OKLAHOMA DEPARTMENT OF TRANSPORTATION
SPECIAL PROVISION
FOR
DRILLED SHAFT FOUNDATIONS

These Special Provisions revise, amend, and where in conflict, supersede applicable sections of the 2009 Standard Specifications for Highway Construction, English and Metric.

(Replace with the following:)

516.01 DESCRIPTION

This work consists of constructing drilled shafts and providing and placing reinforcing steel, concrete, and procedures for integrity testing of drilled shafts including remedial actions.

516.02 MATERIALS

A. General

Use materials in accordance with the following sections:

Material:	Section:
Structural Concrete	509
Reinforcing Steel for Structures	511

B. Concrete

Provide and modify Class AA concrete as follows:

- Limit the maximum aggregate size to ¾ in [19 mm],
- Ensure that water/cement ratio is 0.44 or lower,
- Use a high range water reducing admixture to achieve 6 to 8 in [150 mm to 200 mm] of slump at the placement start. Ensure at least 4 in [100 mm] of slump exists at the completion of placement and casing or reinforcement alignment,
- Maintain the concrete temperature below 85 °F [30 °C] during placement.
- For concrete placed under water or slurry, use cementitious material such as slag or fly ash (not cement) to increase the minimum cementitious content 10%, and
- Submit optional anti-washout additives to the Engineer for approval.

C. Casings

For exterior casings, provide smooth, clean, watertight, steel casings that can withstand handling, driving, driving stresses, and pressures from the concrete and surrounding earth. Provide permanent casing with the dimensions specified by the American Pipe Institute tolerances for regular steel pipe. If only a single casing is used in a shaft, the casing is considered an exterior casing.

Permanent exterior casings, use steel in accordance with AASHTO M 270 Grade 36 (ASTM A709M Grade 250), unless otherwise specified by the Contract. Weld permanent exterior casings in accordance with Section 506. "Structural Steel." The Department defines permanent exterior casing diameters shown on the Plans as outside diameters.

When the Contract requires permanent exterior casings, or if the electing to provide a permanent exterior casing, ensure that a Registered Professional Engineer in the State of Oklahoma stamps and designs the design and calculations for these casings. Submit permanent casings and design calculations to the Engineer. Provide casing thicknesses not less than shown in Table 516:1.

Table 516:1
Minimum Permanent Casing Wall Thickness

<48" [<1220 mm]	0.375" [10 mm]
48" - 78" [1220 - 1980 mm]	0.500" [13 mm]
> 78" [1980 mm]	0.625" [16 mm]

For permanent interior casings, use round corrugated galvanized steel pipe with 3 in x 1 in [75 mm x 25 mm] corrugations in accordance with AASHTO M 36. Ensure the pipe gauge stays round and can withstand the concrete pressure.

516.04 CONSTRUCTION METHODS

A. Plan for Drilled Shaft Installation

Use personnel experienced in constructing drilled shafts.

Submit an installation plan or work plan for approval to the Engineer that includes the following details before constructing drilled shafts:

- List of personnel experienced in constructing drilled shafts including resumes of project experiences and documentation that verifies the information;
- Concrete mix design including results of concrete trial mix and tests for slump loss over time. Include procedures for introducing admixtures during mixing operations including set retarders;
- List of proposed equipment to be used, including cranes, drills, augers, bailing buckets, final cleaning equipment slurry pumps, core sampling equipment, tremies, and concrete pumps;
- List types of casings to be used by the contractor in accordance with Subsection 516.02C. "Casings." Include diameters and thicknesses for all permanent, temporary, and surface casings;
- Details of shaft excavation methods and procedures for maintaining horizontal and vertical alignment of the excavation;
- When the slurry is used, include details of the methods to mix, circulate, desand, and dispose of the slurry;

- Details of methods to clean the shaft excavation including the method to clean the bottom of the hole;
- Use or disposal of the excavated materials;
- Placement of reinforcing steel including support and centering methods required to minimize lateral movement of the steel cage including bolsters and the type of spacers: plastic rollers, concrete rollers, or sleds (when permitted). Provide any required material documentation for bolsters and spacers;
- Concrete placement, including proposed operational procedures for tremie and pumping methods. Include procedure that will be used to verify the outlet end is at least 10 ft (3 m) into the fluid concrete;
- Type and/or method of shaft inspection device to be used; and
- The format of the video that will be provided to the Engineer, and method of delivery.

Revise and resubmit the installation plan if it does not produce Contract required results. Submit requests for changing the top of shaft elevations with the installation plan.

B. Trial Drilled Shafts

If the Contract requires trial drilled shafts, construct them adjacent to the permanent shafts before constructing the permanent drilled shafts. Demonstrate that the methods and equipment can construct the Contract required drilled shafts. Include reinforcement and CSL tubes for the most heavily reinforced drilled shafts as noted on the Plans.

Construct the trial shaft to the size and tip elevation of the deepest shaft shown on the Plans. To monitor excavation stability and groundwater seepage, leave completed excavation open for at least 4 hr before concreting. Clean the excavation and fill the hole completely with mix design concrete. Remove the concrete 2 ft [0.6 m] below the finished grade. Perform all nondestuctive testing including CSL testing as shown on the plans or as directed by the Engineer.

If the Engineer determines that trial drilled shaft is unsatisfactory based on results of CSL other nondestructive testing, and/or coring, modify and resubmit the installation plan and drill a new trial shaft. The Engineer will not allow changes to the installation plan without resubmission.

C. Drilled Shafts

(1) Hole Excavation

Excavate holes in accordance with the installation plan. Before drilling, excavate for structure footings supported on drilled shafts and construct embankments and fills.

Place the drilled shaft horizontally at the top of the shaft elevation within 3 in [75 mm] of the position shown on the Plans. Ensure the vertical shaft alignment does not vary by more than 1 percent of shaft depth.

Use excavation equipment and methods that provide a shaft bottom normal to the axis of the shaft within 5 percent of the shaft diameter. Measurement of the shaft bottom tolerance will be left to the discretion of the Engineer. Use excavation equipment that provides a drilled shaft diameter larger than or equal to the plan diameter minus 1 in [25 mm].

Excavate below the elevation shown on the Plans if the load bearing material does not satisfy Plan requirements. Immediately notify the Engineer of deviations in subsurface conditions that may change the shaft depth or result in a reduced capacity for the bearing area. When excavated material is substantially different than soundings shown on the plans as determined by the Engineer, take soil samples or rock cores consistent with soundings shown in the Plans to determine the character of the material directly below the shaft excavation. Extend cores a minimum of two shaft diameters, or as specified by the Engineer, below the drilled shaft plan elevation logging the type of material and rock quality. Use a geotechnical engineer approved by the Bridge Division.

Check dimensions and alignment of shaft excavations in the presence of the Engineer. The Engineer will measure final shaft depth after final cleaning. If the sidewall of the hole softens due to excavation methods, swells due to delays in concreting, or degrades due to slurry cake buildup, over-ream the sidewall from ½ in to 3 in [12 mm to 75 mm] to sound material. When a shaft constructed using the mineral slurry technique sets more than 4 hours without agitation, ream the shaft to remove the cake build up.

Immediately before placing the reinforcing steel cage or concrete, clean the hole so 50 percent of each hole bottom has less than ½ in [12 mm] of sediment. Ensure the remaining 50 percent of the hole has no greater than 1 ½ in [38 mm] of sediment or debris. For dry holes, reduce the water depth to 6 in [150 mm] or less before placing concrete.

Verify that the hole bottom has been adequately cleaned using a shaft inspection device. Use a device with a high-resolution camera mounted in a watertight chamber and fitted with a depth gauge(s) to indicate the thickness of the debris on the shaft bottom. Furnish all equipment necessary to conduct the inspection. Use air, gas, or other means to pump the water out of the interior of the chamber such that the bottom of the shaft is visible. Do a minimum of five (5) drops as follows: north, south, east, west, and center (Attachment 516:1). As directed by the Engineer, the number of drops may increase for diameters larger than 8 ft [2.4 m], and the number of drops may decrease for diameters less than 4 ft [1.2 m]. Operate the camera and supporting equipment under the direction of the Engineer in such a manner as to obtain optimum clarity from the equipment. Use television cameras and lighting equipment capable of operating in dry or submerged conditions encountered during the inspection. Record the observations for the shaft bottom on a DVD or flash drive in .mov, .avi or other acceptable electronic format specified by the Engineer to become the property of the Department upon completion of the project. Store DVD's or flash drives in proper containers with dust tight closures. Label DVD's or flash drives as to shaft number, project number, job piece, contract number, and contractor name. Furnish DVD's or flash drives to the Engineer upon completion of the inspection. Continue cleaning until the Engineer is satisfied that the hole bottom is adequately cleaned and the excavation is approved.

Use at least one of the following methods for excavation:

(a) ***Dry Method***

Use the dry construction method at sites where the Engineer can visually inspect the shaft before concrete placement. For dry method:

- Drill the shaft,

- Remove accumulated water
- Remove loose material from the excavation,
- Place the reinforcing cage, and
- Concrete the shaft in dry conditions.

If caving, sloughing, or swelling conditions exist or if depth of groundwater seepage exceeds 6 in [150 mm] within one-half hour after pumping is stopped, discontinue the dry construction method and use an alternative method approved by the Engineer.

(b) ***Wet Method***

Use the wet construction method or a casing construction method for shafts that do not meet the requirements for dry construction. For the wet method, use water or slurry with the proper hydraulic head to maintain the stability of the hole while advancing the excavation to final depth, placing the reinforcing cage, and concreting the shaft. The wet method involves the following work:

- De-sanding and cleaning the slurry,
- Final cleaning of the excavation,
- Placing the shaft concrete with a watertight tremie or pumping concrete into a watertight tremie beginning at the shaft bottom,
- Providing temporary surface casings to aid shaft alignment and positioning, and
- Providing temporary surface casings to prevent sloughing of the top of the shaft excavation.
- Refer to subsection 516.04C.(2) for slurry requirements

(c) ***Casing Methods***

1) *General*

The Department will not allow casing to the bottom of the shaft. Discontinue the casing at the top of the founding stratum as shown on the Plans. Excavate below the casing using the dry or wet method. To provide design frictional load capacity, excavate into the founding stratum to the deepest length or depth shown on the Plans. Install casing in accordance with Subsection 516.04.C.3. "Exterior Casings." Do not use the double casing method when a rock socket is not present.

2) *Temporary Casing Method*

If unable to use the dry or wet methods, use the temporary casing construction method. For temporary casing:

- Use the wet method to advance the excavation through caving material into an impervious formation and set the temporary casing or use a vibratory hammer to drive the casing into the impervious formation prior to excavation,
- Complete excavation and seat the casing into rock by twisting the casing,
- Place the reinforcing cage, and
- Concrete the shaft while removing the casing.

3) *Permanent Casing Method*

Use the permanent casing construction method if shown on the Plans or where drilled shafts are in open water. For the permanent casing method, advance the excavation through caving material by driving or drilling a permanent casing to the Contract required depth or into a nearly impervious formation, whichever is deepest. Excavate to the final depth, or into a nearly impervious formation, whichever is deepest. Excavate to the final depth, place the reinforcing cage, and concrete the shaft. If full penetration cannot be attained during casing installation, excavate within the embedded portion of the casing. Drill a pilot hole if necessary. Ensure continuous casing from the top of the shaft to the elevation shown on the Plans. If the drilled shafts are in open water, extend casings from above the water elevation into the ground to protect the shaft concrete from the water during concrete placement and curing.

4) *Double Casing Method*

Use the double casing construction method if the Contract requires or, as an alternative for the temporary casing method, in the presence of severe groundwater or unstable soil conditions. Make the temporary exterior casing larger than the Contract required shaft diameter and set a permanent interior casing into the top of the founding stratum after excavation completion.

Supply the interior casing with a permanent inner diameter equal to the shaft diameter shown on the Plans. Use a temporary exterior casing with an inner diameter at least 6 in [150 mm] larger than the interior casing, but not more that 12 in [300 mm] larger. After placing the exterior casing, complete the excavation as shown on the Plans. Set the interior casing into the top of the founding stratum and brace it at the top. Remove the temporary casing after filling interior casing with concrete. Add concrete to maintain top of shaft elevation during removal. After the concrete initially sets, do not adjust the interior casing position.

(d) ***Obstructions***

The Department defines an obstruction as unexpected manmade materials through which excavation cannot advance. The Department does not consider removal of tools, lost in the excavation, obstructions. Removal of naturally-occurring material, regardless of difficult or removal method, is not considered an obstruction.

Remove obstructions encountered during excavation. Notify the Engineer, in advance, of the proposed obstruction removal method. Include a cost estimate for excess costs in accordance with Subsection 104.03. “Differing Site Conditions,” for obstruction removal compensation.

(2) Slurry

Before introducing it into the shaft, hydrate the slurry by premixing the material with fresh water in accordance with the slurry manufacturer’s instructions. Provide slurry tanks with the capacity for slurry circulation, storage and treatment. The Department will not allow the use of excavated slurry pits. Use either mineral (bentonite or attapulgite) or polymer slurry.

Provide de-sanding equipment to limit slurry sand content at any point in the bore hole. Ensure slurry sand content is less than 4 percent by volume for mineral slurry, and less than 1 percent for polymer slurry. The Engineer does not require de-sanding to set temporary casings.

During drilling, maintain a slurry surface in the shaft at least 5 ft [1.5 m] above the highest expected water table elevation or piezometric head and at a level that prevents the hole from caving.

When there is a sudden loss of slurry from the hole, stop drilling and take corrective action to prevent slurry loss. If the slurry construction method fails to produce the Contract required results, stop and use an alternative method approved by the Engineer.

When the excavation reaches the elevation shown on the Plans and clean, allow at least 30 min for polymer slurry to stand undisturbed. Clean the excavation base with a submersible pump or air lift.

Maintain the density, velocity, and pH of the slurry during shaft excavation in accordance with Table 516:2 for mineral slurry, and Table 516:3 for polymer slurry.

Table 516:2
Acceptable Range of Mineral Slurry

Property, Method	**At the time of Slurry Introduction**	**In Hole at Time of Concreting**
Density, [a] Density Balance (lb/ft^3 [kg/m^3])	64.3 - 69.1 [1,030 - 1,107]	64.3 - 75.0 [1,030 - 1,200]
Viscosity, Marsh Cone (s/qt [s/L])	28 - 45 [30 - 48]	28 - 45 [30 - 48]
pH, pH paper or meter	8 - 11	8 - 11

Note: Perform tests when slurry temperatures are above 40° F [4° C].
[a] Density values are for fresh water. Increase density values 2.0 lb/ft^3 [32 kg/m^3] for salt water

Table 516:3
Acceptable Range of Polymer Slurry

Property, Method	**At the time of Slurry Introduction**	**In Hole at Time of Concreting**
Density, [a] Density Balance (lb/ft^3 [kg/m^3])	62.4 - 63.0 [1,000 - 1,010]	62.4 - 63.5 [1,000 - 1,017]

Table 516:3 Acceptable Range of Polymer Slurry		
Property, Method	**At the time of Slurry Introduction**	**In Hole at Time of Concreting**
Viscosity, Marsh Cone (s/qt [s/L])	30 - 40 [32 - 42]	30 - 40 [32 - 42]
pH, pH paper or meter	9 - 11	9 - 11
Note: Perform tests when slurry temperatures are above 40° F [4° C]. [a] Density values are for fresh water. Increase density values 2.0 lb/ft^3 [32 kg/m^3] for salt water		

Take slurry samples using an Engineer approved sampling tool. Extract slurry samples from the base of the shaft and from 10 ft [3 m] above the shaft base. Perform four sets of tests during the first 8 hr of slurry use. When the results are acceptable and consistent, perform one test set for every 4 hr of slurry use.

Make corrections if the test results indicate unacceptable slurry samples. Place concrete when the resampling and retesting indicate acceptable values.

Provide test reports to the Engineer, signed by an authorized technical representative, after completion of each drilled shaft.

Dispose of slurry at approved locations.

(3) Exterior Casings

Ensure casings produce a positive seal that prevents water or other material from piping into or out of the hole. If substituting a casing with a longer or larger diameter casing through caving soils, stabilize the excavation with slurry or backfill before installing the new casing.

Consider subsurface exterior casings as temporary unless designated in the Contract as permanent casing. Remove temporary casing before completing placement of concrete in cased drilled shaft. While removing casing from the hole, maintain at least 5 ft [1.5 m] of fresh concrete in the casing above the surrounding level of water or slurry. Ensure the excess concrete within the casing displaces fluid trapped behind the casing upward and discharges it at the ground surface without contaminating or displacing the shaft concrete.

The Department defines defects in the drilled shaft as temporary casings that are bound or fouled during shaft construction and cannot be practically removed, as determined by the Engineer.

Extend casings above the surface to keep the excavation clean through concrete placement. Cut the casing off of permanent casings at the elevation shown on the Plans and leave in place after concrete placement.

(4) Reinforcing Steel Cages for Drilled Shafts

(a) ***General***

When tying the drilled shaft cage, support the reinforcing steel off the ground. Protect epoxy coated reinforcing steel from exposure to the sun and ensure that the surface of the bars is free of excessive rust, soil, oil, and as specified in subsection 511.04. Place the reinforcing steel cage as a unit only after the shaft excavation is approved by the Engineer and before concrete placement. Tie reinforcing steel lap splices together using wire.

Tie and support the reinforcing steel to keep it within the Contract required tolerances. Tie spacing devices at least at fifth points around the cage perimeter or one per 12 in [300 mm] of shaft diameter. Provide spacers at intervals no greater than 10 ft [3 m] along the length of the cage. Place spacers within 18 in [450 mm] of the top and bottom of the shaft. Use concrete spacers that equal the shaft concrete in quality and durability. Concrete sleds are acceptable in lieu of the rollers but only when casing is used down to the rock line.

Alternate reinforced or non-reinforced virgin plastic spacers may be used provided the plastic spacers meet the following requirements:

- Use spacers of adequate strength to withstand a 300 lb [1,335 N] concentrated load without permanent deformation or breakage
- Limit deformation under a 300 lb [1,335 N] load to a maximum of 5% of the support height.
- Use spacers able to meet the concentrated load requirements within a working temperature range of 20 to 150°F [-7 to 65°C], and have a maximum water absorption rate of 0.5%, as per ASTM D 570.
- Provide reinforced or non-reinforced virgin plastic when tested in accordance with ASTM D695 having a compressive strength greater 4,000 psi at 1% deformation based on a 2"x2"x2" cubic test specimen.

Protect plastic spacers from exposure to sunlight until placed in the reinforcing steel cage. Remove and replace any broken, cracked, or damaged spacers.

Temporarily strengthen the reinforcing steel cage to resist the lifting forces when the cage is lifted from a horizontal position to a vertical position. Use multiple pick-up points, strongbacks, slings or other means to support the reinforcing cage while it is being lifted. If there is evidence of excessive bending of the steel cage and/or if slippage of the spiral or tie bars occurs, repair or replace the reinforcing steel cage as needed, including CSL tubes.

During concrete placement, provide positive support from the top for the reinforcing steel cage. Support the cage concentrically to prevent racking and distortion. Maintain the top of the reinforcing steel cage no greater than 6 in [150 mm] above and no greater than 3 in [75 mm] below the Contract required position. Make corrections if the reinforcing steel cage is not maintained in that position. Do not construct additional shafts until the method of reinforcing steel cage support has been approved by the Engineer. Alternately, support the bottom of the reinforcing steel cage using footing attachments consisting of concrete, mortar, or plastic bolsters as approved by the Engineer. Use bolsters capable of supporting a 1,000 pound [4,450 N] load without breakage. Do not use bolsters which will extend above the bottom of the reinforcing steel as it may interfere with the CSL testing.

Provide additional reinforcing steel if conditions require shafts longer than shown on the Plans.

(b) ***Access Tubes for Crosshole Sonic Logging***

When the Contract requires Crosshole Sonic Logging (i.e. CSL testing) to be performed, include CSL access tubes in the construction of each drilled shaft. Use access tubes with 2 in [50 mm] inner diameters that are made of schedule 40 steel pipe. Provide tubes, including pipe joints, with a round regular internal diameter that allows a 1.3 in [33 mm] diameter source and receiver probes to pass unobstructed. Make the tubes and joints watertight and corrosion free, with clean surfaces that allow a good bond between the concrete and the tubes.

Install access tubes to the full depth of each shaft for CSL testing equipment. Unless otherwise required by the Contract, install the number of access tubes in each drilled shaft in accordance with Table 516:4.

Table 516:4
Minimum Number of Access Tubes per Drilled Shaft

Planned Shaft Diameter, ft [m]	***Minimum Number of Access Tubes***
$D \leq 3.0$ [$D \leq 0.9$]	3
$3.0 < D \leq 4.0$ [$0.9 < D \leq 1.2$]	4
$4.0 < D \leq 5.0$ [$1.2 < D \leq 1.5$]	5
$5.0 < D \leq 6.0$ [$1.5 < D \leq 1.8$]	6
$6.0 < D \leq 8.0$ [$1.8 < D \leq 2.4$]	7
$8.0 < D \leq 10.0$ [$2.4 < D \leq 3.0$]	8
$10.0 < D \leq 12.0$ [$3.0 < D \leq 3.7$]	9

Fit tubes with a watertight shoe on the bottom and a removable cap on the top. Attach the tubes to the interior of the reinforcement cage in a regular, symmetric pattern, equally spaced around the perimeter of the cage. Install the tubes parallel to each other and vertical. Start the tubes from the shaft bottom and end at least 3 ft [0.9 m] above the ground, water surface, or both.

Avoid bending the CSL tubes during lifting of steel cage, and ensure tubes remain parallel during installation operations in the drilled shaft hole. Before concrete placement, fill the access tubes with clean water and cap the tube tops. Ensure that the tubes remain full of water until CSL testing is complete. When temperatures below freezing are anticipated, protect the access tubes against freezing by wrapping the exposed tubes with insulating material, adding antifreeze to the water in the tubes, or other methods as approved by the Engineer. After concrete placement, avoid breaking the bond between the access tubes and the concrete.

(5) Concrete for Drilled Shafts

In the presence of the Engineer and immediately prior to concrete placement, inspect the hole for caving material falling from the sides or a change in the water elevation. Unless otherwise approved by the Engineer, place drilled shaft concrete within two hours after excavation for the shaft has been approved and the reinforcing cage has been placed. If the concrete placement is delayed or if the hole has become contaminated, remove the cage and verify the integrity of the excavated area, and ensure loose material is removed from the bottom of the hole in accordance with 516.04C.(4) Hole Excavation before resetting the reinforcing steel cage. Complete concreting in a shaft and remove the temporary casing within 2 hr of beginning concrete placement. The Department will not allow retempering concrete that has developed an initial set.

When the wet method is used and prior to placing concrete, ensure that the static water or slurry level is properly maintained in the excavation.

Using a watertight tremie, place concrete in one continuous operation from the bottom to the top of the shaft. Place concrete until acceptable quality concrete reaches the top of the shaft. For a dry shaft, overflow the top with at least 1 ft [300 mm] of concrete. For a wet shaft, overflow the top with at least 5 ft [1.5 m] of concrete. Continue overflow of concrete in shafts until uncontaminated concrete is evident. Before initial concrete sets, consolidate the top 10 ft [3 m] of the shaft using Engineer approved vibratory equipment. Finish the top of the shaft from 3 in [75 mm] lower to 1 in [25 mm] higher than the elevation shown on the Plans. In wet holes, consolidate after removing water above the concrete surface.

Place the discharge end of the watertight tremie at one tremie diameter above the shaft base elevation. Keep the discharge end immersed at least 10 ft [3 m] below the surface of the fluid concrete except when concrete is initially placed. Maintain a positive head of concrete in the tremie during concrete placement. If the discharge end is removed from the fluid concrete column during the concrete placement and concrete is discharged above the rising concrete surface into displaced water, remove the reinforcing cage and concrete, complete sidewall removal as directed by the Engineer, and reconstruct the shaft.

If the top of the shaft is above ground, form the shaft from the top to at least 2 ft [0.6 m] below finished ground. If the top of the shaft is below ground, use a temporary oversize surface casing to control material caving into the freshly placed concrete.

The Engineer will sample concrete for acceptance at the point of discharge into the tremie or concrete pump hopper. Cure exposed concrete surfaces in accordance with Section 509, "Structural Concrete."

During concrete placement and curing, ensure that the concrete temperature does not exceed 150 °F [65 °C]. When drilled shaft diameter exceeds 6 ft [1,830 mm], use recording thermometers, maturity meters, or other means as directed by the Engineer to monitor temperatures inside the drilled shaft. Ensure that the temperature difference between the core of the shaft and the outer edges does not exceed 36 °F [20 °C]. When drilled shaft concrete temperatures exceed 150 °F [65 °C] or when the temperature difference between the core and the outer edges exceed 36 °F [20 °C], reject the shaft.

Record and document the volume of concrete used in each drilled shaft and provide this information to the Engineer.

(a) ***Tremies***

The Department defines tremies as tubes that discharge concrete at the shaft base. Use watertight tremies to place concrete in wet or dry holes. Ensure the bottom of the tremie can be sealed and charged with concrete in the dry, and then opened in place at the bottom of the shaft. The Department will not allow the use of tremies containing aluminum parts that will come in contact with concrete. Ensure that the tremie can be lowered rapidly to retard or stop the flow of concrete. In order to ensure tremie is lowered to the proper depth, mark tremie prior to lowering.

Provide a watertight tremie with an inner diameter from 10 in to 14 in [254 mm to 350 mm], clean and smooth surfaces, and a wall that prevents crimping or sharp bends. Fit the top with a hopper. Ensure that joints are water tight. Construct the discharge end of the tremie to allow free radial concrete flow during placement.

(b) ***Concrete Pumps***

Pump concrete into a watertight tremie as specified above. Pump concrete in one continuous operation from the bottom to the top of the shaft. For wet holes, use a device at the end of the discharge tremie to seal out water while the tremie fills with concrete. If a plug is used, remove it from the hole. Alternatively, use a plug of Engineer approved material that will prevent a defect in the shaft.

(c) ***Acceptance***

The Department may accept drilled shafts with low concrete strengths in accordance with Subsection 105.03, "Conformity with Plans and Specifications." In such cases the Department will use the strength reduction equation as noted in Subsection 509.06, "Basis of Payment."

(6) Application of Construction Loads

If the Contract requires Integrity Testing, the shaft must pass the Integrity testing before application of any loads or proceeding with the construction of the pier. If the Contract does not require Integrity Testing or the Integrity Testing passes the test, wait a minimum of 24 hours and meet the requirements of 509.04C.(2)(b) before application of construction loads. Determine strengths from test cylinders cured at the work site under similar environmental conditions in accordance with Section 701, "Portland Cement Concrete."

(7) Integrity Testing of Drilled Shafts

The Department shall make the determination to conduct non-destructive testing on drilled shafts based on one or more of the following criteria:

- ADT > 750, ADTT > 100
- Bridge deck area > 10,000 ft^2
- Span length > 100 ft
- Drilled shaft depth > 50 ft
- Drilled shaft diameter > 60 in
- Emergency Detour length > 20 miles
- Bridge contains three (3) or more piers
- The pier is located in greater than fifteen feet (15 ft) of water (e.g. a lake).
- Construction of the project involves grade separation.
- The bridge is on either the Interstate, the National Highway System (NHS), or Defense Route.
- The bridge is categorized as an essential or critical structure by either the owner or designer.
- The design of the drilled shaft(s) foundation is based solely on friction.
- The Contract requires the drilled shaft(s) to be constructed using the slurry method, or the Contractor elects to construct the drilled shaft(s) using the slurry method.
- The geological formation is such that voids are present in the rock formation, water is flowing within the soil or rock layers, Artesian water is present, or significant layers of material are suspect to caving and sloughing (e.g. loose sand, loose gravel, etc.).

(a) ***General***

The requirement for non-destructive testing is specified in the Contract documents. When required, perform CSL testing on the first production shaft of each diameter specified in the plans. No additional shafts may be placed until:

- The Contractor demonstrates that the drilled shafts can be constructed in accordance with the Contractor's drilled shaft installation plan, and to the satisfaction of the Engineer, and

- An integrity testing consultant, provided by the Contractor and registered in the State of Oklahoma, has provided the analysis of the tests results, including their recommendation to the Engineer.

If the Engineer concurs with the consultant's recommendation for acceptance, then construction may continue on the remaining shafts using the same construction methods which were used to produce the tested shaft. Construct all subsequent shafts with CSL tubes for the purposes of additional testing.

Provided that all procedures are followed and repeated from the tested shaft, perform additional CSL testing on every sixth drilled shaft. ODOT may require testing, at no additional cost to the Department, on any subsequent shaft not constructed in the same manner as the tested shaft, or where a construction incident occurs which could compromise the shaft's integrity. If defects are discovered, but the Engineer determines that the defects are structurally adequate, the Engineer may accept the shaft in accordance with Subsection 105.03 of the Standard Specifications. Otherwise, repair defective shafts in accordance with Subsection 516.04.C.(8).

Except for the initial shaft, CSL testing is not required on any shaft constructed using the dry method.

(b) ***PIT (Pile Integrity Testing - Pulse Echo)***

Provide Pile Integrity Testing (PIT) only when no other means of testing is readily available and when CSL tubes are not provided. When the Engineer does approve PIT testing, test in accordance with ASTM D5882 and as specified below. After placing concrete in a drilled shaft, wait a minimum of 7 days or ensure the drilled shaft concrete obtains 75% of its design strength prior to the start of the test. Limit PIT to drilled shafts having L/D ratio $\leq$ 30, where L is the length of the drilled shaft and D is the diameter of the drilled shaft. The Engineer will reject the shaft when PIT testing shows voids or discontinuities.

(c) ***Crosshole Sonic Logging (CSL)***

1) *General*

Provide Crosshole Sonic Logging (CSL) in accordance with ASTM D6760 and as specified in the contract or as required by the Engineer. Wait a minimum of three (3) days or four (4) days if retarders are used before starting CSL testing. Provide the Engineer a minimum of three (3) days notice prior to starting the testing.

2) *CSL Test Equipment*

Use CSL test equipment that can perform the following functions:

- display individual CSL records,
- record CSL data,
- analyze receiver responses,
- print logs,
- test in 2 in [50 mm] inside diameter (ID) access tubes,
- generate an ultrasonic voltage pulse to excite the source with a synchronized triggering system to start the recording system,
- measure and record the depths of probes as the time signals are recorded, and
- filter and amplify signals.

3) *CSL Logging Procedures*

Inspect CSL tubes to ensure that probes will freely pass through the entire tube length. Replace tubes with cored holes that restrict the passage of the probes at no expense to the Department. To ensure that cored holes do not damage the reinforcing steel cage, locate cored holes approximately 6" inside the cage. Should the cored holes encounter any voids, poor quality concrete, or any other findings; document the finding and elevations and make this information available to the Engineer.

Test all possible combinations of perimeter tube pairs and diagonal tube pairs. Perform CSL tests with the source and receiver probes in the same horizontal plane. Make CSL measurements at depth intervals of 2 in [50 mm]. Pull the probes, starting from the bottom of the tubes, over a depth-measuring device. Remove slack from the cables before pulling to provide accurate depth measurements. Report indicated defects to the Engineer and conduct further tests to evaluate the extent of the defects.

4) *CSL Testing Results*

In the final report, include the CSL logs with analyses of the initial pulse arrival time versus depth and pulse energy (or amplitude) versus depth. Present a CSL log for each tube pair tested with significant anomalies and/or defects indicated on the logs and discussed in the test report. Unless otherwise specified by the Engineer, accept test results in accordance with Table 516:5. Include the following in the report:

- a summary of the test results that covers drilled shaft identification,
- test date,
- shaft age at time of CSL testing,
- drilled shaft diameter,
- number of CSL tubes tested,
- test length,
- average compression velocity, and
- "waterfall" diagram plotted as a function of time versus depth

In the report include the following items for any significant anomalies and/or defect descriptions:

- the CSL tube number or tube combinations,
- depth below concrete top,
- percent concrete wave velocity reduction, and
- description of anomalies and/or defects.

The Engineer will evaluate the CSL test results and determine the acceptability of the drilled shaft construction in accordance with Table 516:5, "Acceptance of Drilled Shafts."

Table 516:5
Acceptance of Drilled Shafts

Concrete Condition Rating	**Rating Symbol**	**Velocity Reduction**	**Results**
Good	G	0 to 10%	Acceptable Concrete
Questionable	Q	10 to $\leq$ 20%	Minor concrete contamination
Poor	P/D	> 20%	Unacceptable
Water	W	V= 4760 to 5005 ft/sec [1,450 to 1,525 m/sec]	Water or water with gravel, Unacceptable
No Signal	NS	No signal received	* Soil intrusion or tube debonding

* Additional testing is required to determine cause for no signal, soil intrusion into the drilled shaft is unacceptable, debonding leads to false readings.

The percent velocity reduction (VR) based on measured tube spacing is determined using the following equation:

$$VR = (1 - V / V_b) \times 100\%$$

where,

V = theoretical compressional wave velocity in concrete
V_b = baseline velocity (running average of velocity over a 10 ft depth, generally 5 ft above and 5 ft below excluding anomalous zones in the running average; $V_b \geq$ 13,000 ft/s)

(Reference: Publication No. FHWA-NHI-10-016, equation 20-4)

5) *Abandoning CSL Access Tubes*

After completing CSL testing and obtaining the Engineer's approval to continue construction above the shafts, dewater the tubes and use portland cement grout to fill the access tubes in the drilled shafts. Submit the grout mix design and grouting method for the Engineer's approval. Saw cut the top of the CSL tubes even with the top of the drilled shaft.

(d) Core Drilling of Drilled Shaft Concrete

If nondestructive testing indicates voids or discontinuities, or if there are other concerns about a drilled shaft, the Engineer may require full depth coring to determine the soundness of a drilled shaft using continuous coring with a 3" interior diameter core barrel in accordance with ASTM D2113. The Engineer will specify the number, depth, and location of cores.

Submit the methods and equipment for coring and grouting to the Engineer for approval before coring. Place the cores in a commercially available core box and mark the shaft depth at each core recovery interval. Submit the cores and a log for recovered cores.

When the Engineer determines that the quality of the concrete in the shaft, represented by the core samples, is acceptable, construction may proceed. The drilled shaft will be considered defective if the Engineer determines that the quality of the concrete in the core is unacceptable.

(8) Defective Shafts

If the Engineer determines a drilled shaft to be potentially defective based on CSL test results, construction inspection records, and/or structural evaluation, the Contractor may do additional testing and/or investigations. The additional testing may include, but is not limited to crosshole tomography imaging using vertically offset crosshole sonic measurements and recordings to evaluate the extent of anomalous zones, gamma-gamma testing to evaluate differences in relative density surrounding suspected tube debonding, secondary CSL testing 7 to 10 days after the initial test to investigate for improved concrete condition due to delayed curing, or continuous coring of the drilled shaft. All test procedures must be accepted and approved by the Engineer. Regardless of the test results, all additional integrity testing will be done at the Contractor's expense and in accordance with the procedure noted above. No allowance for an increase in contract time or extension of the contract completion date will be made.

Submit a plan for further investigation or remedial action to the Engineer for approval. Provide written procedures or drawings as appropriate to the Engineer for approval showing any modifications to shaft dimensions, plans for remedial actions of the shafts, or proposed testing. When the anomalous zone is near the surface, repair plan may show the mechanical removal and replacement of the concrete. Straddle shafts must be designed by a Professional Engineer registered in Oklahoma and reviewed by the Bridge Engineer. Provide qualifications for subcontractors doing mitigation procedures such as pressure grouting, micro piles, perimeter grouting, or other procedures. At a minimum, provide the following for grouting mitigation: any proposed cutting of high pressure inspection tubes, high pressure washing, water flow testing, flushing (high volume, low pressure washing), down-hole camera observations, grouting procedures, conformance testing, and required documentation. Once the plan has been reviewed and approved by the Engineer, proceed with the remedial action or testing as directed by the Engineer.

The Engineer will make the determination of final shaft acceptance or rejection based on initial and supplemental integrity testing results or repairs done by the Contractor. The Engineer will provide a determination of acceptance of any remedial action proposed by the Contractor. The Engineer may require the complete replacement of the shaft, addition of straddle shafts to compensate for capacity loss, or additional integrity testing including coring. Any remedial action necessary will be done at the Contractor's expense.

516.05 METHOD OF MEASUREMENT

The Engineer will measure the length of *Drilled Shafts* and *Trial Drilled Shafts* from the shaft base to the top of the shaft. The Engineer will base measurements on elevations shown on the plans or approved by the Engineer. The Engineer will not measure corrective work or miscellaneous items, such as, soil samples and rock cores required by the Contract, rebar splices, permanent casings, lost tools and equipment, overreamed excavation, surface excavation and backfill, overflow concrete and concrete placed outside the neat lines of the shaft. If required by the Contract, the Engineer will measure CSL testing per drilled shaft tested. The Engineer will not measure tests for determining the extent of defects. The Engineer will not make reductions in drilled shaft measurements due to obstructions.

516.06 BASIS OF PAYMENT

The Department will pay for each pay item at the contract unit price per the specified pay units as follows:

Pay Item:	**Pay Unit:**
(A) DRILLED SHAFTS	Linear Foot [Meter]
(B) TRIAL DRILLED SHAFTS	Linear Foot [Meter]

(C) CROSSHOLE SONIC LOGGING	Each
(E) OBSTRUCTIONS	Lump Sum
(F) CORE DRILLING	Linear Foot [Meter]

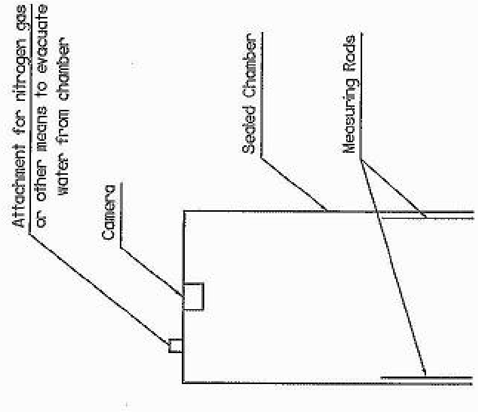
The Department will pay for the following under a Supplemental Agreement:

- Approved obstructions,
- Additional nondestructive testing or core drilling required by the Engineer that reveals no structural defects, and
- Contractor soil sampling or rock coring directed by the Engineer.

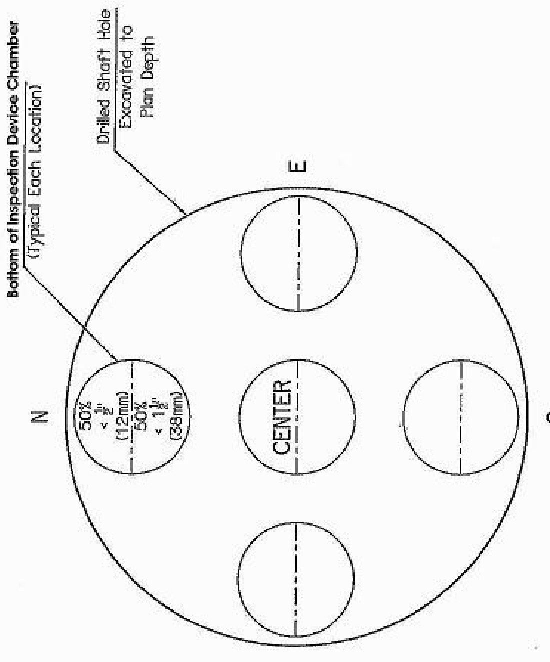
The Department will not pay for the following:

- Nondestructive testing or core drilling directed by the Engineer that reveals structural defects.
- Additional NDT testing or core drilling requested by the Contractor done after a shaft has been rejected regardless of the results,
- CSL tubes (all costs for CSL tubes will be included in price bid for drilled shafts), and
- Shaft inspection devices used to inspect the shaft bottom

ATTACHMENT 516:1



SHAFT INSPECTION DEVICE



NOTE:
Use five (5) drop locations, as noted, to verify bottom of hole has been properly cleaned. Additional drops may be required as directed by the Engineer to verify proper cleaning and acceptance.

SHAFT INSPECTION DEVICE INSPECTION LOCATIONS