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SPECIFICATION 901 – DRILLED SHAFT FOUNDATIONS

901-1 DESCRIPTION

901-1.01 Scope - This work shall consist of the construction of foundations consisting of reinforced concrete drilled shafts in accordance with these specifications and in conformance with the details shown on the plans or established by the Engineer.

901-2 MATERIALS

901-2.01 Concrete - Concrete shall conform to the applicable requirements of Specification 934 – Structural Concrete and special provisions included in this contract. Concrete shall be Class V (Drilled Shaft) (5,000 psi). All course aggregate shall pass the 3/4-inch sieve for cased shafts. A retardant or water-reducing agent will be required in all concrete when a casing is used or when shafts are placed underwater or under slurry. Entrained air will be required in all shaft concrete. The target value for entrained air shall be 4%.

901-2.02.1 Reinforcing Steel - Reinforcing steel shall conform to the requirements of Specification 602 – Reinforcing Steel. Reinforcing steel shall be in accordance with the sizes, spacing, dimensions, and the details shown in the plans.

901-2.03 All other materials, not mentioned above, shall conform to the applicable requirements of the current PRHTA Standard Specifications for Road and Bridge Construction.

901-3 CONSTRUCTION REQUIREMENTS

901-3.01 Contractor Qualifications

a. The Contractor performing the work described in the specification shall have installed drilled shafts for a minimum of five years, and shall provide information (including dates, contacts, and a summary) on five previous similar projects. At least three of the projects presented shall involve construction over water or marine environment.

b. The Contractor shall assign an engineer, licensed under the requirements of the laws of Puerto Rico, to supervise the works. He (she) shall have at least three years of experience in the construction of drilled shafts. The use of consultants or manufacturer's representatives does not satisfy the requirements of this section. Drill

operators and on-site supervisors shall have a minimum of one (1) year experience installing drilled shafts with the Contractor's organization.

c. The Engineer may suspend the drilled shaft works if the Contractor substitutes unqualified personnel for approved personnel; the Contractor shall be fully liable for additional costs resulting from the suspension of work and no adjustment in contract time resulting from the suspension of works, for this reason, will be allowed.

901-3.02 Site Preparation

a. All excavation of the foundations in which drilled shafts are to be constructed shall be completed before shafts construction begins unless otherwise authorized by the Engineer. After shafts construction is completed all loose and displaced materials shall be removed from around the shafts, leaving a clean, solid surface. The soil surface on which concrete is to be placed or which will support the forming system for the concrete shall be compacted to a density not less than 95 percent of the maximum density as determined by AASHTO T 180, or as shown in the Contract documents.

b. When the plans require shafts in abutments, the embankment at the bridge ends shall be completed to grade and thoroughly compacted prior to drilling unless otherwise shown on the plans or as permitted by the Engineer. Temporary casings shall be installed through completed conventional fill when permanent casings are not required.

901-3.03 Templates - Templates will not be required for shafts drilled on land provided the Contractor demonstrates satisfactorily to the Engineer that shaft position and alignment can be properly maintained. A fixed template adequate to maintain shaft position and alignment during all excavation and concrete operations, will be required for shafts drilled on land when the Contractor fails to demonstrate satisfactorily that he can properly maintain shaft position and alignment without use of a template, and for all drilled shafts in water.

901-3.04 Drilled Shaft Installation Plan

a. At the pre-construction conference or no later than 30 days before drilled shaft construction begins, the Contractor shall submit a drilled shaft installation plan for approval by the Engineer. This plan shall provide detailed information including the following:

1. Name and experience record of drilled shaft superintendent or foreman in responsible charge of drilled shaft operations. The responsible person in charge of day-to-day drilled shaft operations shall have satisfactory prior

experience constructing shafts similar to those described in the plans and specifications. Final approval by the Engineer will be subject to satisfactory performance in the field.

2. List and description of the proposed equipment including cranes, drills, augers, bailing buckets, final cleaning equipment, de-sanding equipment, slurry pumps, core sampling equipment, tremies or concrete pumps, casings, etc.

3. Details of overall sequence of construction operations and sequence of shaft construction in bents or shaft groups.

4. Details of shaft excavation methods.

5. Details of slurry including proposed methods to mix, circulate, de-sand, test methods, and proposed testing laboratory to document test results.

6. Details of proposed methods to clean shaft after initial excavation.

7. Details of shaft reinforcement, including methods to ensure centering/required cover, cage integrity during placement, placement procedures, cage support, and tie downs.

8. Details of concrete placement including proposed operational procedures for concrete tremie or pump including initial placement, rising during placement, overfilling of the shaft concrete and proposed admixtures. The Contractor shall also provide details to ensure proper final shaft cutoff elevation.

9. Details of casing removal when removal is required including minimum concrete head in casing during removal.

10. Required submittals including shop drawings and concrete design mixes.

11. Details of any required load tests, including equipment and procedures, and recent calibrations for instrumentation.

12. Details of environmental control procedures used to prevent loss of slurry or concrete into waterways of other protected areas.

13. Other information shown in the plans or requested by the Engineer.

b. The Engineer will evaluate the drilled shaft installation plan for conformance with the plans, specifications and Special Provisions. Within 20 days after receipt of the plan, the Engineer will notify the contractor of any additional information required and/or changes that may be necessary in the opinion of the Engineer to satisfy the plans, specifications and Special Provisions. Any part of the plan that is unacceptable will be rejected and the Contractor shall submit changes agreed upon for reevaluation. The Engineer will notify the Contractor within seven days after receipt of proposed changes of their acceptance or rejection. All approvals given by the Engineer shall be subject to trial and satisfactory performance in the field.

c. The Contractor shall demonstrate the adequacy of methods and equipment during construction of the test hole described in article 901-3.18. Failure to demonstrate the adequacy of methods or equipment to the Engineer is cause for the Engineer to require appropriate alterations in equipment and/or methods by the Contractor to eliminate unsatisfactory results. Any additional test holes required for demonstrating the adequacy of methods or equipment shall be at the Contractor's expense. No changes in methods or equipment will be made after initial approval without the consent of the Engineer. The (6.10 m) exploration hole (cores), required by article 901-3.10, and its grouting shall be included within the services of the test hole.

901-3.05 General Methods and Equipment

a. The Contractor shall perform the excavations required for the shafts through whatever materials encountered, to the dimensions and elevations shown in the plans.

b. The Contractor's method and equipment shall be suitable for the intended purpose and the materials encountered. The Contractor shall provide equipment capable of constructing shafts to a depth equal to the deepest shaft shown in the plans plus 20 feet (6.10 m) or plus three times the shaft diameter, whichever is greater, except when the plans instruct the Contractor to provide equipment capable of constructing shafts to a deeper depth.

c. Drilled shafts shall be constructed as indicated in the plans or described herein, generally by either the dry method, wet method, casing method or permanent casing method as necessary to produce sound, durable concrete foundation shafts free of defects. The permanent casing method shall be used only when authorized by the Engineer or required by the plans. When the plans describe a particular method of

construction, this method shall be used except when permitted otherwise by the Engineer after field trial. When the plans do not describe a particular method, the Contractor shall propose a method on the basis of its suitability to the site conditions and submit it as part of the drilled shaft installation plan for approval by the Engineer.

d. The Contractor shall set a suitable temporary removable surface casing. The minimum surface casing length shall be the length required to prevent caving of the surface soils and to aid in maintaining shaft position and alignment. Pre-drilling with slurry and/or over-reaming to the outside diameter of the casing may be required to install the surface casing at some sites.

901-3.06 Dry Construction Method

a. The dry construction method shall be used only at sites where the ground water table and soil conditions (generally stiff to hard clays or rock above the water table) make it feasible to construct the shaft in a relatively dry excavation and where the sides and bottom of the shaft are stable and may be visually inspected by the Engineer prior to placing the concrete.

b. The dry construction method consists of drilling the shaft excavation, removing accumulated seepage water and loose material from the excavation and placing the shaft concrete in a relatively dry excavation.

c. The dry construction method shall be used only when shaft excavation, as demonstrated in a test hole, has 12 inches (30 cm) or less of seepage water accumulated over a four hour period, the sides and bottom remain stable without detrimental caving, sloughing or swelling for the four hour period and the loose material and water can be satisfactorily removed prior to inspection and prior to placing concrete. The Contractor shall use the wet construction method or casing construction method for shafts that do not meet the requirements for the dry construction method.

901-3.07 Wet Construction Method

a. The wet construction method shall be used at all sites where it is impractical to provide a dry excavation for placement of the shaft concrete.

b. The wet construction method consists of drilling the shaft excavations below the water table, keeping the shaft filled with water (including natural slurry formed during the drilling process) or mineral slurry, de-sanding and cleaning the slurry and final cleaning of the excavation by means of a bailing bucket, air lift, submersible pump

or other approved devices and placing the shaft concrete (with a tremie or concrete pump beginning at the shaft bottom) which displaces the water or slurry as the shaft excavation is filled with concrete. Temporary surface casing shall be provided to aid shaft alignment and position and to prevent sloughing of the top of the shaft except when the Contractor demonstrated to the satisfaction of the Engineer that the surface casing in not required.

c. Where drilled shafts are located in open water areas, construct the shafts by the wet method using exterior casings extending from above the water elevation into the ground to protect the shaft concrete from water action during placement and curing of the concrete. Install the exterior casing in a manner that will produce a positive seal at the bottom of the casing so that there is no intrusion or extrusion of water or other materials into or from the shaft excavation.

901-3.08 Casing Construction Method

a. The casing method shall be used at all sites where it is inappropriate to use the dry or wet construction methods without the use of temporary casings other than surface casings. In this method, the hole is advanced through caving material by the wet method as described above. When a formation is reached that is nearly impervious, a casing shall be placed in the hole and sealed in the nearly impervious formation. After the drilling fluid is removed from the casing, drilling may proceed as with the dry method to the projected depth. The placement of the concrete shall proceed as with the dry method except that the casing shall be withdrawn when the concrete is placed. In the event seepage conditions prevent uses of the dry method, excavation shall be completed using wet methods.

b. Where drilling is through material having a tendency to cave, the drilling shall be advanced by drilling in mineral slurry. In the event that a caving layer or layers are encountered that cannot be controlled by slurry, the Contractor shall install temporary removable casing through such caving layer or layers. Over-reaming to the outside diameter of the casing may be required. The Contractor shall take whatever steps are required to prevent caving during shaft excavation including installation of deeper casings. If the Contractor elects to remove a casing and replace it with a longer casing through caving soils, he shall adequately stabilize the excavation with slurry or backfill the excavation. Soil previously excavated or soil from the site may be used if the excavation is backfilled. Other approved methods, which will control the size of the excavation and protect the integrity of the foundation soils, may be used to excavate through caving layers.

c. Before the casing is withdrawn, the level of fresh concrete shall be at such a level that the fluid trapped behind the casing is displaced upward. As the casing is withdrawn, care shall be exercised to maintain the level of concrete within the casing so that fluid trapped behind the casing is displaced upward out of the shaft excavation without mixing with or displacing the shaft concrete.

d. The casing method may be used, when approved by the Engineer, to construct shafts through weak caving soils that do not contribute significant shaft shear resistance. In this case, a temporary casing is placed through the weak caving soils before excavation begins. Excavation is conducted using the dry construction method where appropriate for site conditions or the wet construction method where the dry construction method is not appropriate. The temporary casing shall be removed during the concrete operations unless approved otherwise by the Engineer.

901-3.09 Permanent Casing Method

a. The permanent casing method shall be used only when required by the plans or authorized by the Engineer. In this method, a casing is placed to the prescribed depth before excavation begins. If full penetration cannot be attained, the Engineer may direct the Contractor to excavate through the casing and advance the casing until reaching the desired penetration. In some cases over-reaming to the diameter of the casing may be required before placing the casing.

b. The casing shall be cut off at the prescribed elevation upon reaching the proper construction sequence and the remainder of the casing is left in place.

901-3.10 Excavation

a. The plans generally indicate the expected minimum depths to which the drilled shaft shall be constructed. Drilled shaft excavations may be extended deeper when the Engineer determines that the material encountered while drilling the shaft excavation is unsuitable and/or is not the same as anticipated in the design of the drilled shaft, or the 20 ft (6.10 m) exploratory holes (cores) indicate that a more competent stratum is located below the expected depth.

b. The Contractor shall take cores as shown in the plans or as directed by the Engineer to determine the character of the material directly below the shaft excavation and to verify the absence of caverns.

c. The cores shall be cut with an approved core barrel to a minimum depth of 20 feet (6.10 m) below the bottom of the drilled shaft excavation at the time the shaft excavation is approximately complete.

d. The Engineer will inspect the cores and determine the depth of any required additional shaft excavation.

e. When considered necessary by the Engineer, additional cores shall be taken.

f. The core barrel should be designed:

1. to cut a core sample from four to six inches (10-15 cm) in diameter,

2. so that the sample of material cored can be removed from the shaft excavation and the core barrel in an undisturbed state,

3. in sufficient length to provide core samples, as directed by the Engineer up to a depth of 20 feet (6.10 m) below the bottom of the drilled shaft excavation and

4. so that the core and any caverns, if encountered, can be grouted by pump or pressure.

g. The Engineer may elect to substitute Standard Penetration Tests (SPT) for coring when he determines that it will be beneficial. In such cases, the Contractor shall supply these tests at no additional cost.

h. The Contractor shall maintain a drilling log during shaft excavation and coring operations. The log shall contain information such as the description of the approximate top and bottom elevation of each stratum encountered, depth of penetration, drilling time in each of the various strata, material description and remarks. Core samples shall be classified, measured, and described in the Contractor's drilling log. Core samples shall be placed in suitable containers, identified by shaft location, elevation from and to, job number and delivered to the Engineer within 48 hours after cutting. The Contractor shall furnish the Engineer two copies of the drilling log, signed by a designated representative of the Contractor, at the time the shaft excavation is completed and accepted. Drilling logs will be co-signed by the Engineer and delivered to the Authority.

i. Material excavated from the shaft, including drilling mud, and not used in the backfill around completed bents or piers shall be disposed of as in accordance with the specifications.

j. The additional drilled shaft concrete and reinforcing over the theoretical amount required to complete filling any excavations for shaft which are larger or longer than required by the plans or authorized by the Engineer, shall be furnished by the Contractor at his expense.

901-3.11 Casings

a. Casings shall be metal (or concrete when indicated in the plans) of ample strength to withstand handling and driving stresses and the pressure of concrete and of the surrounding earth materials, and they shall be smooth and water tight. The inside diameter of casing shall not be less than the specified size of shaft except as provided below. No extra compensation will be allowed for concrete required for filling an oversized casing or oversized excavation.

b. The Contractor may be allowed to supply casing with an outside diameter equal to the specified shaft diameter (OD casing) provided he supplies additional shaft length at the shaft tip. The additional length of shaft required shall be determined by the following relationship:

$$\text{Additional length} = \frac{(D1-D2)\,L}{D2}$$

where

D1 = casing inside diameter specified = shaft diameter specified.

D2 = casing inside diameter provided (D2 = D1 minus twice the wall thickness).

L = authorized shaft length below ground.

c. The Contractor shall bear all costs relating to this additional length including but not limited to the cost of extra excavation, extra concrete and extra reinforcing steel.

d. All casings shall be removed from shaft excavations except those used for the Permanent Casing Method. The portion of casings installed under the Permanent

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Casing Method of construction below the shaft cut-off elevation shall remain in position as a permanent part of the Drilled Shaft. Casings that, in the opinion of the Engineer, will not adversely affect the shaft capacity may be left in place when approved by the Engineer. When casings, which are to be removed, become bound in the shaft excavation and cannot be practically removed, the shaft excavation shall be drilled deeper as directed by the Engineer to compensate for loss of capacity due to the presence of the casing. No compensation will be paid for the casing remaining or additional length of drilled shaft.

e. When the shaft extends above ground or through a body of water, the Contractor may form the portion exposed above ground or through a body of water with removable casing except when the Permanent Casing Method is specified. When approved, the Contractor may form drilled shafts extending through a body of water with permanent or removable casings. However, for permanent casings, remove the portion of metal casings between an elevation 0.6 m below the lowest water elevation and the top of shaft elevation after the concrete is cured. Dismantle casings removed to expose the concrete as required above in a manner which will not damage the drilled shaft concrete.

f. Generally, when removal of the temporary casing is required, the removal of casings shall not be started until all concrete has been placed in the shaft. Movement of the casing by rotating, exerting downward pressure and tapping it to facilitate extraction or extraction with a vibratory hammer will be permitted. Casing extraction shall be at a slow, uniform rate with the pull in line with the axis of the shaft. Temporary casings shall be removed while the concrete remains fluid.

g. When conditions warrant, the casing may be pulled in partial stages. A sufficient head of concrete shall be maintained above the bottom of the casing to overcome the hydrostatic pressure of water outside the casing. At all times the elevation of the concrete in the casing shall be maintained high enough to displace the drilling slurry between the outside of the casing and the edge of the hole as the casing is removed. The Contractor may use special casing systems in open water areas, when approved, which are designed to permit removal after the concrete has hardened. Design special casings so that no damage occurs to the drilled shaft concrete during their removal.

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901-3.12 Slurry and Fluid in Excavation at Time of Concrete Placement

a. Slurry

1. When slurry is employed in the drilling process as described earlier, mineral slurry shall be used. Mineral slurry shall be processed attapulgite or bentonite clays. Polymer slurries will not be allowed. The slurry shall have a mineral grain size such that it will remain in suspension and it shall have sufficient viscosity and gel characteristics to transport excavated material to a suitable screening system. The percentage and specific gravity of the material used to make the suspension shall be sufficient to maintain the stability of the excavation and to allow proper placement of concrete. The material used to make the slurry shall not be detrimental to concrete or surrounding ground strata. During construction, the level of slurry shall be maintained at a height sufficient to prevent caving of the hole. In the event of a sudden significant loss of slurry such that the slurry level cannot practically be maintained by adding slurry to the hole, the construction of that foundation shall be delayed until an alternate construction procedure has been approved.

2. The mineral slurry shall be pre-mixed thoroughly with clean fresh water prior to introduction into the shaft excavation. The Engineer will require adequate water and/or slurry tanks when necessary to perform the work in accordance with these Specifications. These tanks shall be of sufficient capacity to fill the excavation and for recovery of the slurry during concrete placement. The Engineer will not allow excavated pits on projects requiring slurry tanks without the written permission of the Engineer. The Engineer will require adequate de-sanding equipment when shown in the contract Documents.

3. The Contractor shall take the steps necessary to prevent the slurry from "setting up" in the shaft including, but not limited to, agitation, circulation and/or adjusting the composition and properties of the slurry. Disposal of all waste slurry shall be off site in suitable areas provided by the Contractor and shall be subject to all requirements pertaining to pollution.

4. Control tests using suitable apparatus shall be carried out on the mineral slurry mixture by a qualified professional soil-testing laboratory approved by the Engineer and engaged by the Contractor, to determine the following parameters:

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(a) Freshly mixed mineral slurry: The density of the freshly mixed mineral slurry shall be measured regularly as a check on the quality of the suspension being formed. The measuring device shall be calibrated to read within ± 0.5 lb/cf (8.00 kg/m^3).

(b) Mineral slurry supplied to the drilled shaft excavation: The following tests shall be applied to the mineral slurry supplied to the shaft excavation and the results shall be within the ranges stated in the table below.

Item to be measured	**Range of results @ 20 F**	**Test Method***
Density	64 -73 lb/cf	Mud density balance
Viscosity	28 - 40 seconds	Marsh Cone Method
pH	8 – 11	Electric pH meter or pH indicator paper strips
Sand Content	4% or less (by volume)	API Sand Content Test

* Test methods will be supplied to the Contractor upon request to the Engineer.

(1) The limits in the above table may be adjusted when field conditions warrant as successfully demonstrated in a Test Hole or with other methods approved by the Engineer. All changes must be approved in writing by the Engineer before continued use.

(2) Tests to determine density, viscosity and pH value shall be carried out initially until a consistent working pattern has been established, taking into account the mixing process, and blending of freshly mixed mineral slurry and previously used mineral slurry. A minimum of four sets of tests shall be made to determine density, viscosity and pH value during the first eight houses the mineral slurry is in use.

(3) When the results show consistent behavior, the tests for pH value may be discontinued and tests to determine density and viscosity shall only be carried out during each four hours the mineral slurry is in use. In the event of a change in the

established working pattern, the additional tests for pH value shall be reintroduced for the time required to establish consistency of the test values within the specification parameters.

(c) Reports of all mineral slurry test is required above, signed and sealed by a Professional Engineer registered in the Commonwealth of Puerto Rico, representing the soil testing laboratory engaged by the Contractor, shall be furnished to the Engineer upon completion of each drilled shaft.

(d) Representatives of the Authority may perform comparison tests as determined necessary during the mineral slurry operations.

5. During construction the level of mineral slurry in the shaft excavation shall be maintained within the excavation and at a level not less that four feet (1.20 m) above the highest expected piezometric water pressure along the depth of a shaft.

6. At any time the wet method of stabilizing excavations fails in the opinion of the Engineer to provide the desired final result, the Contractor shall discontinue this method of construction and he shall proposed modifications in procedure or alternate means of construction for approval.

b. Fluid in Excavation at Time of Concrete Placement

1. Prior to placing concrete in any shaft excavation, the Contractor shall ensure that heavily contaminated suspensions, which could impair the free flow of concrete from the tremie pipe, have not accumulated in the bottom of the shaft. Samples of the fluid in the shaft (water, natural slurry formed during the drilling operations or mineral slurry) shall be taken from the base of the shaft and at intervals not exceeding ten feet (3.0 m) up the shaft, using an approved sampling tool. When mineral slurry is used applicable density test method and reporting requirements described in article 901-3.12.a. shall apply to test fluids in the shaft prior to the placing of the concrete. When water (including natural slurry formed during the drilling process) is used and a testing laboratory is not required for testing, the tests prior to placing the concrete shall be performed by an experienced person furnished by the Contractor and approved by the Engineer. Such tests shall be performed in the presence of the Engineer or his representative. In such case, the density of the fluid in the shaft excavation prior

to placing the concrete shall be less that 75 pounds per cubic foot (1,200. kg/m^3). When de-sanding equipment is required, fluid samples shall have a sand content not greater than 4% by volume.

2. The Contractor shall take whatever action is necessary to modify the fluid in the shaft excavation prior to placing the concrete to bring the fluid within the specification requirements.

901-3.13 Tremies - Tremies used to place concrete shall consist of a tube of sufficient length to meet the requirements below. No aluminum parts having contact with concrete will be permitted. The Contractor may use concrete pumps approved by the Engineer in lieu of tremies to place concrete for drilled shafts. Tremies and concrete pumps shall have sufficient capacity to place the concrete within the time limit specified. The pump lines shall have a minimum four-inch (10.2 cm) diameter and shall be constructed so that all sections have watertight joints.

a. Dry Excavation – The tremie for depositing concrete in dry-drilled shaft excavation shall consist of : a tube of solid construction, a tube constructed of sections which can be added and removed; or a tube of other approved design. Concrete may be passed through a hopper at the top of the tube or through side openings as the tremie is retrieved during concrete placement. The tremie shall be supported so that the free fall of the concrete is less that five feet (1.5 m) at all times. If the free falling concrete causes the shaft excavation to cave or slough, the Contractor shall control the movement of concrete by reducing the height of free fall of the concrete and/or reducing the rate of flow of concrete into the excavation.

b. Wet Excavation – The tremie or pump line used to deposit concrete beneath the surface of water shall be constructed so that it is watertight and will readily discharge concrete. The discharge end of the tremie or pump line shall be constructed to prevent water intrusion and permit the free flow of concrete during placement operations. The tremie or pump line shall have sufficient weight so that it will rest on the shaft bottom before start of concrete placement. The length of the tremie or pump line shall be sufficient to extend to the bottom of the excavation. The discharge end shall be entirely immersed in concrete at all times after starting. Ensure that the free fall of concrete into the hopper is less than five (5) feet (1.50 m) at all times. The tremie shall be supported so that it can be raised to increase the discharge of concrete and lowered to reduce the discharge of concrete. The Engineer will not allow rapid raising or lowering of the tremie to increase the flow of the concrete. The flow of the concrete shall be continuous and the concrete in the tremie shall maintain a positive pressure differential at all times to prevent water or slurry intrusion into the shaft concrete.

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901-3.14 Excavation and Drilling Equipment

a. All shaft excavation shall be "Unclassified Shaft Excavation". "Drilled Shaft Sidewall Over-reaming" will be required when inspection shows it to be necessary. These terms are defined in paragraphs c and d, respectively, of this section.

b. The excavation and drilling equipment shall have adequate capacity including power, torque, and down thrust and the excavation and over-reaming tools shall be of adequate design, size and strength to perform the work shown in the plans or described herein. When the material encountered cannot be drilled using conventional earth auger and/or under-reaming tools, the Contractor shall provide drilling equipment including but not limited to rock augers, core barrels, rock tools, air tools, blasting materials and other equipment as necessary to continue the shaft excavation to the size and depth required. In the event blasting is necessary, the Contractor shall obtain all necessary permits and shall consider and be responsible for its effect on already completed work and adjacent structures. Approval of the Engineer will be required for all blasting.

c. Unclassified Shaft Excavation - Unclassified shaft excavation shall be defined as all processes required to excavate a drilled shaft of the dimensions shown in the plans and/or described in the specifications to the depth at or below that indicated in the plans or directed by the Engineer, completed and accepted. The work shall include all shaft excavation, whether the material encountered is soil, rock, weathered rock, stone, boulders, natural or man-made obstructions, or materials of other descriptions.

d. Drilled Shaft Sidewall Over-reaming

1. This item is defined as the unclassified excavation required to roughen its surface or to enlarge the drilled shaft diameter due to softening of the sidewalls or to remove excessive build-up of slurry cake when slurry is used. Over-reaming shall increase the shaft radius minimum of 1/2 inch (1.25 cm) and a maximum of three inches (7.60 cm). Over-reaming may be accomplished with a grooving tool, over-reaming bucket or other approved equipment.

2. The limit for depth of sidewall over-reaming into the shaft sidewall material and the elevation limits between which sidewall over-reaming shall be accomplished as authorized by the Engineer.

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901-3.15 Inspection of Excavations

a. Dimensions and Alignment - The Contractor shall provide equipment for checking the dimensions and alignment of each permanent shaft excavation. The dimensions and alignment of the shaft excavation shall be determined by the Contractor under the observation and direction of the Engineer. Generally, the alignment and dimensions may be checked by any of the following methods as necessary:

1. Check the dimensions and alignment of dry shaft excavations using reference stakes and a plumb bob.

2. Check the dimensions and alignment of casing when inserted in the excavation.

3. Insert a casing in shaft excavations temporarily for alignment and dimension checks.

4. Insert a rigid rod or pipe assembly with several 90-degree offsets equal to the shaft diameter into the shaft excavation for alignment and dimension checks.

5. Other methods provided by the Contractor and approved by the Engineer.

Any casing, rod or pipe assembly or other device used to check dimensions and alignment shall be inserted by the Contractor into the excavation to full depth.

b. Depth - The depth of the shaft during drilling shall generally be referenced to appropriate marks on the Kelly bar or other suitable methods. Final shaft depths shall be measured with a suitable, weighted tape or other approved methods after final cleaning.

c. Shaft Cleanliness Requirements

1. The Contractor's cleaning operation will be adjusted so that a minimum of 50 percent of the base of each shaft will have less than 1/2 inch (1.2 cm) of sediment at the time of placement of the concrete. The maximum depth of sedimentary deposits or any other debris at any place on the base of the shaft excavation shall not exceed 1-1/2 inches (3.80 cm). The Engineer will

determine shaft cleanliness by visual inspection for dry shafts, or other methods deemed appropriate to the Engineer for wet shafts.

2. When slurry is used it shall meet the requirements of 901-3.12 at the time of concrete placement.

d. Time of Excavation

1. Any unclassified excavation work lasting more that 36 hours (measured from the beginning of excavation for all methods except the Permanent Casing Method which shall begin at the time excavation begins below the casing) before placement of the concrete may require over-reaming the sidewalls to the depth of softening or to remove excessive slurry cake build-up as indicated by samples taken by the sidewall sampler or other test methods employed by the Engineer. The minimum depth of over-reaming the shaft diameter shall be 1/2 inch (1.20 cm) and the maximum depth shall be three inches (7.60 cm). The Contractor shall bear the cost of any over-reaming required when the 36-hour limit is exceeded, unless the time limit is exceeded solely to accomplish unclassified extra depth excavation ordered by the Engineer. The Authority will pay the Contractor for authorized over-reaming resulting from softening or excessive slurry cake build-up, which is indicated by sidewall samples or other test methods employed by the Engineer during the initial 36-hour time period and when sidewall samples indicate softening or excessive filter cake build-up in shaft excavations which exceed the 36-hour time limit in order to accomplish unclassified extra depth excavation ordered by the Engineer.

2. When slurry is used, the Contractor shall adjust his excavation operations so that the maximum time that slurry is in contact with the bottom five feet (1.5 m) of the shaft (from time of drilling to placing concrete time) does not exceed 12 hours. If the 12-hour time limit is exceeded, the bottom five feet (1.5 m) of shaft shall be over-reamed at no additional cost to the Authority prior to performing other operations in the shaft.

901-3.16 Reinforcing Steel Construction and Placement

a. Cage Construction and Placement

1. The cage of reinforcing steel consisting of longitudinal bars, ties on spirals, and cage stiffener bars shall be completely assembled and placed as a

unit immediately after the shaft excavation is inspected and accepted and immediately prior to concrete placement.

2. All intersections of drilled shaft reinforcing steel shall be tied with cross ties or “figure 8" ties. Double strand ties or ties with large tie wire shall be used when necessary. Final approval of the cage construction and placement is subject to satisfactory performance in the field.

b. Splicing Cage - If the bottom of the constructed shaft elevation is lower than the bottom of shaft elevation in the plans, a minimum of one-half of the longitudinal bars required in the upper portion of the shaft shall be extended the additional length. Tie bars shall be continued for the extra depth, spaced on two-foot (0.61 m) centers, and the stiffener bars shall be extended to the final depth. These bars may be lap-spliced or not spliced bars of the proper length. Welding to the planned reinforcing steel will not be permitted.

c. Support, Alignment, and Tolerance

1. The reinforcing steel in the shaft shall be tied and supported so that the reinforcing steel will remain within allowable tolerance as specified in article 901-3.19.

2. Concrete wheels or other approved non-corrosive spacing devices shall be used at sufficient intervals (near the bottom and intervals not exceeding 15 feet (4.60 m) up the shaft) to insure concentric spacing for the entire length of the cage. Wire or block-type spacers will not be allowed. A minimum of one spacer per 2.5 feet (76-cm) of circumference of cage with a minimum of three spacers at each level shall be used. Concrete spacers, constructed as shown in the plans or approved by the Engineer, shall be provided at the bottom of the drilled shaft reinforcing cage to insure that the specified distance between the bottom of the cage and bottom of the shaft is maintained. The number of bottom spacers shall be as shown in the plans or approved by the Engineer. The spacers shall be constructed of approved material equal in quality and durability to the concrete specified for the shaft. Approval of spacers is subject to satisfactory field performance.

3. The elevation of the top of the steel cage shall be checked before and after the concrete is placed. If the rebar cage is not maintained within the specified tolerances, corrections shall be made by the Contractor as directed by the Engineer shall make corrections. No additional shafts shall be constructed

until the Contractor has modified his rebar cage support in a manner satisfactory to the Engineer.

901-3.17 Concrete Placement

a. General – Concrete shall be placed as soon as possible after all excavation is completed, the shaft excavation has been cleaned, inspected and found satisfactory, and immediately after reinforcing steel placement. Concrete placing shall be continuous in the shaft to the top elevation of the shaft. Concrete placement shall continue after the shaft is full until good quality concrete is evident at the top of the shaft. Concrete shall be placed through a tremie or concrete pump using approved methods. If pressure head is lost during concrete placement for any reason, the Engineer may direct the Contractor to perform integrity test at no expense to the Authority.

b. Placement Requirements

1. The elapsed time from the beginning of concrete placement shall not exceed two hours except as provided herein. The beginning of placement time is defined as the time that concrete is first placed in the tremie or the time that concrete (or grout preceding the concrete) is placed in the concrete pump used to place the concrete.

2. The completion of placement includes the removal of any temporary casings that cause or should cause the concrete to flow into the space previously occupied by the casing. Drilled shaft concrete shall have a slump between 6 and 9 inches (15 to 23 cm) when placed. The concrete shall maintain a minimum slump of four inches (10.2 cm) or more throughout the two-hour maximum placement time. All admixtures used to meet the specified placement time shall meet the requirements of Specification 934 – Structural Concrete – Adverse Conditions. The admixtures in the concrete mix shall be adjusted as approved for the conditions encountered on the job so that the concrete remains in a workable plastic state throughout the placement. Satisfactory slump loss tests that demonstrate that the concrete will maintain a four-inch (100 mm) or greater slump for a period of time equal to the estimated mixing and transport plus the two-hour placement time shall be provided before drilled shaft construction begins.

3. The Contractor may request a longer placement time provided he supplies a concrete mix that will maintain a slump of four inches (100 mm) or greater over the longer placement time as demonstrated by slump loss tests.

The slump loss tests shall be conducted using concrete and ambient temperatures appropriate for site conditions.

c. Slump Loss Tests - The Contractor shall provide slump loss tests before drilled shaft operations begin, demonstrating that the drilled shaft concrete will maintain a slump of a least six (6) inches (150 mm) throughout the concrete placement operations. The Contractor shall inform the Engineer at least 48 hours prior to performing such tests in order to allow arrangements be made for a Engineer's representative to witness the mixing and testing required. Slump loss testing of drilled shaft mix shall be performed by a laboratory acceptable to the Engineer.

Procedures for slump loss tests shall be as follows:

1. Duplicate tests shall be provided.

2. The mix for the slump loss tests shall be prepared a temperature consistent with the highest ambient and concrete temperatures expected during actual concrete placement. The test temperature shall be formally approved by the Engineer.

3. The mix shall be at least 2.3 m^3 and shall be mixed in a mixer truck.

4. After initial mixing, the slump, concrete temperature, ambient temperature, and air percent shall be determined. The properties of the concrete shall be within the specification allowable limits.

5. The concrete shall be mixed intermittently for 30 seconds every five minutes at the agitation speed of the mixer.

6. Slump, concrete temperature, ambient temperature and air percent shall be determined at 30 minute intervals until the slump is two inches (50 mm) or less. The trial mix shall be re-mixed for one minute at the agitation speed of the mixer before these tests are run.

7. All elapsed times shall begin when water is initially introduced into the mix.

8. The concrete shall maintain a slump of at least four inches (100 mm) for the estimated mixing and transit time plus anticipated placement time. Necessary adjustment shall be made to meet this requirement.

d. Forms - When top of shaft elevation is above ground the portion of the shaft above ground shall be formed with a removable form or another approved method to the dimensions shown in the plans. Protect portions of drilled shafts exposed to a body of water from the action of water by leaving the forms in place for a minimum of seven (7) days after casting the concrete, or until strength has reached 2,500 psi (17 Mpa).

e. Riser Block - A riser block of equal diameter as the column and of a maximum height of six inches (15.2 cm) may be cast at the top of the completed shaft. When the Contractor elects this option he shall extend any dowel steel above the top of shaft an additional six inches (15.2 cm).

f. Curing - The top surface shall be cured in accordance with Specification 934 – Structural Concrete – Adverse Conditions and any construction joint area shall be constructed as shown in the plans.

901-3.18 Test Holes

a. The construction of test holes will be used to determine if the methods and equipment used by the Contractor are sufficient to produce a shaft excavation meeting the requirements of the plans and specifications. The ability to control dimensions and alignment of excavations within tolerances; to seal the casing into impervious materials; to control the size of the excavation under caving conditions by the use of mineral slurry or by other means; to properly clean the completed shaft excavation; to determine the elevation of ground water; satisfactorily place concrete meeting the specifications within the prescribed time frame; and to satisfactorily execute any other necessary construction operation will be evaluated during Test Hole excavations. The Contractor shall revise his methods and equipment as necessary at any time during the construction of the test hole when he is unable to satisfactorily carry out any other the necessary operation described above or he is unable to control the dimensions and alignment of the shaft excavation within tolerances.

b. Test holes will be drilled out of permanent position as shown on the plans or as directed by the Engineer. The diameter and depth of the test hole or holes shall be the same diameter and depth of the production drilled shafts as shown in the plans or as directed by the Engineer. The Test Hole will be reinforced and shall be filled with concrete in the same manner that production-drilled shafts will be constructed. When shown in the plans or directed by the Engineer, the test holes may be backfilled with suitable soil in a manner satisfactory to the Engineer. The test holes with concrete will be left in place, except that the top of the shaft will be removed to a depth of two feet

(60 cm) below the ground line. The disturbed areas at the sites of test holes drilled out of position shall be restored to their original condition. When the Contractor fails to demonstrate to the satisfaction of the Engineer the adequacy of his methods or equipment and alterations are required, additional test holes shall be provided at no cost to the Authority.

901-3.19 Construction Tolerances - The following construction tolerances shall apply for drilled shafts:

a. The top of the drilled shaft shall be no more than three inches (7.62 cm) laterally from the position indicated in the plans.

b. The vertical alignment of the shaft excavations shall not vary from the alignment shown in the plans by more than 1/4 inch per foot (2.07 cm per meter) of depth.

c. After all the concrete is placed, the top of the reinforcing steel cage shall be no more that six inches (15.2 cm) above and no more than three inches (7.62 cm) below plan position.

d. The reinforcing cage shall be concentric with the shaft within a tolerance of 1-1/2 inches (3.81 cm). Concrete cover shall be six inches (15.2 cm) plus or minus 1-1/2 inches (3.81 cm) unless shown otherwise in the plans.

e. All casing diameters shown in the plans refer to I.D. (inside diameter) dimensions. However, casing with an outside diameter equal to the specified shaft diameter may be used if the extra length described in article 901-3.11 is provided. In this case, the I.D. of the casing shall not be less than the specified shaft diameter less one-inch (2.54-cm). When approved, the Contractor may elect to provide a casing larger in diameter than shown in the plans to facilitate this requirement. When casing is not used, the minimum diameter of the drilled shaft shall be one inch (2.54 cm) less than the specified shaft diameter. When conditions are such that a series of telescoping casings are used, the casing shall be sized so that the minimum shaft diameters listed above can be maintained.

f. The top elevation of the drilled shaft concrete shall have a tolerance of plus one inch (2.54 cm) and minus three inches (7.62 cm) from the top of shaft elevation shown in the plans.

g. The dimensions of casings are subject to American Pipe Institute tolerances applicable to regular steel pipe.

h. Excavation equipment and methods shall be designed so that the completed shaft excavation will have a flat bottom. The cutting edges of excavation equipment shall be normal to the vertical axis of the equipment within a tolerance of plus or minus 3/8 inch per foot (3.12 cm per meter) of diameter.

901-3.20 Drilled Shaft Excavations Constructed Out of Tolerance

a. Drilled shaft excavations constructed in such a manner that the concrete shaft cannot be completed within the required tolerances are unacceptable. When approved, corrections may be made to an unacceptable drilled shaft excavation by any approved combination of the following methods:

1. Overdrilling the shaft excavation to a large diameter to permit accurate placement of the reinforcing steel cage with the required minimum concrete cover.

2. Increasing the number and/or size of the steel reinforcement bars.

3. Other method proposed by the Contractor and approved by the Engineer.

b. The approval of correction procedures is dependent on analysis of the effect of the degree of misalignment and improper positioning. Correction methods will be approved only as design analyses indicate.

c. Redesign drawings and computations prepared by the Contractor's Engineer shall be signed and sealed by a Professional Engineer licensed by the Commonwealth of Puerto Rico. Any out of tolerance shafts shall be backfilled in an approved manner when directed by the Engineer until the redesign is complete and approved. Additional materials and work necessary, including engineering analysis and redesign, to effect corrections of out of tolerance drilled shaft excavations shall be furnished by the Contractor at no cost to the Authority.

SPECIAL PROVISION

SPECIFICATION 901 – DRILLED SHAFT FOUNDATIONS

901-3.21 Drilled Shaft Load Tests

a. General

1. Load tests on drilled shafts shall be realized according to Specification 915- Statnamic Load Testing or Specification 916 – Osterberg Cell Load Testing as indicated on plans or by the Engineer.

2. All load tests shall be completed before construction of any additional production drilled shafts. The Contractor shall allow up to four weeks after the last load for the analysis of the load test data and to provide all estimated production drilled shaft tip elevations. If the Contractor is willing to construct production shafts in areas designated by the Engineer, shaft tip elevations can be set as required to keep the Contractor working beginning one week after the successful completion of the final load test.

3. The number of load test and the locations shall be as shown on the plans or as designated by the Engineer. Loads for the tests shall be based on the design load shown on the plans.

4. This load testing methods are non-destructive load tests and it are intended that the test shaft be left in a condition suitable for use as a production shaft in the finished structure. Should the test shaft be in a condition not suitable for use in the finished structure, the shaft shall be repaired or replaced. In such case, the designer shall be contacted to design the repair or replacement. Should load testing result in damage to the shaft such that it must be repaired or replaced, the remaining tests shall be re-evaluated to determine whether the remaining test program should be modified.

5. Load testing of drilled shafts shall not begin until the concrete has attained a compressive strength of 4,000 psi. High early strength concrete may be used to obtain this strength at an earlier time to prevent testing delays. Drilled shafts shall be load tested in the order directed by the Engineer. Loadings shall be completed as described hereafter. The Contractor shall supply the equipment and personnel needed to conduct the load tests. The Contractor shall supply specialty sub-contractors for the load tests. Unless shown otherwise in the plans or Specifications, the Contractor shall supply all equipment, materials, labor and technical personnel required to conduct the load tests. The Contractor's loading apparatus shall be designed to accommodate the maximum load plus an adequate safety factor.

6. During the performance of the load tests, the Contractor shall provide safety equipment and employ safety procedures consistent with the latest approved practices for this work. These safety procedures shall include adequate support for the load test plates and jack to prevent them from falling in the event of a release of load due to hydraulic failure, test shaft failure or any other cause.

7. The Contractor shall notify the Engineer at the pre-construction conference or no later than 30 days before drilled shaft construction begins, of his proposed testing schedule. If the Contractor is not directed by the Contract Documents as to the test to be utilized, the Contractor will specify which test he will use as part of his bid. The Engineer will monitor and approve load tests completed by the Contractor's specialty sub-contractor.

b. Disposition of Loading Material - After all load test have been completed, the Contractor shall remove the load test equipment along with any temporary piling installed. All equipment and materials required to perform the load test that were provided by the Contractor will remain the property of the Contractor and shall be removed from the site. The site shall be cleaned up and restored to the satisfaction of the Engineer.

c. Disposition of Tested Shafts - After testing is completed, if required on the plans or by the Engineer, the tested shafts shall be cut off at their planned cut-off elevation surface. The shaft cut-off removed shall remain the property of the Contractor and shall be disposed of in areas provided by him. All instrumentation holes shall be completely grouted with non-shrinking grout.

901-4 METHOD OF MEASUREMENT

901-4.01 Drilled Shafts

a. Drilled shafts will be measured by the linear meter, to the nearest tenth of a meter, of the reinforced concrete drilled shaft of the diameter shown on the plans, in place, completed and accepted. This shall include all necessary works for completing the drilled shaft as requested by this specification or directed by the Engineer, including but not limited to: test holes, temporary casing, slurry, exploratory holes (coring), unclassified shaft excavation, concrete, concrete placement, reinforcing steel, tremies, shaft inspection works and all other incidentals. The length shall be determined as the

difference between the bottom elevation of the cap beam or abutment shown on the plans and the final bottom of shaft elevation as authorized and accepted by the Engineer.

b. When the Contractor elects to provide outside diameter (OD) sized casing rather than inside diameter (I.D.) sized casing as allowed in article 901-3.11, the pay quantity measured as described above shall be multiplied by a factor (F) determined as follows:

$$F = \frac{2D2-D1}{D2}$$

where,

F = factor to adjust pay quantities to compensate or small shafts

D1 = casing inside diameter specified = shaft diameter specified

D2 = casing inside diameter provided (D2 = D1 minus twice the wall thickness)

901-4.02 Permanent casings will be measured by the linear meter, to the nearest tenth of a meter, of permanent casing in place, completed and accepted. Casing will be only measured when the Engineer authorizes to leave a casing which will become a permanent part of the drilled shaft. No measurement will be done for casings that become bond or fouled during shaft construction and cannot be removed.

901-4.03 Drilled shaft over-reaming will not be measured directly for payment, but shall be considered a subsidiary obligation.

901-5 BASIS OF PAYMENT

901-5.01 The completed and accepted quantities, measured as provided above, will be paid for at the contract unit price per unit of measurement for each of the pay items listed below which are included in the contract. Such prices and payment shall constitute full compensation for furnishing, placing and finishing all works and for all materials, equipment, tools, labor and incidentals necessary

to complete each item as required by the plans, specifications or directed by the Engineer.

901-5.02 Payment will be made under:

Pay Item	Pay Unit
Drilled Shaft, ____ inch Diameter	Linear Meter
Permanent Casing, ____ inch Diameter	Linear Meter
Drilled Shaft Sidewall Over – reaming (___inch Diameter)	Linear Meter