

728-B-203 DRILLED SHAFT FOUNDATIONS

(Adopted 03-21-13)

The Standard Specifications are revised as follows:

SECTION 728, BEGIN LINE 1, DELETE AND INSERT AS FOLLOWS:

SECTION 728 - ~~BLANK~~ DRILLED SHAFT FOUNDATIONS

728.01 Description

This work shall consist of the construction of reinforced concrete drilled shaft foundations, 5.0 ft or smaller in outside diameter, in accordance with 105.03.

MATERIALS

728.02 Materials

Materials shall be in accordance with the following:

Admixtures for Use in Concrete*	912.03
Cement Grout	707.09
Coarse Aggregate	
For exposed concrete, Class A or Higher,	
Size No. 8 or No. 9	904
For non-exposed concrete, Class B or Higher,	
Size No. 8 or No. 9	904
Fine Aggregate, Size No. 23	904
Fly Ash	901.02
Ground Granulated Blast Furnace Slag	901.03
Portland Cement, type I, II, IP, or IS**	901.01(b)
Reinforcing Bars	910.01
Water	913.01

* Except as modified herein

** Air- entraining cement shall not be used. This includes type IA, IIA, IIIA, IP-A, IS-A. If type IP cement is used, the pozzolan in the blended cement shall not be class C fly ash.

If indicated on the plans, casings shall be in accordance with either ASTM A 252, grade 2 or ASTM A 36. Otherwise, casings shall be steel, smooth, clean, watertight, and of adequate strength to resist construction stresses. The outside diameter of casing shall not be less than the specified diameter of the drilled shaft unless otherwise shown on the plans. Casing diameters shall be within the American Pipe Institute's tolerances for regular steel pipe. The Contractor may request to provide a casing larger in diameter than that specified.

Slurry shall be either a polymer or mineral, using sodium bentonite or attapulgite. Slurry shall have a grain size that will remain in suspension with sufficient viscosity and gel characteristics to transport excavated material and shall be capable of maintaining the stability of the drilled shaft excavation to allow proper concrete placement.

728.03 Drilled Shaft Concrete Mix Design

The mix design for the drilled shaft concrete shall be determined based on the design compressive strength, f'_c , and the requirements stated in Appendix X1 of ASTM C 94, as well as the following conditions:

- (a) The target water/cementitious ratio for the mix design shall not exceed 0.450.*
- (b) The design total cementitious content shall be set such that it is no less than 650 lbs and not more than 800 lbs. Fly ash or GGBFS as outlined below shall be used in combination with portland cement.*
 - 1. If class F fly ash is used, the fly ash content for a mix design shall be a minimum of 25% and shall not exceed 30% of the total cementitious, by weight. Class F fly ash shall not be used in conjunction with blended cement or ground granulated blast furnace slag, GGBFS.*
 - 2. If class C fly ash is used, the fly ash content for a mix design shall be a minimum of 35% and shall not exceed 40% of the total cementitious, by weight. Class C fly ash shall not be used in conjunction with blended cement or ground granulated blast furnace slag, GGBFS.*
 - 3. If GGBFS is used, the GGBFS content for a mix design shall be a minimum of 35% and shall not exceed 45% of the total cementitious, by weight. GGBFS shall not be used in conjunction with blended cement or fly ash.*
- (c) The drilled shaft concrete shall be air entrained. The target air content for the mix design shall be set at 6.5% air or 1.755 cu ft/cu yd of concrete.*
- (d) The target fine aggregate content shall be set such that it is no less than 35%, but not more than 50% of the total weight of the aggregate in each cubic yard. Aggregate proportions shall be based on material in the saturated surface dry condition.*

The air content shall be $6.5\% \pm 2.0$ by volume at the time of acceptance. Air content shall be determined in accordance with 505.

The temperature of the concrete at time of placement shall not exceed 80° F. The concrete temperature shall be controlled by one of the pre-cooling methods described in ACI 207.4R and as approved by the Engineer.

Drilled shaft concrete mix shall remain workable until the entire placement operation is complete and any temporary casings have been removed from the excavation. When the dry construction method is used, the concrete shall have a slump of 6 in. to 9 in. When the wet construction method or casing construction method is used, the concrete shall have a slump of 7 in. to 10 in. The concrete shall maintain a slump within the ranges specified herein until the entire placement operation is complete. One of the following admixtures shall be used to achieve and maintain the required slump:

- (a) type F admixture,
- (b) type G admixture,
- (c) high range water reducing admixture system, or
- (d) high range water reducing retarding admixture system.

A rheology-modifying admixture meeting the requirements of type S chemical admixture in accordance with ASTM C 494 may be used if approved by the Engineer and admixture manufacturer. Chemical admixtures type B, type C, and type E will only be permitted with prior written permission. The concrete shall not be rettempered with additional amounts of chemical admixtures type F or type G after the initial mixing has been completed.

A concrete mix design, CMD, shall be prepared for the drilled shaft based on the requirements as specified herein and shall be verified by a trial batch. The CMD shall be submitted to the Engineer for verification at least seven days prior to the trial batch demonstration. The CMD submittal shall include the following:

- (a) list of all ingredients
- (b) source of all materials
- (c) gradation of the aggregates
- (d) absorption of the aggregates
- (e) SSD bulk specific gravity of the aggregates
- (f) specific gravity of pozzolan
- (g) batch weights
- (h) names of all admixtures
- (i) range of admixture dosage rates as recommended by the manufacturer

728.04 Trial Batch

An American Concrete Institute certified concrete field testing technician, grade 1, hereinafter referred to as the Contractor's certified technician, shall be on site to direct and perform all sampling and testing.

A trial batch shall be produced and tested by the Contractor's certified technician and the Department's qualified technician to verify that the CMD meets the concrete mix criteria. The trial batch shall be of sufficient quantity to allow the Contractor and the Engineer to perform all required tests from the same batch. Concrete shall be batched, mixed, and delivered in accordance with 702.06, 702.07, and 702.09. The Engineer will test the trial batch and provide the Contractor with the results. Trial batch concrete shall not be used for more than one test, except the concrete used for the unit weight may be used to conduct the air content test. In order for the trial batch concrete to be considered acceptable, the air content will measure at least 6.5%. After mixing, the concrete shall be agitated for a time period to simulate delivery, not to exceed 45 minutes.

The Contractor shall cast four 6 in. diameter by 12 in. cylinders for compressive strength determination. Two of the cylinders shall be tested at an age of 7 days and two cylinders tested at an age of 28 days. Compressive strength shall be reported as the average of the two cylinders tested at the appropriate age.

The Department will cast four 6 in. diameter by 12 in. cylinders. Two of the cylinders will be tested at an age of 7 days and two cylinders tested at an age of 28 days. Compressive strength will be reported as the average of the two cylinders tested at the appropriate age. Additional cylinders may be cast and tested at another age. Average compressive strength test results by the Department, which achieve the minimum compressive strength requirement at an earlier age, will be considered as validating the compressive strength requirement for the CMD; however, compressive strength at 28 days is still required. The 28-day compressive strength shall meet or exceed the requirements of ASTM C 94, Appendix X1, unless otherwise approved by the Engineer.

The Department's test results will be used to validate CMD compliance with the required concrete properties.

All molds, facilities, and materials necessary to prepare and initially cure cylinders shall be provided.

Gradations will be determined to validate the fine and coarse aggregates used.

The Department's qualified technician will measure the concrete properties and verify compliance to the Contractor's results within the following tolerances.

CONCRETE PROPERTIES AND ALLOWABLE TOLERANCES BETWEEN RESULTS

Concrete Property	Tolerance between results
Aggregate Correction Factor	±0.1 percentage point
Air Content	±0.5 percentage points
Slump	±1.0 in.
Temperature	±1.9°F
28-day Compressive Strength	±8.5%
Unit Weight	±1.9 lb/cu ft
Water/Cementitious ratio	±0.015

All test results not within the tolerance are to be investigated by the Department and the Contractor as to the cause and determine corrective actions required to resolve the discrepancy. The relative yield shall be determined by both the Department and the Contractor and compared to the theoretical value for relative yield in the following table based on the measured air content. A relative yield that is more than ±0.005 from the theoretical is not cause for rejection, but will be investigated for cause and possible corrective action.

THEORETICAL EFFECT OF AIR CONTENT ON RELATIVE YIELD

(@ 6.5% Target Air Content)

Air Content	Theoretical Relative Yield	Air Content	Theoretical Relative Yield	Air Content	Theoretical Relative Yield
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3.0 (fail)	0.965	5.7	0.992	8.4	1.019
3.1 (fail)	0.966	5.8	0.993	8.5	1.020
3.2 (fail)	0.967	5.9	0.994	8.6 (fail)	1.021
3.3 (fail)	0.968	6.0	0.995	8.7 (fail)	1.022
3.4 (fail)	0.969	6.1	0.996	8.8 (fail)	1.023
3.5 (fail)	0.970	6.2	0.997	8.9 (fail)	1.024
3.6 (fail)	0.971	6.3	0.998	9.0 (fail)	1.025
3.7 (fail)	0.972	6.4	0.999	9.1 (fail)	1.026
3.8 (fail)	0.973	6.5	1.000	9.2 (fail)	1.027
3.9 (fail)	0.974	6.6	1.001	9.3 (fail)	1.028
4.0 (fail)	0.975	6.7	1.002	9.4 (fail)	1.029
4.1 (fail)	0.976	6.8	1.003	9.5 (fail)	1.030
4.2 (fail)	0.977	6.9	1.004	9.6 (fail)	1.031
4.3 (fail)	0.978	7.0	1.005	9.7 (fail)	1.032
4.4 (fail)	0.979	7.1	1.006	9.8 (fail)	1.033
4.5	0.980	7.2	1.007	9.9 (fail)	1.034
4.6	0.981	7.3	1.008	10.0 (fail)	1.035
4.7	0.982	7.4	1.009	10.1 (fail)	1.036
4.8	0.983	7.5	1.010	10.2 (fail)	1.037
4.9	0.984	7.6	1.011	10.3 (fail)	1.038
5.0	0.985	7.7	1.012	10.4 (fail)	1.039
5.1	0.986	7.8	1.013	10.5 (fail)	1.040
5.2	0.987	7.9	1.014	10.6 (fail)	1.041
5.3	0.988	8.0	1.015	10.7 (fail)	1.042
5.4	0.989	8.1	1.016	10.8 (fail)	1.043
5.5	0.990	8.2	1.017	10.9 (fail)	1.044
5.6	0.991	8.3	1.018	11.0 (fail)	1.045

CMD's, which have had a successful trial batch demonstration for another drilled shaft on a separate contract may be submitted for the Engineer's approval. The results from Department and Contractor testing of the concrete properties listed above from the trial batch concrete shall be included in the submittal. If the Engineer approves the use of the submitted CMD, verification of the tolerances shall be made during the first day of production by tests conducted by the Contractor's certified technician and the Department's qualified technician. The results of the tests from the first day of concrete production shall be within the concrete property tolerances listed above.

Except for adjustments to compensate for routine aggregate moisture fluctuations, changes in target aggregate SSD batch weights shall be documented and submitted to the Engineer for approval, prior to implementing. A maximum adjustment of ± 3 percentage points of fine to total aggregate ratio by volume will be permitted. Changes to the admixture dosages will be permitted.

A new CMD shall be prepared and successfully demonstrated by trial batch for any change in material, cementitious content or target water/cementitious ratio.

CONSTRUCTION REQUIREMENTS

728.05 Quality Control Testing

The Contractor shall perform all quality control testing including, but not limited to, slurry testing and plastic and hardened concrete testing. The Contractor shall provide copies of all quality control test reports to the Engineer no later than five business days after the tests are completed. If the Contractor fails to submit test reports within the timeframe allowed, the Engineer may withhold progress estimates until the reports are provided.

728.06 Blank

728.07 Submittals

A minimum of 45 days prior to the start of drilled shaft construction, the Contractor shall submit a QCP in accordance with ITM 803 detailing the plan for construction of the drilled shafts. The QCP shall at a minimum include the following:

- (a) The name of the contractor that will perform the drilled shaft construction.
- (b) A list of equipment to be used including, but not limited to cranes, drills, augers, bailing buckets, final cleaning equipment, de-sanding equipment, slurry pumps, core sampling equipment, tremies, concrete pumps, and temporary casings.
- (c) A list of proposed materials and suppliers including, but not limited to concrete, reinforcement bars, permanent casings and slurry.
- (d) A detailed description of the proposed sequence of construction through the project, at each structure and at each bent and pier of each structure.
- (e) A detailed explanation of methods and procedures for construction including, but not limited to the following:
 - 1. The method of construction proposed for each drilled shaft.
 - 2. The procedures for ensuring correct horizontal and vertical alignment of each drilled shaft.
 - 3. The procedures for removing or excavating through subsurface obstructions, whether natural or man-made.
 - 4. The procedures for advancing casing, as applicable.

5. *The details regarding the lengths, sizes and locations of the temporary casings and details regarding the methods to install and extract the temporary casing as applicable.*
6. *The methods of mixing, circulating and de-sanding slurry. A copy of the slurry manufacturer's recommendations shall be included.*
7. *The names and qualifications of technicians that will perform slurry testing.*
8. *The names and qualifications of the certified technicians.*
9. *The procedures for dewatering and cleaning drilled shaft excavations.*
10. *The methods for placing and supporting reinforcement bars in the correct locations.*
11. *The materials and methods for installing, protecting and grouting crosshole sonic logging testing access tubes.*
12. *The procedures for concrete placement.*
13. *The procedures and materials for pressure grouting voids when using permanent casing.*
14. *Detailed procedures for how construction problems will be addressed.*

Drilled shaft construction shall not begin until the QCP is approved in writing by the Engineer.

728.08 Preconstruction Meeting

The Contractor shall hold a pre-construction meeting with the Engineer after approval of the QCP and a minimum of 14 days prior to construction. The pre-construction meeting shall include at a minimum representatives of the Contractor, the subcontractor performing the drilled shaft construction, the Engineer, the design consultant, the geotechnical consultant drilled shaft inspector, and the Office of Geotechnical Services.

728.09 Equipment

Drilling and excavation equipment shall be capable of producing a drilled shaft that is a minimum of 20% of the planned drilled shaft length below the tip elevations shown in the plans. Blasting will not be permitted for drilled shaft excavation unless approved in writing by the Engineer.

Drop chutes for concrete placement shall consist of a smooth tube of one piece construction with an attached hopper.

Tremies shall consist of a watertight tube of sufficient length, diameter, and wall thickness to discharge concrete at the base of the drilled shaft excavation without bending, crimping or impeding the flow of concrete. The inside diameter of the tremie shall be a minimum of 10 in. The discharge end of the tremie shall be constructed to permit the free radial flow of concrete during placement operations. The inside and outside surfaces of the tremie shall be clean and smooth.

Concrete pumps shall be capable of maintaining a continuous flow of concrete from beginning to completion of a drilled shaft pour. Pump lines shall have a minimum 4 in. diameter and shall be constructed with watertight joints.

728.10 Construction Methods

The Contractor shall use the construction methods specified in the contract for each drilled shaft. If more than one method is specified or no method is specified for a drilled shaft, the Contractor may choose the method suitable for the drilled shaft. Construction methods shall be one of the following:

(a) Dry Construction Method

The dry construction method shall consist of drilling the excavation, removing accumulated water and loose material from the excavation, and placing concrete and reinforcement in a relatively dry excavation.

The dry construction method shall only be used in locations where conditions are such that the rate of groundwater infiltration into the excavation does not exceed 12 in. per hour. The maximum depth of water shall not exceed 2 in. prior to concrete pour. The sides and bottom of the excavation shall remain stable without any caving, sloughing, or swelling, and the full depth of the excavation may be visually inspected prior to placing concrete.

(b) Wet Construction Method

The wet construction method shall consist of drilling the excavation, cleaning the excavation by muck bucket and air lifting, and placing concrete in a manner to displace water and slurry up and out of the excavation as concrete is placed.

The wet construction method shall be used where conditions are not suitable for the dry construction method. To prevent caving, sloughing, or swelling of the excavation during drilling, slurry shall be added to the excavation prior to encountering groundwater.

(c) Casing Construction Method

The casing construction method shall consist of placing either a temporary or permanent casing in accordance with the following:

1. Temporary Casing Method

The temporary casing method shall consist of drilling the shaft excavation in accordance with the dry or wet construction method, placing a casing to maintain the excavation, and then withdrawing the casing during placement of the concrete.

2. Permanent Casing Method

The permanent casing method shall consist of driving, vibrating, or drilling a casing to a specified depth prior to excavation of the drilled shaft. Material inside the casing is then excavated and concrete placed in accordance with the dry or wet construction method.

728.11 Construction

The Contractor shall maintain a construction log for each drilled shaft. The log shall include the following as a minimum:

- 1. The drilled shaft number.*
- 2. The method of construction.*
- 3. A description and approximate top and bottom elevation of each soil or rock material encountered during excavation.*
- 4. The rate of groundwater infiltration.*
- 5. The depth of water in the excavation just prior to concrete placement.*
- 6. The type of slurry, as applicable.*
- 7. The results of all slurry testing, as applicable.*
- 8. The methods used to clean and check the excavation prior to concrete placement.*
- 9. The method of concrete placement.*
- 10. The results of all plastic concrete testing including temperature readings.*
- 11. The number of concrete cylinders made for compressive strength testing.*
- 12. Time of completion of excavation cleaning.*
- 13. Time of installation of reinforcing steel.*
- 14. Time that concrete placement begins and ends.*
- 15. The rate of concrete placement and the total time required to place concrete.*
- 16. The method of temporary casing removal, as applicable.*
- 17. A record of the head of concrete before and during removal of temporary casing, as applicable.*
- 18. The total volume of concrete placed versus theoretical volume of concrete required.*
- 19. A description of all equipment and materials used.*
- 20. A record of any problems encountered including possible soil and water inclusion, possible voids, and possible drilled shaft or casing collapse.*

A drilled shaft excavation shall not be left unfilled overnight unless cased to full depth.

(a) Exploratory Rock Cores, Soil Borings, and Proof Testing

The Contractor shall obtain soil samples and exploratory rock cores within the footprint of each drilled shaft prior to the start of production drilling to determine the character of the material throughout the entire drilled shaft length and to a depth directly below the complete shaft excavation. Soil borings and exploratory rock cores shall extend a minimum of 15 ft below the planned tip elevation of the drilled shaft or three times the diameter of the rock socket, whichever is greater, or as directed by the Engineer. Soil samples and exploratory rock cores shall be obtained by an approved Geotechnical Consultant and complete boring logs shall be prepared and submitted by the geotechnical consultant.

Soil samples shall be taken within soils at a maximum spacing of 5 ft, or as otherwise directed by the Engineer, using the standard penetration test method with the soil samples extracted with a split-barrel sampler or with undisturbed sample excavation.

Exploratory rock cores shall be NX-size. The exploratory rock coring operation shall include observing such indicators as speed of drilling under given drill pressure, dropping or clogging of the drill bit and loss of drill water, if used. The Engineer will observe exploratory rock coring and will inspect cores to determine if the material is suitable for the planned depth and size of drilled shaft. Additional exploratory rock cores shall be obtained as directed by the Engineer. The core hole shall be grouted upon completion of coring. The exploratory rock cores shall be extracted with a core barrel. Cores shall be measured, visually identified, and described on the Contractor's field log within 24 hours after the exploration is completed. The Engineer will inspect the cores and determine the final depth of required excavation based on evaluation of the material's suitability.

(b) Casing

All subsurface casing shall be considered temporary unless specified as permanent casing in the contract.

If the Contractor elects to remove a casing and substitute a longer or larger diameter casing through caving soils, the excavation shall be stabilized either with slurry or by backfilling before the new casing is installed.

If the dry construction method is used and casing is not placed during excavation, the Contractor shall take appropriate measures to prevent deterioration of the excavation. If the excavation has deteriorated, the Contractor shall over-ream the excavation prior to placement of concrete and reinforcement. Over-reaming shall be by methods approved by the Engineer.

If the temporary casing method is used, the casing shall be advanced with the drilling until a nearly impervious ground formation is reached. The casing shall be seated in the formation and excavation shall continue until the required tip elevation is reached. Dependent on the rate of groundwater infiltration, construction shall proceed in accordance with either the dry or wet construction method. The temporary casing shall be withdrawn during placement of the concrete and while the concrete is still in a plastic state. The casing shall be withdrawn at a slow, uniform rate in a direction parallel to the axis of the drilled shaft. The casing shall not be rotated, reinserted, driven, or vibrated during withdrawal unless prior approval is granted by the Engineer. The rate of concrete placement and rate of casing withdrawal shall be such that the concrete displaces all loose materials, water and slurry up and out of the excavation without mixing with or displacing the concrete. At a minimum, a 5 ft head of concrete shall be maintained above either the highest hydrostatic water level or slurry, whichever is higher, as the casing is withdrawn.

Temporary casing which becomes bound and cannot be practically removed will constitute a defect in the drilled shaft. The Contractor shall submit a proposed method to

remediate the defect to the Engineer for approval. The submittal shall include design drawings and calculations stamped by a professional engineer.

When temporary casing is used and the drilled shaft extends above ground or through a body of water, the portion of the drilled shaft above the existing ground or above the bottom of the body of water may be formed with a removable casing. Removable casings may be removed when the following conditions are met:

1. The concrete has cured for a minimum of 72 hours.
2. The concrete attains a compressive strength of at least 2,500 psi, as determined from 6 in. diameter by 12 in. concrete cylinder breaks.
3. The drilled shaft concrete is not exposed to moving water for seven days.

If the permanent casing method is used, the casing shall be driven, vibrated, or advanced by drilling to the specified tip elevation. If the casing cannot be driven to the full depth of the excavation, the Contractor may either excavate material within the embedded portion of the casing or drill a pilot hole ahead of the casing until the casing reaches the specified depth. If a pilot hole is drilled, it shall be centered in the drilled shaft and shall be no larger than one-half the diameter of the drilled shaft. The Contractor shall not over-ream the excavation to the outside diameter of the casing. Permanent casing shall be continuous between the elevations shown on the plans. Any length of permanent casing installed below the shaft cutoff elevation, shall remain in place. Temporary casing shall not be used instead of, or in addition to, permanent casing. After the permanent casing is placed, all loose materials and water shall be removed. Reinforcement shall be placed and the casing shall be filled with concrete. All voids between the casing and the soil surrounding the casing shall be pressured grouted with cement grout.

(c) Slurry

When slurry is used during drilled shaft excavation, the Contractor shall perform testing to determine the density, viscosity, and pH of the slurry. A minimum of four sets of tests shall be made during the first eight hours of slurry use. If the first four sets of tests indicate consistent, acceptable results, the testing frequency may be decreased to one set of tests for every four hours of slurry use. Tests shall be performed when the slurry temperature is above 40°F. Test results shall be within the ranges shown below:

SLURRY PROPERTIES

<i>Property</i>	<i>Test Method</i>	<i>Required Range</i>
<i>Density, pcf</i>	<i>Density Balance</i>	<i>64.3 - 69.1</i>
<i>Viscosity, seconds/quart</i>	<i>Marsh Cone</i>	<i>28 - 45</i>
<i>pH</i>	<i>pH paper or meter</i>	<i>8 - 11</i>

The Contractor shall perform sand content testing in accordance with the American Petroleum Institute. The sand content shall not exceed 4% by volume at any point in the excavation when slurry is used.

Prior to placing concrete in a drilled shaft excavation with slurry, the Contractor shall obtain slurry samples from the base of the excavation and at intervals of 10 ft along the length of the excavation. The samples shall be tested and two consecutive samples shall have acceptable results for density, viscosity, pH, and sand content before concrete is placed in the drilled shaft excavation. If test results are not acceptable, the Contractor shall take corrective action to bring the slurry in to compliance with the requirements.

The Contractor shall ensure that heavily contaminated slurry suspension, which could impair the free flow of concrete, has not accumulated in the bottom of the shaft.

The level of slurry in a drilled shaft excavation shall be maintained at a level sufficient to prevent caving of the hole, but not less than 4 ft above the highest expected piezometric pressure head along the depth of the shaft. In the event of a sudden significant loss of slurry in the excavation, the construction of that drilled shaft shall be stopped until either a method to stop slurry loss or an alternate construction procedure has been approved by the Engineer.

728.12 Excavation Inspection

The Contractor shall provide all necessary equipment for checking the dimensions, alignment, and cleanliness of the drilled shaft excavation. The dimensions and alignment shall be determined by the Contractor under the direction of the Engineer. Final drilled shaft depths shall be measured with a suitable weighted tape or other approved method after final cleaning.

The bottom of the drilled shaft excavation shall be clean such that a minimum of 50% of the base surface of each drilled shaft has less than 1/2 in. of loose material at the time of concrete placement. The maximum depth of loose material at any location on the base surface of the drilled shaft excavation shall not exceed 1 1/2 in. The Contractor shall remove any loose material adhering to the vertical sides of the bedrock socket. Acceptability of the excavation for cleanliness will be determined by the Engineer by means of visual inspection and sounding for dry excavations and by measuring and sounding with a weighted tape or by other methods deemed appropriate by the Engineer for wet excavations. For dry excavations, the maximum depth of water shall not exceed 2 in. at the time of concrete placement and the rate of groundwater flow into the excavation shall not exceed 12 in. per hour.

728.13 Construction Tolerances

Drilled shafts shall meet the following construction tolerances:

- (a) Drilled shafts shall be within 3 in. horizontally of the location shown in the plans.
- (b) The top of drilled shafts shall be within plus 1 in. and minus 3 in. of the elevation shown in the plans.
- (c) The alignment of vertical drilled shafts shall not vary from plumb by more than 1/4 in. per ft of depth.
- (d) The alignment of battered drilled shafts shall not vary by more than 1/2 in. per ft of depth from the specified batter rate.

- (e) After placement of concrete, the top of reinforcing bars shall be within plus 6 in. and minus 3 in. of the location shown in the plans.
- (f) Excavation equipment and methods shall be such that the completed drilled shaft will have a planar bottom. The cutting edges of excavation equipment shall be normal to the vertical axis of the drilled shaft within a tolerance of 3/8 in. per ft of diameter.

728.14 Reinforcing Bar Cage Construction and Placement

Reinforcement shall be fastened and placed in accordance with 703. Approved non-corrosive spacing devices shall be installed to hold the reinforcement at least 3 in. from the sides of the drilled shaft excavation along its entire height and concentrically centered within the drilled shaft. At a minimum, spacers shall be placed within 1 ft of the bottom of the drilled shafts and at intervals not exceeding 10 ft along the height of the drilled shaft. Approved bottom supports shall be installed to hold reinforcement the required dimension above the bottom of the drilled shaft. Concrete shall be placed immediately after placing reinforcement in the drilled shaft excavation. If concrete is not placed immediately after placing reinforcement, the Contractor shall remove the reinforcement to allow the Engineer to verify the integrity of the drilled shaft excavation and to ensure loose material has been removed.

Prior to placement of concrete, the Contractor shall determine and record the elevation of the bottom of the drilled shaft excavation and provide a copy of the record to the Engineer.

728.15 Concrete Production and Placement

The concrete used in the drilled shaft shall be in accordance with 728.03 and 728.04. Concrete temperature shall be measured in accordance with AASHTO T 309.

Concrete placement shall be in accordance with the applicable portions of 702, except as modified herein.

Concrete shall not be placed in a drilled shaft excavation without approval from the Engineer. Concrete placement shall be made by one continuous pour from the bottom to the top of the drilled shaft. The elapsed time from batching of the first load of concrete to the completion of concrete placement shall not exceed two hours. At no time during construction shall the slump loss result in a slump below the minimum specified. The Contractor may submit a request for approval by the Engineer for a longer placement time provided the concrete mix maintains the minimum specified slump requirements over the longer placement time as demonstrated by a trial batch and results of slump loss testing from a trial batch.

Concrete shall be placed by means of a chute, tremie or a concrete pump. Placement of concrete by a chute shall only be for the dry construction method in excavations where the maximum depth of water does not exceed 2 in.

Concrete placed by chute shall fall directly to the base of the drilled shaft without contacting either the reinforcement or sides of the drilled shaft excavation. The drop chute shall be supported so that the free fall of the concrete measured from the bottom of

the chute is no more than 60 ft. If concrete placement causes the drilled shaft excavation to cave or slough, or if the concrete strikes the rebar cage or sidewall, the Contractor shall reduce the height of free fall or reduce the rate of concrete flow into the excavation. If concrete placement cannot be satisfactorily accomplished by chute, the Contractor shall use either a tremie or concrete pump to accomplish the pour.

Placement of concrete under water or slurry by tremie shall not begin until the tremie is in place at the base of the drilled shaft. Valves, bottom plates, or plugs shall be used only if concrete discharge can begin within a distance of one-half times the diameter of the tremie from the base. Plugs shall be removed from the drilled shaft excavation or be of a material approved by the Engineer, which if left in place will not cause a defect in the drilled shaft. The tremie discharge end shall remain at least 10 ft below the head of the plastic concrete at all times after the first 10 ft of concrete is placed. The flow of concrete shall be continuous and the concrete in the tremie shall be maintained at a positive pressure differential at all times to prevent water or slurry intrusion into the drilled shaft concrete.

Placement of concrete under water or slurry by concrete pump shall not begin until the pump discharge opening is in place at the base of the drilled shaft. A plug or similar device shall be used to separate the concrete from the fluid in the drilled shaft excavation until pumping begins. The plug shall either be removed from the drilled shaft excavation or be of a material approved by the Engineer which will not cause a defect in the drilled shaft if left in place.

The Contractor shall pump an adequate quantity of grout, mortar, or concrete without coarse aggregate through the pump system and lines ahead of the drilled shaft concrete to lubricate the pumping system. Material used for lubrication shall not be allowed to remain in the drilled shaft, but shall be discharged ahead of the drilled shaft concrete up and out of the drilled shaft excavation. The lubrication process shall not be repeated during the remainder of the pour. The pump shall be operated so that a continuous stream of concrete without air pockets is delivered into the excavation. The discharge opening shall remain at least 10 ft below the head of the plastic concrete at all times after the first 10 ft of concrete is placed. When lifting the pump line during concrete placement, the Contractor may temporarily reduce the line pressure until the opening has been repositioned at a higher level in the excavation. The rate of concrete placement shall be controlled to prevent displacement of the reinforcement. When the concrete reaches the top of the drilled shaft excavation, all laitance shall be removed.

If at any time during the concrete pour, the tremie or pump discharge opening is removed from the plastic concrete column and discharges concrete above the rising concrete head, the shaft shall be considered defective. In such case, the Contractor shall remove the reinforcement and concrete, clean the excavation, and complete any other remedial actions as directed by the Engineer.

Concrete in the drilled shaft shall not be vibrated, except that in dry excavations, the concrete in the top 10 ft of the shaft shall be vibrated.

Concrete placement shall continue after the drilled shaft excavation is full and quality concrete is evident at the top of the shaft. Any laitance or contaminated concrete shall be displaced or removed.

The Contractor shall maintain a concrete volume as a function of depth chart for all concrete placed under slurry. Minimum depth measurements shall be taken after every load of concrete placed by tremie and after every 3 ft if pumped.

728.16 Acceptance

The Engineer will perform all quality assurance testing and acceptance testing.

(a) Drilled Shaft Concrete

Acceptance of drilled shaft concrete will be determined on the basis of tests performed by the Department. Concrete and any necessary labor to conduct sampling shall be furnished as required by the Department. During concrete placement at each drilled shaft, testing for slump, unit weight, relative yield, and air content will be conducted on the first load of the day and once every 30 cu yds. Slump, slump retention, and air content shall be in accordance with 728.03. The relative yield should not exceed 0.010 more than the theoretical value shown in the THEORETICAL EFFECT OF AIR CONTENT ON RELATIVE YIELD table in 728.04, based on the measured air content. If this occurs, the process and material will be reviewed through an increase in testing frequency to check results, establish trends, or validate impact of corrective actions.

During the concrete placement at each drilled shaft, two cylinders will be cast for compressive strength at a frequency of once every 60 cu yds. If plastic concrete properties of high air content, high slump, or high relative yield indicate a cause for concern, additional pairs of cylinders will be cast for compressive strength. Initial curing of cylinders shall be completed by submerging the cylinders in water saturated with calcium hydroxide at a temperature range of between 60 to 80°F for no less than 16 hours and no more than 48 hours. Each cylinder will be tested for 28-day compressive strength and the paired values averaged to determine the sample result. Concrete placed in the drilled shafts shall have a 28-day compressive strength that meets or exceeds the compressive strength shown in the plans.

If at any time a construction method fails, in the opinion of the Engineer, to produce the desired final results, the Contractor shall stop construction of drilled shafts and submit a proposed remedy and alternate method for approval to the Engineer.

(b) Slurry

The Contractor shall provide copies of all slurry test reports, signed by the testing technician, to the Engineer. The Contractor shall receive written approval from the Engineer indicating that the slurry is acceptable prior to placing concrete in the drilled shaft.

(c) Drilled Shaft

Completed drilled shafts will be tested for acceptance by the Engineer using crosshole sonic logging, CSL, and impulse response spectrum, IRS, test methods. The Contractor shall provide all equipment, labor, and material required by the Engineer to

perform CSL and IRS testing. CSL and IRS testing will be performed no sooner than five business days after placement of concrete in the drilled shaft.

The Contractor shall provide access for the Engineer to the top of each drilled shaft for CSL and IRS testing. Access shall include a stable work platform for the test operators and equipment close to the head of each shaft, and be large enough to accommodate two operators with a standard surveyor's tripod and a small bench or table.

1. CSL Testing

Unless otherwise specified, the Contractor shall provide and install access tubes for CSL testing in all drilled shafts. The Contractor shall at a minimum provide the following for CSL testing:

- a. Schedule 40, 1 1/2 in. I.D. mild steel tubes for each drilled shaft. The bottom of each tube shall be sealed watertight with a threaded end-cap. Any coupling of tubing required to make up the required lengths shall be made using threaded sleeve couplers, sealed watertight. The tubing shall be round and regular in section, with a clean interior surface, free of defects or obstructions that would prevent the passage of a 1 1/4 in. diameter probe through the tube. The exterior surfaces shall be free of dirt, oil, grease, heavy rust scale, or other contaminants which may inhibit formation of a good mechanical bond with the drilled shaft concrete. The use of used or recycled tubing or slightly rusted tubing is acceptable provided that it meets the requirements herein.*
- b. Clean, potable water sufficient to fill the access tubes completely.*
- c. Cement grout sufficient to fill the access tubes on completion of testing.*
- d. Grout mixing equipment and operator.*
- e. Grout pumping equipment and operator. The pump shall have a 1.0 in. tremie pipe capable of reaching the bottom of the access tubes.*
- f. Hosepipe, pump, or other means of placing clean water in the access tubes prior to testing, and for topping off the tubes during testing.*

The Contractor shall install access tubes for CSL testing as follows:

- a. A minimum of four tubes or one tube per foot of drilled shaft diameter, whichever is greater, shall be installed at approximately equidistant points around the interior of the reinforcement. Tubes shall be installed parallel to each other and securely attached to the reinforcement to prevent excessive movement during handling,*

installation, and placement of concrete. The diameter used when figuring the number of tubes shall be the largest diameter of the shaft and shall be rounded up to the next 1 ft. increment.

- b. The bottoms of each tube shall be set a minimum of 3 in. and not more than 6 in. above the bottom of the drilled shaft. Tubes shall not be placed in contact with the bottom of the drilled shaft excavation. The top of each tube shall extend 3 ft to 6 ft above the planned top of the drilled shaft. If the top of the drilled shaft will be below grade or water, tubes shall extend 3 ft to 6 ft above grade or water level, or other reasonable access level if cofferdams or casings are used.
- c. Reinforcement shall be handled and installed to prevent kinking or permanent bending of the access tubes or displacement of the tubes from the required position. Access tubes shall be parallel, undamaged, and securely fixed at the time of concrete placement.
- d. Prior to placing concrete, the Contractor shall determine and record the bottom elevation of at least one of the access tubes and provide the record to the Engineer.
- e. Prior to placing concrete, access tubes shall be completely filled with potable water and the top of the tubes sealed with watertight fittings. Anti-freeze shall be added to the water in cold weather to prevent freezing.
- f. Upon acceptance of the drilled shaft by the Engineer, the Contractor shall remove the water from the CSL access tubes and completely fill the tubes with cement grout.

2. IRS Testing

The Contractor shall prepare a minimum of two areas on the top of each completed drilled shaft for IRS testing. The areas shall be prepared using chipping hammers or other hand tools not weighing more than 15 lb. Each prepared area shall be a minimum of 3 in. in diameter, shall be within ± 1 in. of the level of surrounding concrete, shall be clean, sound, level, and free of standing water and all foreign or loose materials. Chipping hammers shall not be heavier than 15 lb. At least one area shall be in the center of the drilled shaft and at least one area shall be a minimum of 18 in. from the center of the drilled shaft, but shall not be outside of the reinforcement of the drilled shaft.

The Engineer will make a preliminary interpretation of the IRS test results on site. If anomalous responses are recorded, or the data indicates a low modulus or contaminated concrete near the top of the drilled shaft, the Contractor shall prepare a new test area near the perimeter of the shaft, at a minimum of 60° rotation from the first test location.

The Engineer will provide copies of all CSL and IRS test results to the Contractor.

The Engineer will evaluate the results of CSL and IRS testing and notify the Contractor in writing if the drilled shaft is accepted or rejected.

If a drilled shaft is rejected, the Engineer may require excavation or coring in order to allow for further assessment of the drilled shaft. If coring is required, the Contractor shall obtain full depth cores from the drilled shaft at locations determined by the Engineer. An accurate log of the coring shall be kept. The cores and coring log shall be submitted to the Engineer for testing and inspection. The Contractor may provide calculations or other test results to the Engineer to support the acceptability of the drilled shaft.

The Engineer will evaluate cores and any additional information provided and will notify the Contractor in writing of the final determination of whether the drilled shaft is accepted or rejected. If a drilled shaft is rejected, the Contractor shall submit a plan to the Engineer for approval to either repair or replace the defective drilled shaft. The Contractor shall not continue construction on a drilled shaft until authorized in writing by the Engineer.

728.17 Method of Measurement

Drilled shafts will be measured by the linear foot for the diameter of drilled shaft specified. The length of drilled shaft will be the difference between the top of drilled shaft elevation and the actual tip elevation of the drilled shaft.

Exploratory cores for drilled shafts will be measured by the linear foot of core.

Permanent casing will be measured by the linear foot for the outside diameter of casing placed.

Reinforcing bars, concrete, slurry, and other incidental items will not be measured.

728.18 Basis of Payment

Drilled shafts will be paid for at the contract unit price per linear foot of the diameter of drilled shaft specified. If, after inspecting exploratory rock cores, the Engineer determines that the final depth of the excavation needs to be extended further into rock, a contract adjustment for the cost of this additional excavation in rock will be developed in accordance with 104.02 or 104.03 and 109.05.

Exploratory cores for drilled shafts will be paid for at the contract unit price per linear foot.

Permanent casing for drilled shafts will be paid for at the contract unit price for the outside diameter placed.

Payment will be made under:

<i>Pay Item</i>	<i>Pay Unit Symbol</i>
<i>Drilled Shaft, _____</i> <i>LFT</i> <i>diameter</i>	
<i>Drilled Shaft, Exploratory Core</i> <i>LFT</i>	
<i>Drilled Shaft, Permanent Casing</i> <i>LFT</i>	

All costs required for the construction of drilled shafts, including, but not limited to labor, equipment, and materials, excavation, cleaning and dewatering, temporary casing, reinforcement, trial batches, thermal control plan and its implementation, all required reports, quality control plans and logs, and all other incidentals shall be included in the cost of the drilled shaft.

The cost of reinforcing bars, concrete, slurry, and other incidentals necessary to construct a drilled shaft in accordance with this specification shall be included in the cost of the drilled shaft pay item.

All equipment, labor, materials, and costs for the testing of the drilled shaft and quality control testing and reports shall be included in the cost of the drilled shaft.

Rejected drilled shafts shall be repaired or replaced, as approved by the Engineer, with no additional payment.