intervals.

Furnish new, expendable instrumentation to be cast into drilled shafts, from manufacturer with at least five years experience, within last 10 years, manufacturing such instrumentation. Instrumentation shall be calibrated or certified as accurate and operational prior to installation. Submit previous field experience records documenting that instrumentation to be used is capable of remaining calibrated and operational for duration of load test. Strain gages shall be capable of measuring temperature, should thermal correction need to be applied to readings.

Furnish flat, hydraulically expanded load cells, 30 inches in diameter, capable of applying load of at least 500 tons in each direction, as indicated in the contract documents. Cells shall be accurate to within 1 percent, expand uniformly, and capable of being installed and operated as specified in the contract documents. Cells

shall have provisions for monitoring displacement of both upper and lower plates.

2. Load Test Requirements. The bi-directional load test separately tests shear resistance and end bearing of drilled shaft by loading shaft in two directions (upward-shear resistance, downward-end bearing), using a hydraulically expanded load cell, or by loading shaft using other methods, accepted by the Engineer, capable of full separation of shear and end bearing components.

The Contractor shall obtain the services of a specialty contractor with minimum three years bi-directional load test experience, accepted by the Engineer, to be responsible for instrumenting shaft(s), conducting bi-directional load testing in accordance with the contract documents, recording all data, and submitting test results.

Unless otherwise specified in the contract documents, load test shaft to capacity of load cell or to plunging failure, whichever occurs first.

The Contractor shall furnish equipment required to install load cell, conduct load test, and remove load test apparatus as required. Use the following load test set-up procedures:

a. In suitable area provided by the Contractor adjacent to test shaft, assemble load cells, piping, and other attachments and prepare for installation under direction of load test specialty contractor. While reinforcing steel cage is being constructed, place load cell assembly at bottom of cage.

b. Advance test shaft to depth as specified in the contract documents.

c. Clean bottom of shaft excavation after drilling is complete.

d. Place concrete at bottom of shaft to a level even with bottom of load cell. Minimum concrete thickness shall be one-half of difference between shaft diameter and load cell diameter.

e. Pump cement grout to bottom of shaft to allow seating of load cell.

f. Immediately after placing grout for load cell seating, install reinforcing steel cage assembly and load cell, under direction of load test specialty contractor and the Engineer. Ensure that load cell is seated firmly in grout bed. Prevent damage to instrumentation during installation of reinforcing steel cage assembly. Alternatively, to seat cell, load cell and support system may be lowered to near bottom of shaft and center pipe from cell may be used to grout space between cell and shaft bottom.

g. After load cell installation, place shaft concrete as specified in the contract documents for production shafts.

After completion of bi-directional load testing, remove equipment, material, and waste that are not part of finished structure. Grout load cell through piping provided in load cell assembly.

(12) Integrity Testing. Test drilled shafts for soundness and integrity, as specified in the contract documents. Perform specified testing as follows:

(a) Nondestructive Testing (CSL Testing).

1. When CSL testing is specified in the contract documents, the Engineer or the Engineer's authorized representative will perform CSL testing and analysis, including 3-dimensional tomographic images on all completed shafts designated by the Engineer for testing. Notify the Engineer at least seven days prior to time when drilled shaft concrete will have cured sufficiently (minimum three days) to allow CSL testing. CSL testing will be conducted only after concrete has cured for minimum of three days and within 45 days of concrete placement.

2. Provide independent, stable, 110 volt, 55-60 hertz, AC power supply for CSL testing.

3. After placing shaft concrete and before beginning CSL testing, inspect access tubes and pass test probes through access tubes. Replace each access tube that

test probe cannot pass through, at no increase in contract price or contract time, with 2-inch diameter hole cored through concrete for entire shaft length. Unless otherwise directed by the Engineer, locate cored hole approximately 6 inches inside shaft reinforcing steel, without damaging steel. Log descriptions of inclusions and voids in cored holes and submit copy of log. Identify as to location and preserve findings from cored holes. Make these findings available for inspection by the Engineer.

4. Prior to CSL testing, remove caps or plugs at top of access tubes. When removing caps or plugs, do not hammer or apply excess torque or other stresses to access tubes that could break bond between access tubes and concrete. If debonding is indicated by CSL test results, submit alternative test method to determine concrete integrity in debonded region. After the Engineer's acceptance, conduct alternative test method at no increase in contract price or contract time.

5. Conduct CSL testing on minimum of 50 percent of shafts in which CSL test access tubes have been installed. For bridge shafts, apply 50 percent testing rate on a pier-by-pier basis. Test a minimum of one shaft per pier. For retaining wall shafts, apply 50 percent testing rate to each wall. Conduct CSL testing on first shaft constructed at each bridge and retaining wall. After initial testing, the Engineer will determine if further CSL testing will be required, and if so, will identify those shafts to be tested.

6. Submit results and analysis of CSL testing for each shaft tested. The Engineer will determine final acceptance of each tested shaft, based on CSL test results and analysis; and will provide response to Contractor within three working days after receiving test results and analysis submittal.

7. The Engineer may require that additional shafts be tested. If additional testing indicates the presence of defects in the additional shafts, the Contractor shall assume testing and delay costs resulting from additional testing. If additional testing indicates no defects, additional testing and delay costs will be the State's responsibility; and if shaft construction is on critical path of the Contractor's schedule, a time extension equal to the delay created by additional testing will be granted.

8. Submit remedial action plan for all shafts determined by the Engineer to be unacceptable, including calculations and working drawings necessary to support modifications to shaft dimensions or layout required by the contract documents. Begin repair operations only after the Engineer accepts remedial action plan.

9. At the discretion of the Engineer, coring, as specified in Subsection 511.03(C)(12)(b) – Coring, to determine shaft integrity will be required.

10. After tests are completed, dewater and completely fill with grout, all access tubes and cored holes. Use grout tubes that extend to bottom of tube or hole to fill access tubes or cored holes.

(b) Coring.

1. Core inspection holes on 5 percent of production shafts.

2. Core a 3-inch diameter vertical hole, centrally located, throughout full depth of drilled shafts designated by the Engineer. Fill cored holes with non-shrink grout of the same minimum strength as drilled shaft.

(13) Corrective Action. Fill with grout, all voids or separations revealed by integrity testing, using the following procedures:

(a) Core additional holes, as ordered by the Engineer, to define flow path to the void. Place grout tube in cored hole with its tip adjacent to the void. Seal hole and inject cement grout at a gage pressure of 10 pounds per square inch. Continue injection until refusal or until gage reads 15 pounds per square inch, whichever occurs first.

(b) Use one part Type I portland cement and two and one-half parts sand (by volume), from which all sizes larger than No. 8 have been removed, and with just sufficient water to provide fluidity and compressive strength equal to compressive strength of drilled shaft concrete.

(c) After inspection and after all voids have been filled and accepted by the Engineer (proof coring may be required, at the discretion of the Engineer), fill cored holes completely with specified grout.

(d) Submit alternative corrective methods for review and acceptance prior to use.

(e) Perform corrective actions at no additional increase in contract price or contract time.

(14) Revised Concreting Procedure. If voids or inclusions are found through testing, submit revised concreting procedure for new shafts. Indicate steps to be taken to eliminate such voids in the future. Continuation of shaft concreting will not be allowed until the Engineer has accepted revised procedure. Prepare and submit revised concreting procedure at no additional increase in contract price or contract time and with no extension of time allowed.

511.04 Measurement.

(A) Furnishing drilled shaft drilling equipment; and furnishing instrumentation and collecting data will be paid on a lump sum basis. Measurement for payment will not apply.

(B) The Engineer will measure obstruction per hour in accordance with the contract documents. Once the Engineer authorizes compensation for obstruction removal, duration of obstruction removal, including time required for obstruction disposal, will be measured for payment. Depth of obstruction removed will be subtracted from total depth measured for payment under other applicable drilled shaft excavation pay items.

(C) The Engineer will measure load test per each in accordance with the contract documents.

(D) The Engineer will measure drilled shaft per linear foot. The Engineer will compute length between plan top of shaft elevation and final bottom of shaft elevation.

(E) The Engineer will measure standard excavation per linear foot along shaft centerline, including bells.

(F) The Engineer will measure special excavation per linear foot along shaft centerline, including bells, from elevation authorized by the Engineer as the accepted shaft bottom elevation.

(G) The Engineer will measure unclassified shaft excavation per linear foot, along shaft centerline, including bells. The Engineer will compute length between plan top of shaft elevation to plan estimated tip elevation.

(H) The Engineer will measure unclassified extra depth excavation per linear foot, along shaft centerline. The Engineer will compute length between plan estimated shaft tip elevation and final authorized and accepted shaft bottom elevation.

(I) The Engineer will measure drilled shaft sidewall overreaming per linear foot, between plan elevation limits or as authorized by the Engineer.

(J) The Engineer will measure trial shaft holes per linear foot. The Engineer will compute length between existing ground surface elevation at trial shaft hole center, before drilling, and authorized bottom elevation of hole, including bells.

(K) The Engineer will measure coring samples (shaft excavation) per linear foot. The Engineer will compute length between bottom of shaft elevation and bottom of exploration hole, for each authorized exploration drilled below shaft excavation.

(L) The Engineer will measure permanent casing per linear foot, along casing. The Engineer will compute length between top of shaft elevation or top of casing, whichever is lower, and bottom of casing, at each shaft location where permanent casing is used.

511.05 Payment. The Engineer will pay for the accepted pay items listed below at the contract price per pay unit, as shown in the proposal schedule. Payment will be full compensation for the work prescribed in this section and the contract documents.

The Engineer will pay for each of the following pay items when included in the proposal schedule:

Pay Item	**Pay Unit**
Furnishing Drilled Shaft Drilling Equipment	Lump Sum

The Engineer will pay for:

(A) 60 percent of the contract bid price when drilling equipment is on job site, assembled, and ready to drill foundation shafts.

(B) 40 percent of the contract bid price upon completion of drilling shafts, and placing shaft concrete up to top of shafts.

Furnishing Instrumentation and Collecting Data	Lump Sum

Obstruction — Hour

The Engineer will pay for:

(A) 80 percent of the contract bid price upon completion of removing the obstruction.

(B) 20 percent of the contract bid price upon removing and disposing of the obstruction.

The maximum payment per designated obstruction shall not exceed 20 times the unit cost for standard excavation or unclassified excavation whichever is less.

Load Test — Each

The Engineer will pay for:

(A) 100 percent of the contract bid price upon completion of testing the load and other related costs to performance of load test.

Drilled Shaft — Linear Foot

The Engineer will pay for:

(A) 60 percent of the contract bid price upon completion of drilling.

(B) 15 percent of the contract bid price upon completion of furnishing, assembling, and placing steel cage.

(C) 15 percent of the contract bid price upon completion of furnishing and placing concrete.

(D) 10 percent of the contract bid price upon completion of removing and disposing of excavated material.

Standard Excavation — Linear Foot

The Engineer will pay for:

(A) 80 percent of the contract bid price upon completion of excavating for drilled shaft by using conventional tools include augers fitted with soil or rock teeth, drilling buckets, and overreaming (belling buckets) attached to drilling equipment.

(B) 20 percent of the contract bid price upon completion of removing and disposing of excavated material.

Special Excavation — Linear Foot

The Engineer will pay for:

(A) 80 percent of the contract bid price upon completion of excavating by using special tools or other acceptable procedures to advance the hole.

(B) 20 percent of the contract bid price upon completion of removing and disposing of excavated material.

Unclassified Shaft Excavation — Linear Foot

The Engineer will pay for:

(A) 60 percent of the contract bid price upon completion of using slurry, using drilling equipment, blasting, using special tools and drilling equipment to excavate shaft

(B) 20 percent of the contract bid price upon completion of furnishing and installing temporary casing

(C) 20 percent of the contract bid price upon completion of removing and disposing of excavated material.

Unclassified Extra Depth Excavation — Linear Foot

The Engineer will pay for:

(A) 80 percent of the contract bid price upon completion of excavating below bottom of shaft elevations including permanent casing.

(B) 20 percent of the contract bid price upon completion of removing and disposing of excavated material.

Only when authorized by the Engineer, the Engineer will pay for the accepted unclassified extra depth excavation at 150 percent of the contract unit price per linear foot of the diameter specified.

Drilled Shaft Sidewall Overreaming — Linear Foot

The Engineer will pay for:

(A) 80 percent of the contract bid price upon completion of overreaming sidewall drilled shaft.

(B) 20 percent of the contract bid price upon completion of removing and disposing of excavated material.

Trial Shaft Holes — Linear Foot

The Engineer will pay for:

(A) 60 percent of the contract bid price upon completion of excavating trial shaft holes through to bottom of shaft elevation or as authorized by the Engineer (using mineral slurry as necessary) and providing inspection facilities.

(B) 20 percent of the contract bid price upon completion of backfilling hole.

(C) 20 percent of the contract bid price upon completion of restoring the site.

The Engineer will not pay for trial shaft holes that the Contractor failed to demonstrate to the Engineer the adequacy of its proposed methods and equipment.

Coring Samples (Shaft Excavation) — Linear Foot

The Engineer will pay for:

(A) 70 percent of the contract bid price upon completion of soil sampling and rock coring.

(B) 20 percent of the contract bid price upon completion of filling cored holes with non-shrink grout of the same minimum strength as drilled shaft.

(C) 10 percent of the contract bid price upon completion of packaging and classifying samples or cores and delivering them to the Engineer

Permanent Casing — Linear Foot

The Engineer will pay for:

(1) 100 percent of the contract bid price upon completion of furnishing and installing permanent casings.

END OF SECTION 511