5.0 DRILLED SHAFTS

Table of Contents

Appendix

5.0 DRILLED SHAFTS

5.4.1 General

KDOT’s Construction Specifications and current special provisions can be found in section 703. Revisions to the specification address pumpability issues, and take advantage of the new mix design components.

Schedule a meeting prior to beginning drilled shaft construction. Discuss the Contractor's plan including excavation methods, rock socket cleaning methods and placement methods. See the appendix at the end of this chapter. A representative of the State Bridge Office will gladly attend to answer any questions.

Drilled shafts are deep foundation elements. KDOT uses drilled shafts to support bridge and sign structures. Drilled Shafts are considered where footing conditions are such that the structure's loads need to be carried to a rock formation and the following conditions exist:

a. The footing would have short piles (10 feet (3 meters) or less) and it is unlikely any penetration of the piles could be obtained to anchor the ends of the pile without predrilling.

b. The water table is relatively high and thus, to construct a footing on formation, a deep cofferdam would be needed. Previous experience may also indicate a cofferdam would be difficult to seal.

c. A spread footing foundation would be uneconomical because the depth of the rock formation would require an excessive amount of shoring and excavation.

d. There are concerns about pile driving vibrations, noise or overhead clearance.

The capacity of a drilled shaft may be dependent upon end bearing, side friction or a combination of the two. End bearing resistance is achieved by solid and full contact with the bottom of the rock socket. Loose material, left in the bottom of the rock socket from the excavation, or poorly placed concrete, may greatly affect the capacity of the drilled shaft

Drilled shafts are constructed using drilling (excavating) equipment capable of auguring or coring 30" to 120" diameter excavations into soil and rock. After the excavation is completed, a reinforcing cage is placed in the excavation and the excavation is filled with high slump concrete.

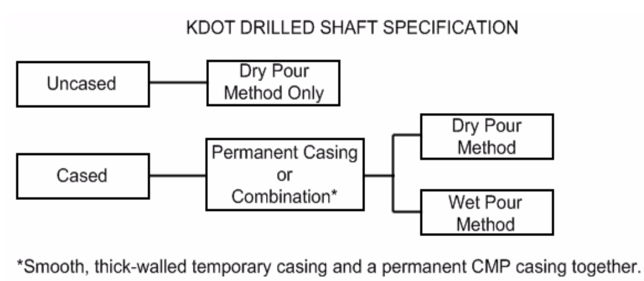
Drilled shafts are excavated using either cased or uncased methods. If the excavation will stay 'open' without caving, as when drilling through cohesive materials such as stiff clay, shale or limestone, then generally no casing is required. However, if soils are prone to caving, casings are used to support the sides of the excavation. Sometimes, even in 'solid material', a surface casing is used to prevent caving at the top of the excavation. Temporary casings are heavy-walled pipes that are usually driven, screwed or vibrated into the earth. Drilling may occur either before or after the casing is in place.

Sometimes the plans call for a permanent casing to be installed. Permanent casing is usually corrugated metal pipe (CMP) having the same nominal diameter as the completed shaft. The permanent casing becomes a form to contain the concrete between the top of the shaft and the rock socket. A Bentonite or Polymer slurry may also be used to keep the excavation open or to assist in the advancement of a temporary casing. The use of these materials requires special care in mixing, removal, and recycling. Currently, KDOT allows the use of slurries or drilling compounds above the rock socket only. It is important to keep slurries and drilling fluids out of the rock socket.

Drilled shafts are either considered to be "wet" or "dry". A "dry" shaft is defined as a drilled shaft in which both of the following conditions are met:

- Inflow of water does not fill the excavation more than 4" in depth in a 5 minute period, and;
- The shaft can be dewatered with a 2" pump, and no more than 2" of water is in the excavation when concrete is placed.

The location of the water table and the type of materials that make up the underlying geology control whether the excavation is considered a "wet" shaft or a "dry" shaft. For wet shafts, the concrete must be placed through a tremie or pump extension so that the water does not mix with the concrete as it is being placed in the excavation.



The previous graphic is a summary of the general type of excavations and methods of concrete placement; these are controlled both by plan call-out or in-field conditions.

Reinforcing steel (rebar) is tied into cages on the ground according to the plans and carefully lifted and lowered into the excavation before the concrete placement begins. KDOT requires that Cross-Sonic Logging (CSL) pipes be installed in every drilled shaft. Therefore, the cage will have at least three steel pipes tied securely to the inside of the cage. The pipes are to be evenly spaced throughout the cage, filled with potable water and sealed prior to placing concrete. The pipes provide access, for Cross Hole Sonic Logging (CSL), to the bottom of the shaft.

5.4.2 Bid Items:

The following bid items include all labor, material and equipment needed and is full compensation for the work.

Drilled Shaft: The bid item "Drilled Shaft" addresses excavation, reinforcing steel, and concrete placement. The Engineer will measure accepted drilled shafts by the linear foot measured to the nearest 0.01 lin. ft. and paid to the nearest 0.1 lin. ft. from the bottom of the rock socket to the top of the completed drilled shaft. Unless the overall length of a drilled shaft changes by more than 20 percent, the Engineer will not consider a request for additional compensation.

Permanent Casing: The "set price" is a measure of the length of the casing. Measure the casing only when the site requires it (caving or excess water) and if it is not called for in the plans. Surface casing used at the Contractor's discretion is not paid for under this item. Temporary casing is a Contractor's tool and is not paid for.

Sonic Test (Drilled Shaft) (set price): The Engineer will measure each completed and accepted sonic test, at Contract locations and added locations, per shaft (i.e. sonic logging between all possible combinations of pipes represents a single sonic test). The first set of sonic tests will be paid for at the contract price. If a problem in the shaft is identified, the Contractor will be required to retrieve core samples. If the core samples show sound concrete, the cores will be measured and paid for as "Extra Work" as in Division 100. If the core contains material other than sound concrete, the core and the repairs will not be measured. The Contractor will suggest with sealed plans, a proposal for the repair of the shaft. Core holes and CSL pipes are to be pressure grouted before constructing the next phase of the substructure (the column or abutment). No payment will be made for subsequent sonic testing required to verify that the repairs were successful.

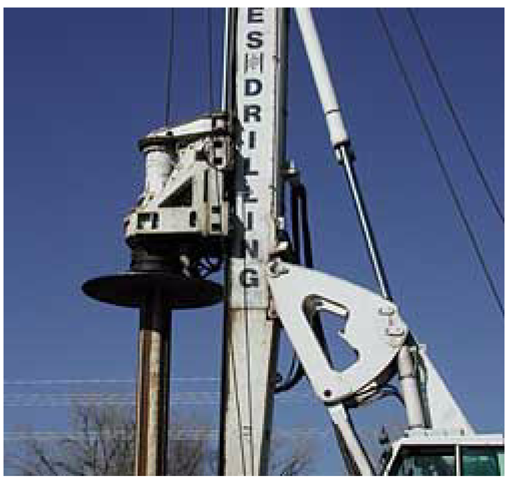
Core Hole (Investigative): This bid item addresses the exploration of the geologic formation of the shaft rock socket. The recovery, labeling and treatment of the core sample will follow standard Kansas Department of Transportation (KDOT) practices. The Contractor will maintain the core at the site for review by the regional geologist. The core material (10 feet) will be placed in cardboard core boxes in descending order and labeled. This investigation is done before the drilled shaft is constructed and is located (surveyed) to the same spot as the production shaft.

5.4.3 Equipment:

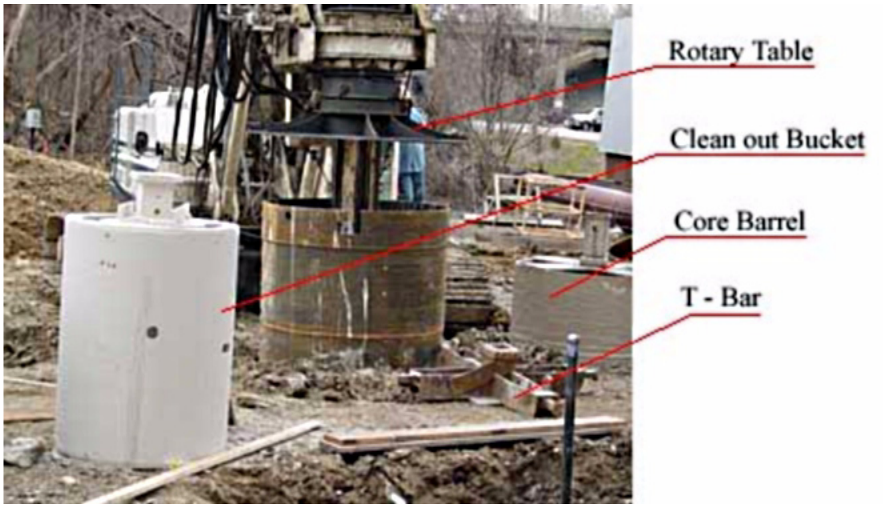
The Contractor is responsible for supplying all the materials, tools, and labor to install the shaft. The types of materials being drilled drive the Contractor's choice of tools to use. As such, there are several tools which will aid in the forming of the excavation and placement of the concrete. The main piece of equipment is the rotary table. The rotary table is basically a machine which transmits energy from a power unit to rotate the Kelly bar. The rotary table may be attached to a crane, or built onto a truck or modified excavator. Many different drilling attachments may be attached to the Kelly bar, such as earth augers, rock augers, rock bits, core barrels, clean out buckets and t-bars.

Rock Auger

Modified Excavator Drill Rig



Rotary Table



Clean-out Bucket , Rotary Table, T-bar & Core Barrel.

Core Barrel

5.4.4 Materials:

A slurry is sometimes used during drilling. This material is a bentonite or polymer powder that is added to clean water to create a dense fluid. The purpose of this fluid is to support the walls of the excavation. It is mixed thoroughly before being used in the excavation. The slurry is never mixed in the excavation, but only in tanks, and pumped, as it is needed. This will create pressure on the excavation walls preventing caving. Slurries are also effective in stopping water from flowing into the excavation. Bentonite solution should be mixed 24 hours prior to use. Polymers may be used immediately after thorough mixing. Currently, KDOT does not allow slurry in the rock socket because these fluids may reduce skin friction.

A rebar cage is constructed of longitudinal bars and tie bars bent into rings or continuous spirals. Spacers tied to the cage maintain the clearance between the wall of the shaft or rock socket and the rebar cage. These spacers are to be non-metallic circular wheels that roll along the side of the excavation during the installation of the cage. It may be necessary for the contractor to use additional tie wire on these wheels to keep them intact. Bar chairs are not an acceptable substitution because they generally are not rigid enough to maintain proper spacing between the reinforcing cage and the side of the shaft. And they create a conduit for corrosion between the side of the shaft and the reinforcing cage.

CSL pipes are to be 2" Schedule 40 steel pipe with watertight caps and joints. These pipes are tied to the inside of the rebar cage. They are then filled with potable water and sealed prior to concrete placement. The water is necessary to keep the pipes from debonding from the shaft concrete and thus invalidating the CSL test. It is important for the water to be clean so that sediments do not settle out to the bottom and prevent the CSL testing probes from reaching the bottom of the shaft.

The concrete used in drilled shafts must have a high slump and small aggregate size. This will allow the concrete flow through the rebar cage, fill voids and displace water. A slump of 8" ± 1" is recommended for all drilled shafts. The Contractor should not vibrate drilled shaft concrete because of the possibility of segregating the aggregates. Due to the great placement times required in large diameter shafts, the Contractor will often use set retarders or plastisizers to slow the curing process. The addition of approved (Type C) fly ash is also beneficial in maintaining workability.

Clean granular material is used to back-fill the space between the permanent and temporary casing (annular space) for excavations where scour or exposing the founding material to moisture is not considered a problem. However, pressure grouting will be used on some projects up to the top of the shaft; in this case, the plans will specify the material to be used for backfilling and up to what elevation. If not stated otherwise in the plans, it is assumed that granular material may be used.

Grout is used for both core holes and CSL pipes. When a hole or space is to be grouted, a tube (or pipe) is placed in the hole or space so that grout is discharged at the bottom of the hole. This way the grout pushes unwanted materials to the top. If the contractor can expel the water from the CSL pipes so that there is less than 2 feet left in the pipe, he may pour the grout in from the top. The grout materials used for core holes or CSL pipes will be from KDOT's pre-qualified list and mixed according to the manufacturer's specifications. The Contractor will provide a grout or flowable fill for backfilling the annular void space between the temporary and permanent casing that has 28 day strength of 1000 psi.

5.4.5 Investigative Core Hole:

At least one investigative core will almost always be specified in the plans. The purpose of this core is to determine the geology at the exact location of the shaft. Results of the core may lead to lowering or raising the shaft tip elevation. In general, the core will be recovered from 4’-0" above the plan tip elevation to 6’-0" below the plan tip elevation. The Engineer may choose to have a larger core sample retrieved. The sample is to be properly stored on site for use by the Engineer. Contact the regional geologist prior to performing investigative coring so that a representative may be on site at the time the coring is performed.

5.4.6 Drilling (Excavation):

The shaft is to be located laterally within 2 inches of the plan location. Unless shown otherwise in the plans the shaft must be plumb to within 1 inch in 10 feet of shaft length, not to exceed 6 inches. The bottom of the shaft should be as flat as possible.

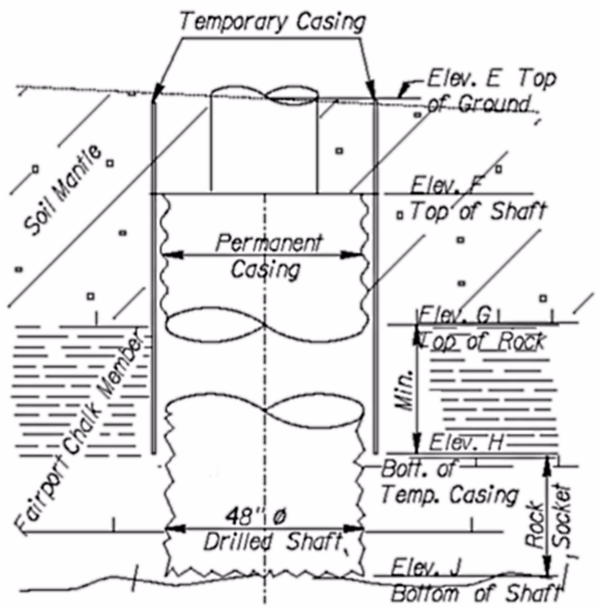
The method of construction will be called out in the plans as cased or uncased. This is based on borings from the field investigations. If the plans do not specify casing, and the investigative core shows that overburden material differs from the geology report, the cased method may need to be used. If the water in-flow cannot be stopped, as in the case of a "wet" shaft, a casing is required. Drilling will begin only after adjacent grading at the pier location is completed. The Contractor will use whatever means he deems reasonable to complete the required shaft to a length determined by the contract plans or by additional field investigation. This will include, but not be limited to; augers, core tools, alignment tools, casing tools and vibratory hammers. Blasting is not an option. As the shaft progresses, the inspector should log the materials encountered along with seepage and caving elevations.

If the shaft is to be cased, the contractor will seat either a permanent or temporary casing into the top of the rock formation. This is done to prevent loose material from caving into the rock socket.

5.4.7 Rock Socket:

The rock socket is that portion of the shaft between the bottom of the lowest casing to the bottom of the shaft. A minimum uncased rock socket length will be specified on the plans. This length is measured from the bottom of the lowest casing down to the bottom of the excavation. Often, a Contractor will lower the casing to try to stop the inflow of water. The Contractor might also need to lower the casing if the top of rock is not properly located on the plans. In either case, this will necessitate the lowering of the tip elevation to maintain the minimum rock socket length. Before this is attempted, the State Bridge Office and the Regional Geologist should be notified for approval. It is critical to provide the specified minimum rock socket length because the designer may be relying on that surface area for a portion of the load capacity of the shaft.

The socket material is usually removed with a rock auger or core barrel tool. The core barrel cuts a thin amount of material from the perimeter of the socket. Then the plug or core is broken loose from the bottom. Contractors have many ingenious ways to accomplish this. The use of explosives is not allowed without express written approval from the State Bridge Office. After the socket is broken loose from the bottom, the Contractor has the difficult task of removing the core. Again, there are a variety of ways to do this; methods range from chains and cables to special tools attached to the core barrel. The bottom of the rock socket is to be level to within 3/8" per foot.



Rock Socket Cores

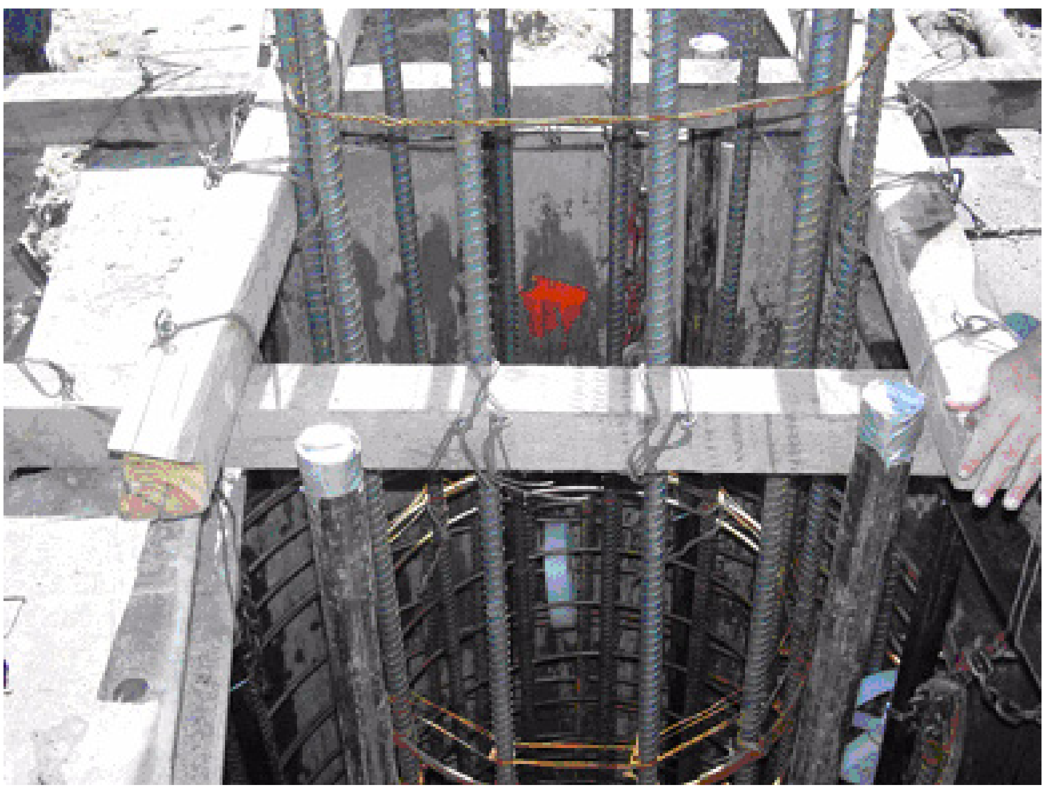
5.4.8 Reinforcement:

The drilled shaft reinforcement is tied within either a spiral or hoops. Spiral reinforcement is a continuous coil of smooth bar stock pulled to the pitch shown on the plans then tied to the longitudinal bars. A tied cage has (#3, #4 or #5 (#10, #13, or #16)) rebar bent into rings. The rings are then tied to the longitudinal bars at the spacing called out in the plans. Sometimes the Contractor will use wires or single bars across the cage to prevent it from racking or twisting. As the rebar cage is being placed in the excavation, any temporary cross tied bars or wire that will get in the way of the flow of concrete or tremie should be removed.

The placement and handling of the reinforcing cage should be done so that the bars are not displaced or overstressed. The use of spreaders, stiffbacks, and multiple pick points is required on all but very short drilled shafts. These protect the rebar cage from bending excessively.

The top of the drilled shaft is connected to the bottom of the column. The shaft reinforcement must extend into the column by the splice length shown in the plans. This is done either by extending the shaft steel (if the shaft is the same size as the column) or by inserting a splice or dowel bar that extends into the shaft and into the column. The graphic below shows this splice rebar cage which has spiral reinforcement and longitudinal bars. It is bad construction practice to "stab" reinforcing into wet concrete. Therefore, it is required that the splice bars be supported in place prior to concrete placement. This cage must be supported in a plumb position until the concrete is fully cured. If the longitudinal bars extending above the shaft are very long, adding temporary hoops will help keep these bars in proper position and ease construction.

It is important that the top of the reinforcing cage is at the proper elevation. If for some reason the bottom of the shaft elevation is lower than the plan elevation it may be necessary to extend the length of the cage. If the distance is less than one foot, the Contractor should hang the cage or support it in such a manner so that the extra clearance is at the bottom of the shaft. If the distance is greater than one foot contact the State Bridge Office for guidance.



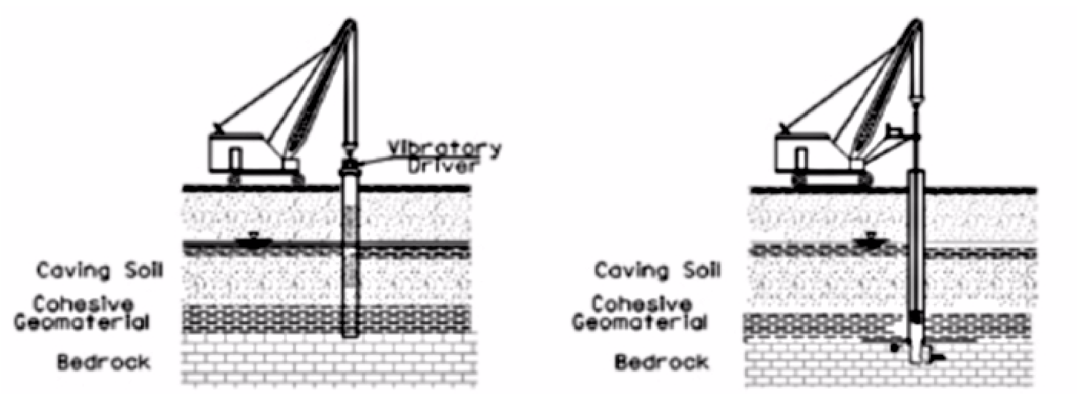
Properly supported column bars

5.4.9 Casing:

The casing may be either permanent or permanent used in conjunction with temporary casing depending on the design plans and/or the site conditions. Temporary casing are simply heavy-walled sections of pipe that are vibrated, driven or screwed into the ground to prevent the sides of the open excavation from caving in. This pipe sometimes has cutting teeth on the bottom to help seat the casing into the bedrock. As the name implies, permanent casing is left in the excavation while temporary casing is removed.

Temporary Casing:

In sandy conditions it is typical to vibrate the temporary casing to full length and seat it into the bedrock then excavate the overburden material.

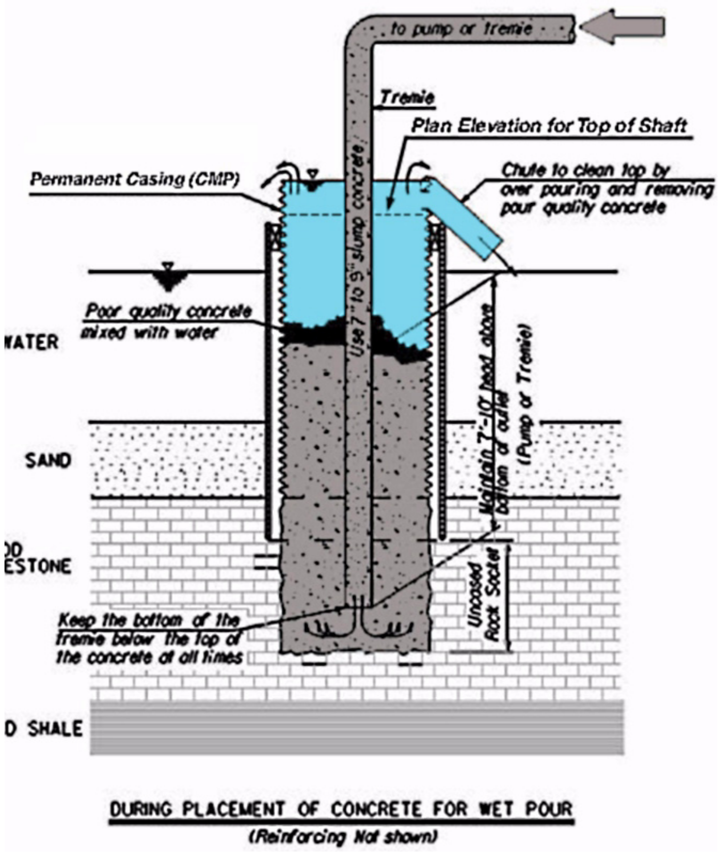


Permanent Casing:

As stated earlier, the plans may call for, or the site conditions may dictate, the use of a permanent casing. Permanent casing (usually corrugated metal pipe (CMP)) acts as a form liner for the shaft and stays in place after the concrete is poured. This form is usually anchored at the bottom by 'screwing' it into the top of a relatively soft formation. As shown in the graphic below, the Contractor may use burlap tied to the bottom of the permanent casing as a seal between the casing and the rock socket. Sealing the permanent casing within the rock socket is important to the Contractor because it reduces problems with removal of the temporary casing. This is sometimes achieved by adding about 2 feet of sand in the annular space above the burlap after the permanent casing is placed in the excavation. This seal can be checked by rodding or using a weighted tape to sound the bottom of the socket after the sand is placed. Any sand which falls into the bottom of the shaft must be cleaned out prior to placing the concrete. If sand is detected in the previously clean socket, then the casing did not seal. If the Contractor cannot create a seal between the CMP and the rock socket, concrete may be forced up between the casings. This leak may prevent the Contractor from retrieving the Temporary Casing.

Note: CMP with burlap to anchor and seal the bottom of the shaft in rock socket and prevent concrete leaking between the casing.

The top of permanent casing is usually blocked (wooden blocks are common) against the temporary casing so it will not move during concrete placement. If the permanent casing extends above the temporary casing and the shaft must be poured using wet pour techniques, a slot will be cut into the side of the permanent casing at the cutoff elevation with a chute or ramp attached so that it can be overfilled. The chute allows over-pumped concrete to be pumped out of the shaft without filling the annular space between the permanent and temporary casings. If the annular space fills up with concrete, the Contractor may not be able to retrieve the temporary casing.



Overfilling is required to remove any ground water mixed with concrete scum or debris. Be sure that the Contractor is aware of this requirement, as any spoils that overtop the CMP will fill the space between the two casings (annular space). For wet pours in addition to normal concrete cylinder sampling requirements, take one set of cylinders from the top of the shaft after completing over-pumping to verify a compressive strength of 3,000 psi before proceeding with subsequent substructure (i.e. columns, abutments, etc.) construction.

After placing concrete in the permanent casing, the Contractor may want to break the seal on the temporary casing by raising it approximately six inches above the top of the bedrock formation and holding it. This is done to insure recovery of the temporary casing and is not a problem as long as the concrete is very 'green'. 'Green' concrete for a shaft may vary due to additives such as set retarders and plasticizers. Generally, concrete without additives less than 4 hours old is considered 'green' concrete. Sometimes the casing "jumps" during this pulling process. With one pull the casing may be moved more than the prescribed amount. If this happens the Contractor should stop pulling and secure the casing until time for removal as described below.

Before the Contractor is allowed to pull the temporary casing past this initial 'green' lift, the drilled shaft concrete must be allowed to cure for a minimum of 24 hours after the completion of concrete placement and must have attained a compressive strength of at least 1800 psi. Or, provided the concrete used in the shaft has demonstrated satisfactory results from previous compressive strength tests, the Engineer will allow extraction of the temporary casing to proceed when the shaft has cured 72 hours after completion of the concrete placement.

After confirmation of the test results the Contractor will backfill the annular space with material specified in the plans. If the annular space is to be filled with grout, the Contractor should use a tremie that extends to the bottom of the space. A level head should be maintained within the space (within 2 shaft diameters). The temporary casing may be pulled after the grout has filled the space to the height of the shaft.

An alternate method is to grout the annular space between the temporary and permanent casing before the shaft is poured. This allows the contractor to retrieve the temporary casing in a timelier manner. The Contractor fills the annular space with grout; then, while the grout is still fluid, he pulls the temporary casing.

There are two details which must be addressed when using this method. The first is that the Contractor must use great care to support the permanent casing laterally during grouting. The grout level must remain uniform around the casing as not to force it out of plumb during the grouting operation. If the casing is moved so that it is no longer plumb it will be nearly impossible to plumb it back into place. The Contractor would need to remove the permanent casing and start over. After the annular space is filled to the top of the casing, but before it sets up, the Contractor completely removes the temporary casing. Once again, care must be taken not to misalign the permanent casing. The second detail is that the Contractor must allow the grout to cure before he places the reinforcing steel in the shaft.

5.4.10 Concrete Placement:

General Methods:
The method used to place the concrete falls into one of two categories, wet pour or dry pour. The inflow of water dictates the method to be used to place the concrete in the shaft. As stated above, a dry pour may be performed if the Contractor is able to dewater the excavation using a 2" (50 mm) pump to a depth of 2" before the concrete is to be placed, and the inflow of water is less than 4" in 5 minutes. If both of these criteria are not met then the wet pour method will be used. A wet pour requires the use of a permanent casing.

5.4.10.1 Cleanliness:

The condition at the bottom of the excavation may affect the entire bridge structure. If the bottom of the socket contains sediments, full bearing will not be achieved. Excessive sediments may cause settlement of the shaft under the full load of the structure, which causes distress in the rest of the structure. The Contractor will use several methods to clean the sediment from the bottom of the excavation including mucker buckets, airlifts, and special coring tools that have gates that can be opened and closed. Just prior to concrete placement, the Engineer will inspect the bottom of the socket. For a dry excavation the inspection is simply a visual check using mirrors or lights from the surface. This is not possible in the case of a wet excavation. Within the excavation, large amounts of sediments may be suspended in the water from the cuttings of the socket. The Contractor should let the excavation sit undisturbed until the sediments have settled out and use a mucker bucket or similar tool to remove the sediment. Probing the bottom of the excavation with a weighted tape or rod is an effective method of checking wet excavations for cleanliness.

Bottom conditions may be inferred by looking at the return from an airlift. Airlift devices vary in type, but generally consist of a pipe with a high pressure airline. The high pressure line directs air into the bottom of the pipe. The movement of the air up through the pipe causes the pipe to act as a vacuum, forcing solids and liquids from within the excavation out the end of the pipe. The bottom is to be cleaned so that 3/4 of the bottom of the socket will have less than 1/2" of sediment.

Airlif

5.4.10.2 Placement:

Concrete placement is performed using either 'wet' pour methods or 'dry' pour methods. 'Dry' pour methods may only be used when the conditions meet the requirements listed above. For a dry pour with a casing, the Contractor may use a centering chute or tube and free fall the concrete down to the bottom of the shaft. The Contractor will use a centering device at least 8' long to reduce the amount of concrete impacting the side of the excavation or the reinforcing steel. For an uncased excavation, the free fall is limited to 5'. It may be necessary to overpump a shaft when using the 'Dry' pour method to dispel any poor concrete or debris. Usually this is not an issue.

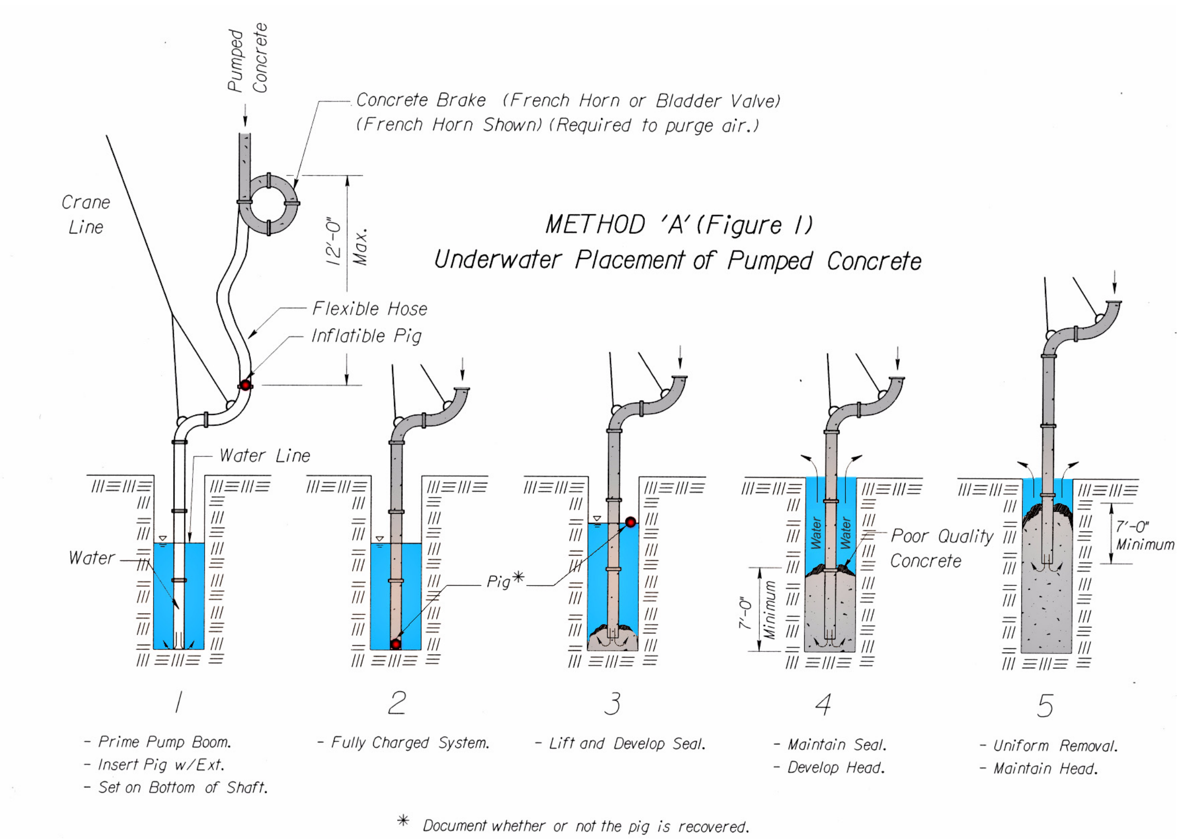
Underwater concrete placement requires experience, skill and special equipment. Before placing concrete by the wet pour method, it is imperative that the water level inside the excavation is equal to or higher than the surrounding ground water or river and that is static, i.e. "not moving".

Some Contractors will pump water into the permanent casing and fill it to the top. This additional pressure head insures that the flow of water is away from the shaft.

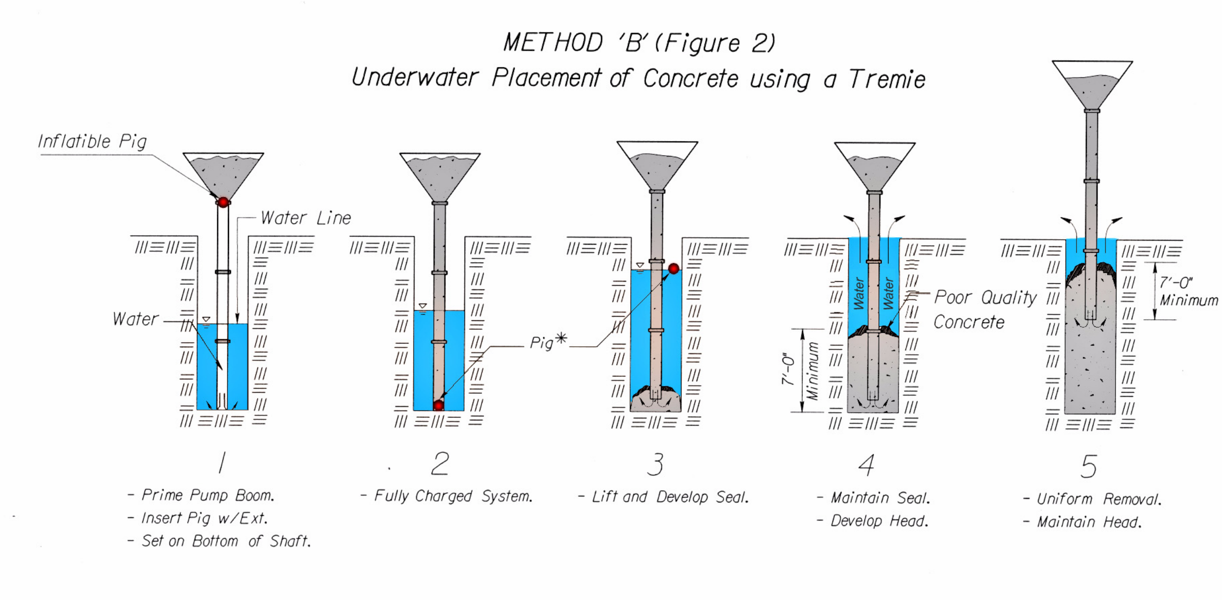
The concreting operation is begun by inserting a sealed pipe into the excavation and charging, (i.e."filling") it with concrete and then releaseing the concrete into the excavation. The most important thing is to not let concrete mix with water or sediments. Trapped air in the pump line or tremie will cause mixing of the concrete and ground water. Letting concrete fall through any water or debris may create trapped areas within the shaft that are weak and will show up as flaws in the CSL testing equipment.

Once concrete placement begins, the end of the pipe must be kept well below the newly placed concrete surface. A 7' to 10' head of concrete must be maintained at all times. This should be monitored using a weighted tape and a marked tremie pipe. In addition, it is good practice to know the volume placed per stroke of the concrete pump. Knowing this volume, it is possible to count the strokes of the pump and chart the theoretical depth of the placed concrete vs. strokes. For an example of this procedure, see Section 5.4.10.3 Concrete Volume, below. Once concrete placement begins, a continuous flow is necessary until the work is completed. A concrete seal that is monolithic and homogeneous must be maintained. When the concrete reaches the top of the shaft, placement should continue to displace all water, debris, and unsound concrete. If a tremie is used to place the concrete, an inflatable pig with a diameter at least 110% of the diameter of the tremie must be used. If a sealed line connected to a pump is used, a commercially available dense foam pig must be used.

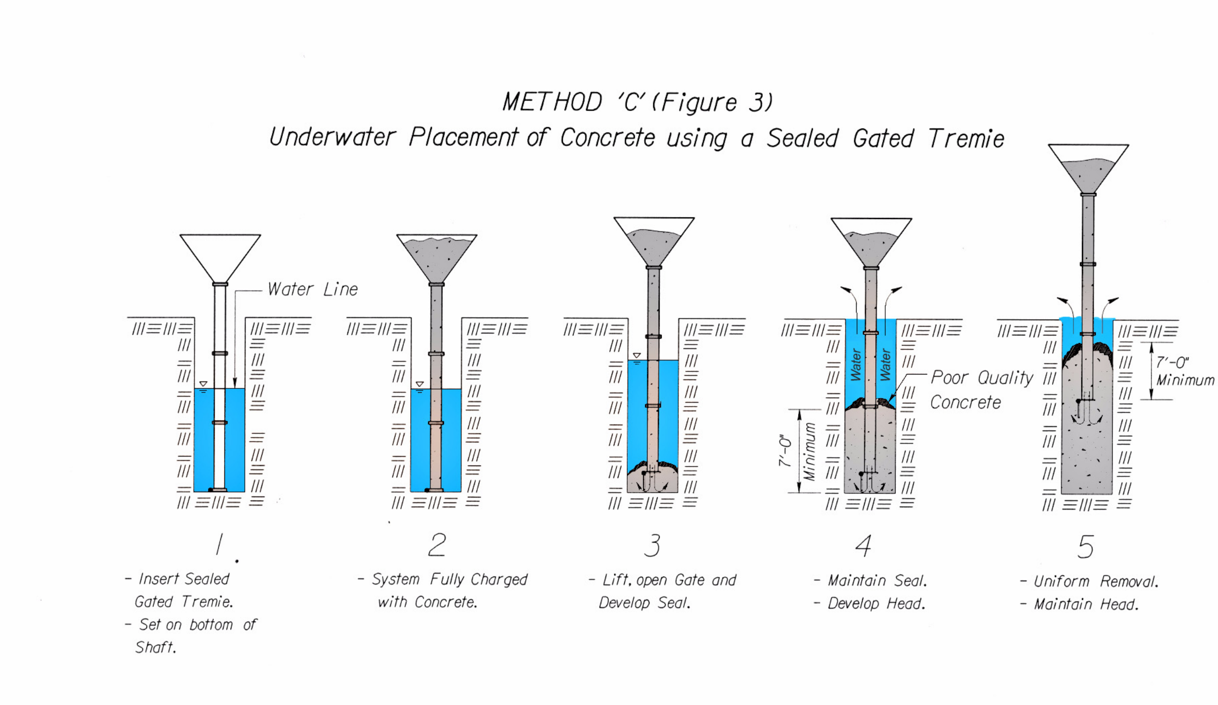
If the Contractor does not have the equipment listed above and is not prepared to properly place shaft concrete, do NOT let placement begin. The consequences of a poorly placed drilled shaft are much greater than the consequences of delaying a pour.



Method 'A' (Figure 1) uses a pump to place concrete directly into the shaft by means of an extension pipe. A "Concrete Brake" is required near the top of the extension pipe. This allows a head of concrete to be built up in the pump boom, and reduces the air pumped into shaft. The brake will consist of a bladder valve or French horn. The Contractor will insure that concrete completely fills the boom without air gaps. A commercially available 'pig' will be installed in the top of the extension pipe connection between the boom and the extension pipe. The pig separates the concrete and the ground water, which prevents the concrete from washing. This 'pig' is essentially a cylindrical piece of dense foam, which is larger than the diameter of the extension pipe. When mashed into the pipe, it allows the concrete to push out the water in the pipe without mixing.

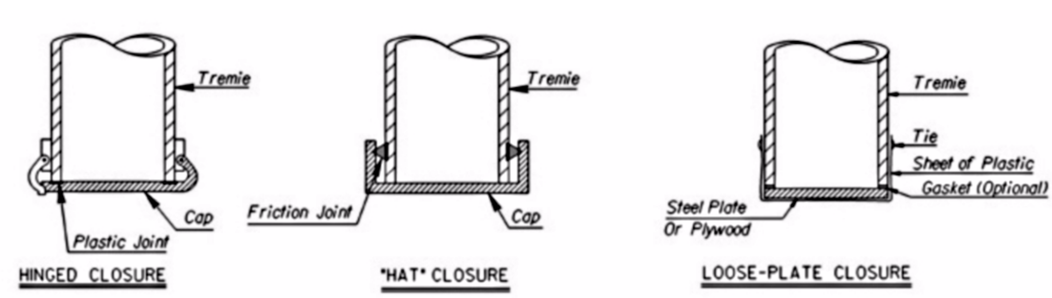


Method 'B' (Figure 2) uses a tremie pipe, which is lowered to the bottom of the drilled shaft and allowed to fill with water. An inflatable 'pig' will be installed in the top of the tremie pipe. The 'pig' must form a tight seal within the tremie. The Contractor will fill the tremie completely, and forceing the 'pig' to the bottom of the drilled shaft and thus forcing the water out of tremie providing separation between the concrete and the ground water. The Contractor will then lift the full tremie one tremie diameter to start the flow and seal the discharge end of the tremie.



Method 'C' (Figure 3) uses a tremie pipe with a seal on the end, which is lowered into the drilled shaft. The seal prevents water from entering the pipe and mixing with the concrete. The tremie may have a vent tube to reduce the possibility of an air bubble being trapped in the tremie. The tremie is charged completely with concrete and then lifted off the bottom one tremie diameter to start the flow of concrete into the shaft.

Shown below are the methods of sealing the bottom of the tremie pipe, for wet pours.



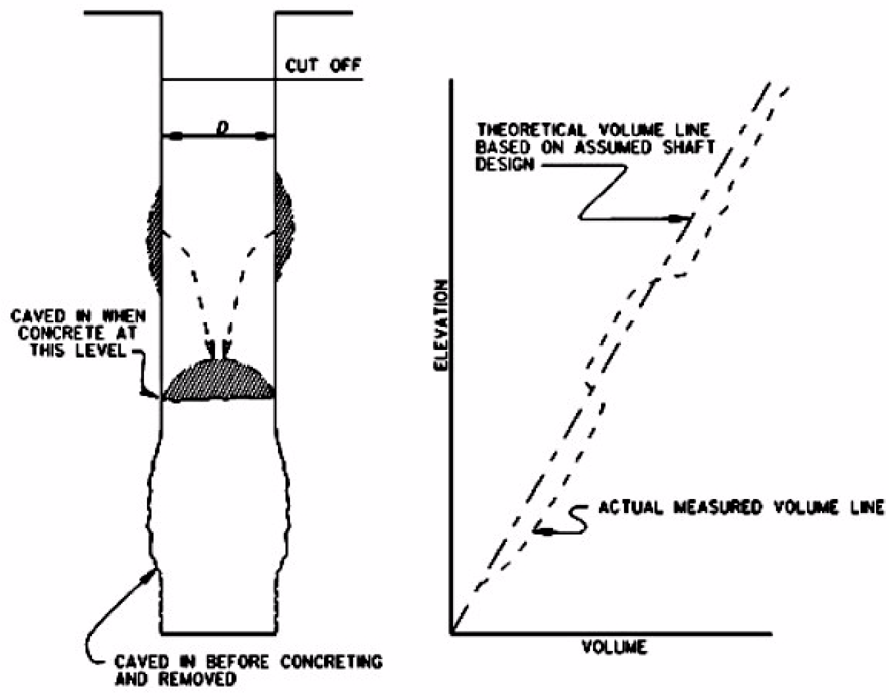
The Contractor may have problems breaking the seal on the tremie and letting the concrete flow into the excavation. The cause may be unmixed clumps of concrete from the batch plant or inadequate slump. The concrete should be passed through a grate to prevent unmixed concrete chunks from entering the drilled shaft or the tremie. Do not allow the Contractor to "yo-yo" (move up and down rapidly), the tremie pipe in an effort to release the cap. This may cause water to mix with the concrete and prevent a good head from being developed outside the tremie.

5.4.10.3 Concrete Volume:

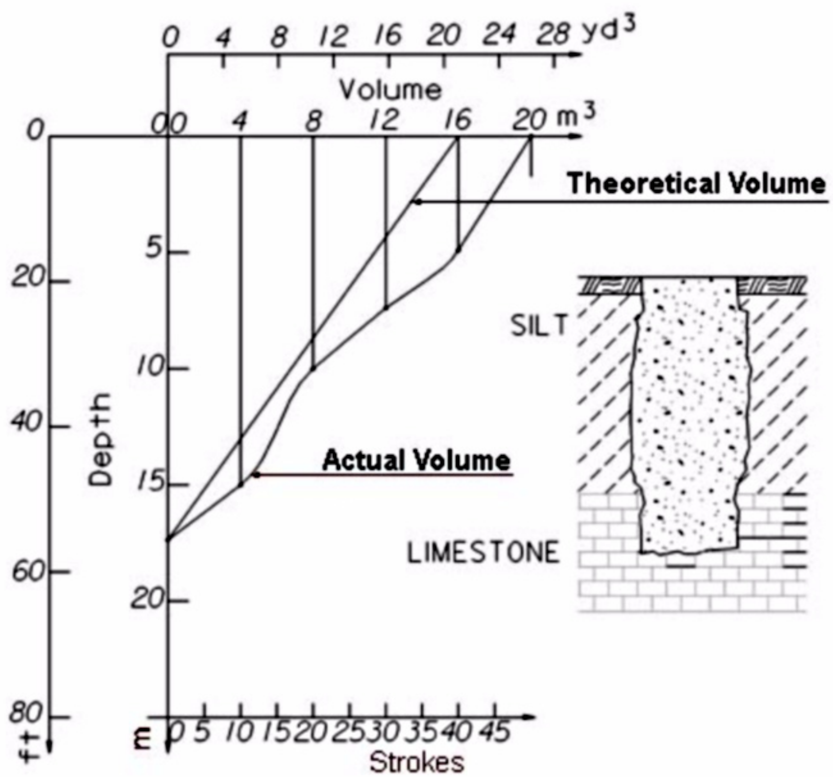
The following method may be used in conjunction with a weighted tape to determine the depth of concrete in the shaft.

The volume of concrete required to fill the shaft must be known prior to beginning placement. As the concrete is being placed, the volume verses the depth can be plotted and compared to the theoretical (the amount that should be placed). To do this, the pump used to place concrete in the shaft must be calibrated before concreting begins. To calibrate the pump, concrete is discharged into a barrel or bucket using a number of strokes (say 5). Calculate the volume of concrete discharged into the barrel. This number (vol./stroke) is used to determine how many strokes are required to achieve a 'good head of concrete' (7'-0" - 10’-0") in the shaft. This ’number of strokes’ method only works for a 'perfect' (perfectly round) shaft or 'theoretical' shaft; the actual shaft may be different.

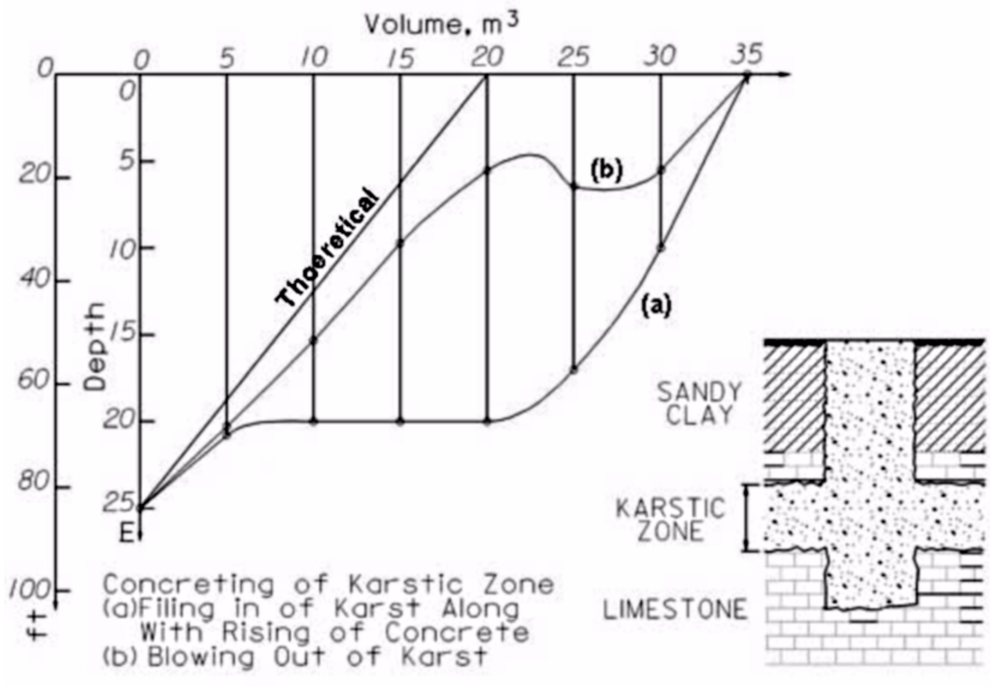
(USC) Example of pump volume field calculation:
Pump 5 strokes into to empty drum with a 2'-0" diameter. Assume the depth of concrete is 2'-9".
Volume of Concrete / Stroke = (Area of barrel x Depth of Concrete) / 5
Area of Barrel = pi x r^2 = 3.1415 x $(1'\text{-}0")^2$ = 3.142 ft^2
Volume/Stroke = (3.142 ft^2 x 2'-9") / 5 = 1.728 ft^3 / Stroke
For example, a 5'-0" diameter shaft or socket requires: 19.63 ft^3 /(1.728 ft^3 / Stroke) = 11.4 strokes to provide one foot of head in the shaft. (or 57 strokes to achieve a 5-ft head).



The concrete volume in a shaft being placed by the use of a tremie or drop chute is determined as a per truck or per bucket volume. Count the actual number of trucks used and compare to the amount that should fill the excavation. For both methods of concrete placement, pumping or chute, the Contractor is required to measure the concrete depth. To do this the Contractor must, with a weighted tape, be constantly determining the distance to the top of the newly placed concrete. The measured distance is subtracted from the total shaft length. It is this concrete depth and stroke count information that is plotted with the actual volume. This is all plotted on the theoretical volume verses depth chart. The difference between the theoretical and the actual volumes may describe the condition of soft silt or voids being filled along the shaft length. Also, the integrity of the drilled shaft can be implied from the concreting curves. Flaw locations or sloughed side walls show up as the portion of the curve that is above the line.



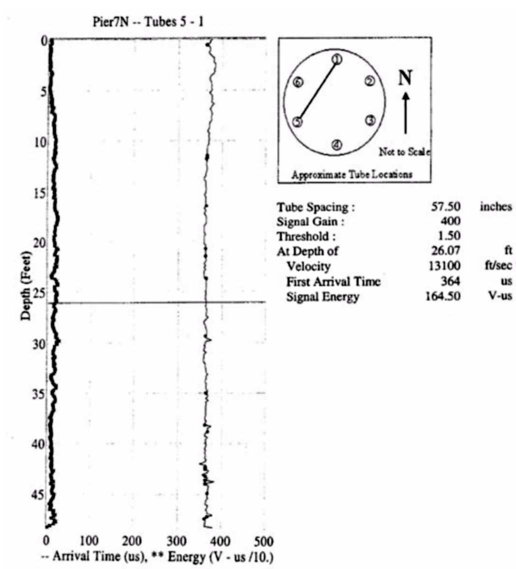
Shafts with soft sidewalls may bulge slightly, requiring more concrete to be used.



The above two graphics show the effects of subsurface conditions that may change the volume of concrete that is placed in the shaft. The above shows soft silts and karstic zones which require the actual concrete volume to be greater than the theoretical calculated volume.

5.4.11 Cross Hole Sonic Logging:

Cross-hole sonic logging (CSL) is an integrity test that uses variations in sound wave strength and speed to determine flaws in the concrete within the shaft. The operation uses the pipes attached to the inside of the rebar cage. It is critical (for the tests to be accurate), that the pipes be full of water from the time of concrete placement until the time of testing. Testing companies are hired by the Contractor and report to both the Inspector and Contractor at the time of the test. If the test results show potential problems, shaft coring may be used to verify voids or poor quality concrete. A formal report, signed by a Professional Engineer, will be provided to the Field Engineer, no later than one week after the test is performed. If the report shows a velocity drop of less than 10% no action needs to be taken. If the report shows a drop in velocity of between 10 and 15%, consult with KDOT Geology; depending on the results of the CSL testing, coring may be required. If the CSL results show a drop in velocity in excess of 15%, consult with KDOT Geology; coring will be required in this case. The Contractor should not be allowed to grout the sonic tubes until the results are approved by the Chief Geologist.
The tests are performed on all pairs of pipes within the shaft. The Inspector or Field Engineer has the option to require sonic testing at locations he designates (e.g. wet pours).



In performing the sonic logging, the probes are lowered into the CSL pipes and then raised simultaneously using a tripod at a rate not to exceed 1'-0" per second. Any sudden lengthening of the arrival time and a simultaneous drop in the energy may be an indication of poor quality concrete. This is where the concrete curves discussed above may be useful in identifying any areas in the shaft that could have problems.

If anomalies occur during testing, KDOT will require coring the shaft within the region of the anomaly detected by CSL testing. Inferences of concrete properties, including strength, from a reduced signal strength, or signal arrival times, will not be allowed. If anomalies are detected by CSL testing, core extraction and testing is the only method accepted by KDOT's Bridge Office to determine the drilled shaft's concrete properties.

5.4.12 DRILLED SHAFT REPAIR (Repair of voids)

TESTING

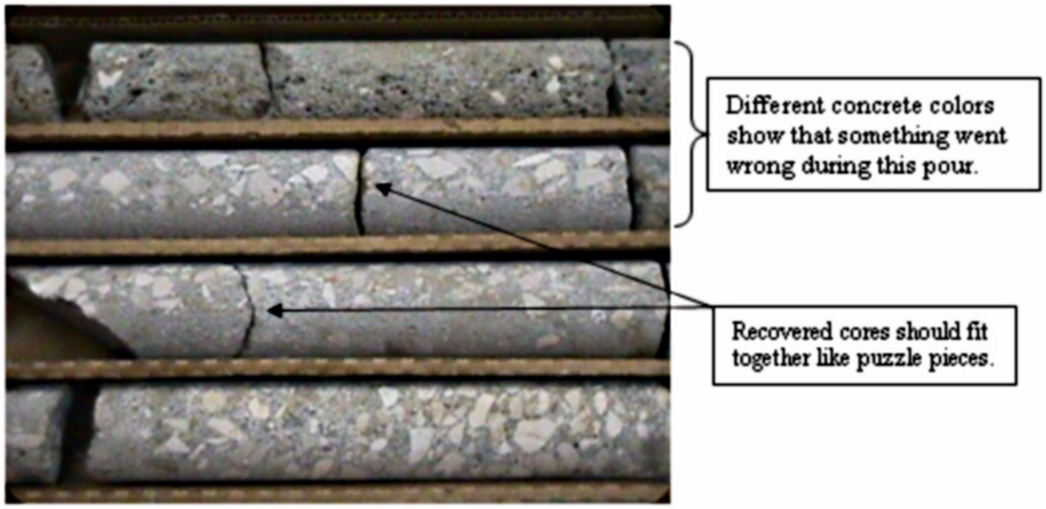
All possible combinations of CSL tests will be performed. If CSL testing has verified that there is an anomaly within the drilled shaft, review with the testing company the extent, nature and potential cause of the anomaly. The testing company will recommend the diameter, depth and location of concrete core drilling that must be performed to confirm the anomalous zone(s) identified in the CSL survey. The KDOT Regional Geology Office and State Bridge Office will make the final decision about core drilling size and location. DO NOT GROUT THE CSL TUBES UNTIL THE REPAIR IS COMPLETE.

CORE DRILLING

Core the shaft in the location(s) determined by the CSL testing company. Begin coring only after receiving approval by KDOT representatives.

The core location will be inside the drilled shaft reinforcement. If the core location is within three longitudinal bar diameters of the reinforcing steel, use a pacometer to verify that the drilled shaft reinforcing steel will not be in conflict with the core hole. The core hole must be drilled plumb.

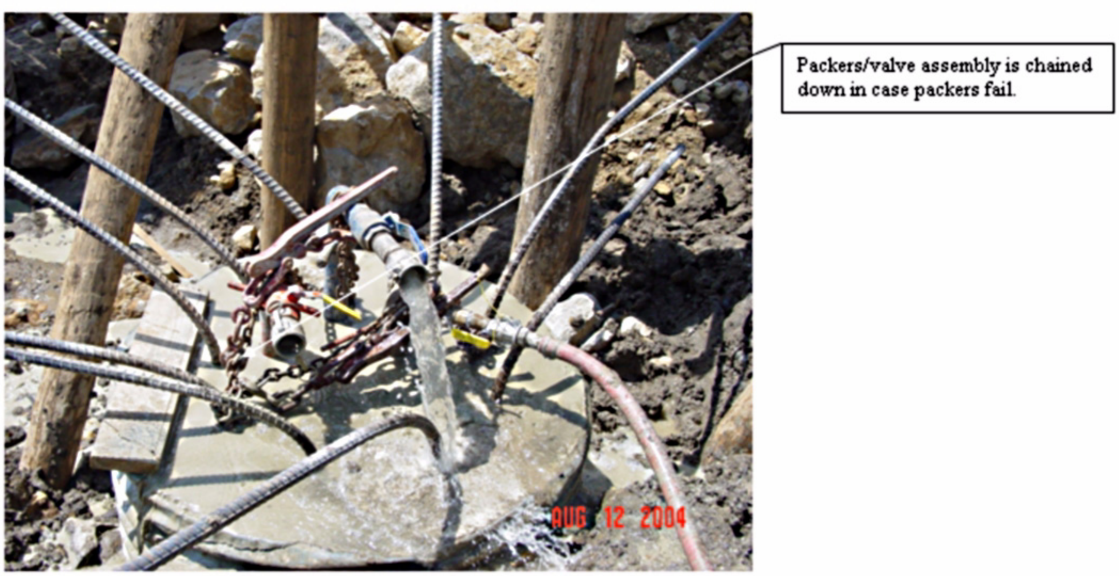
All core samples obtained must be placed in labeled core boxes by the coring company for review. The core must be reassembled to determine the size of the void. The coring company must also produce a field log of drilling activity that includes shaft identification information, drilling depths, length of core runs, length of core recovered for each run, and percent core recovery for each run. In addition, zones of poor quality concrete or other variations of concrete condition should be noted on the log based upon visual observations made by the driller. The core boxes must be left in the field with KDOT representatives and a copy of the coring log will be provided to the contractor within 24 hours of completion of coring.



If a repair is required, at least one more hole will be required so that there will be an input hole and a return hole for cleanout and grouting. Do not core any hole more than 6” below the void. Coring below the void complicates cleaning out the hole.

CLEAN OUT

A large volume of clean water will be required to flush out the partially cemented material. It is important that all combinations of core holes be flushed with high-pressure air and water. When the void has been properly cleaned, the return water should become clear.

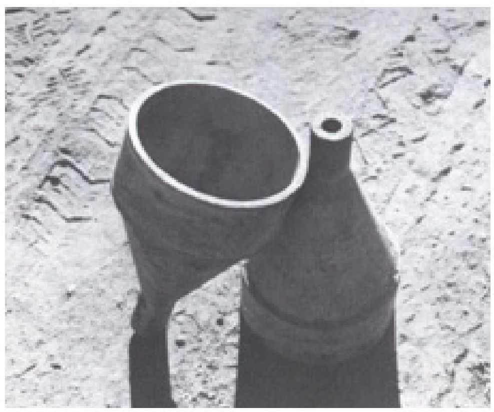


If the void is within the uncased rock socket, care must be taken to prevent “mining” of new material from the side of the hole. This problem exists mostly when the socket is founded in shale or a weathered limestone. If the return water during cleanout does not get clearer as the process progresses or the cleanout water becomes dark, stop flushing and contact the regional geology office on how to proceed.

GROUTING TERMS

Grout: A mixture of portland cement concrete, sand and water

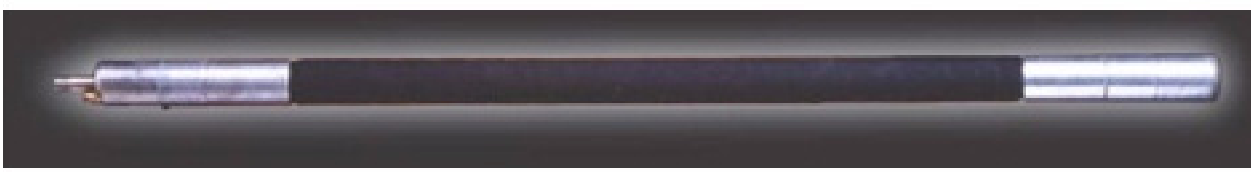
Flow Cone: A device used to measure the consistency of grout. The cone measures the time it takes, in seconds, for a known volume of grout to flow through a nipple in the bottom of the device. The nipple has either a 3/4” opening or a 1/2” opening. The 9-second and 15-second grouts referred to in this section are based on a 3/4” opening.



Pressure Gauge: This is used to measure the pressure that the grouting system applies to the void. It must be a membrane type. A non-membrane type of pressure gauge will become plugged with grout and stop reading correctly.

Inline Flow Device (meter): This is used to measure the volume of grout passing by a point in the grouting system.

Packer: A plug used to resist pressure of cleanout water and grout in the core hole. Usually this is attached to a grout tube which has a fitting and a valve attached. The packer binds against the hole to resist the pressure of the grouting operation.



Tremie pipe: Sealed tube which will convey grout to the bottom of the hole. This prevents the cementitious material from being "washed out."

GROUTING PROCEDURE

1)Attach a valve and tremie pipe to each packer and insert one packer and valve into each core hole.

2)Connect the grout pump to one of the valves.

3)Insert packers with valves and tremie pipes in all core holes.

4) The grout pump is connected to one of the packers. This location is called the input hole.

5)Open one input line and one return. Using a thin grout (9-second), pump grout until the return grout is the same consistency as the grout going into the hole from the pump. Repeat this process for all combinations of core holes. Close the first return valve before opening the next one.

6)Close all exit valves. Pump up the pressure until 20 psi is maintained for 10 minutes. Pressure is applied to ensure that the grout makes it into all of the crevices in the anomaly and coats all of the partially cemented material.

Note: If the flow of grout continues past the estimated volume or if the pressure drops off with all the valves shut, then there may be a leak in the equipment, or the grout is leaking into the geologic formation. In this case, check the equipment. If the equipment is working properly, wait until the grout gets stiff before moving to the next step.

7)Open one input line and one return. Using a thick grout (15-20 second), pump grout until the return grout is the same consistency as the grout going into the hole from the pump. Repeat this process for all combinations of core holes. Close the first return valve before the next one is opened.

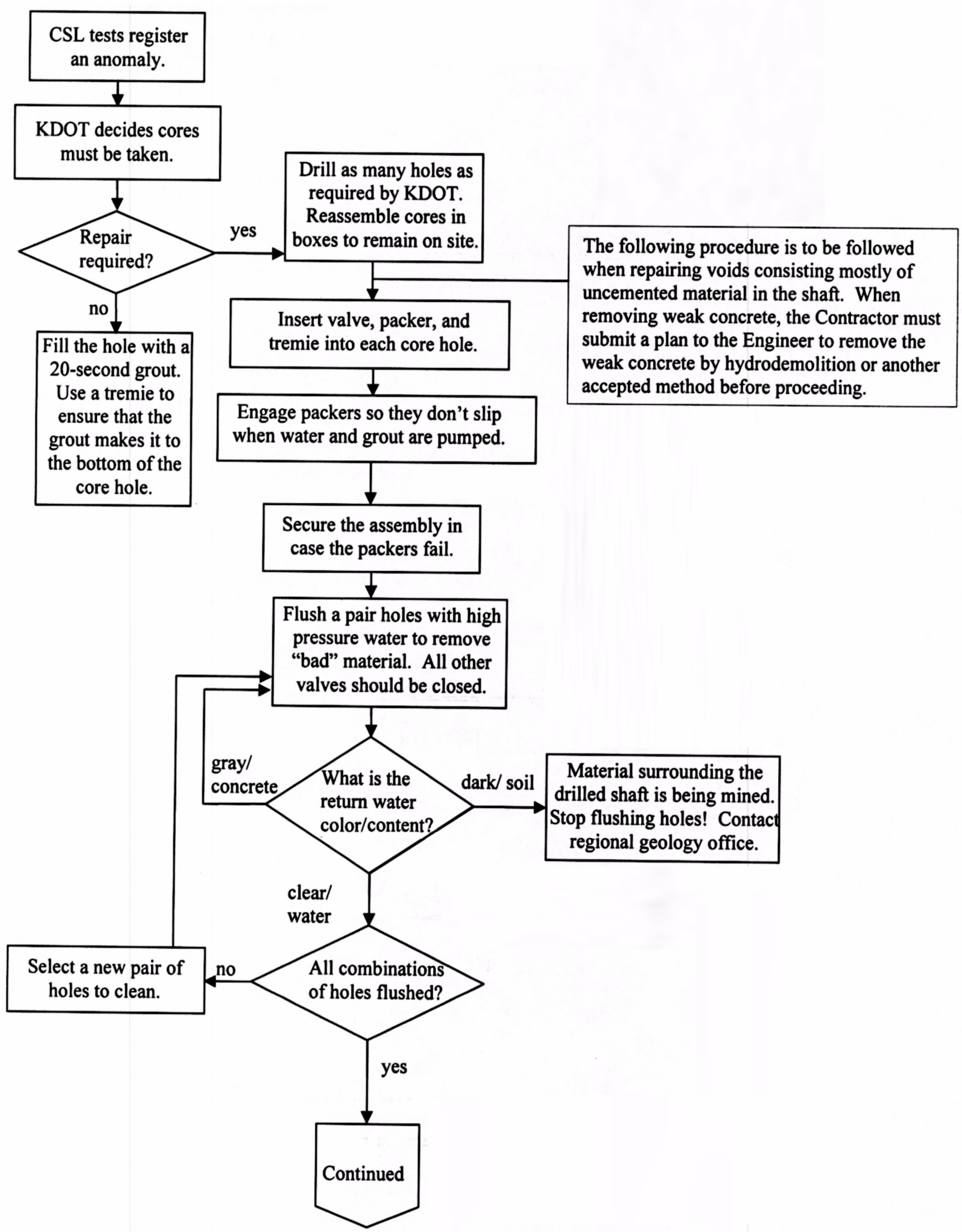
8)Close all exit valves, pump the pressure to 100 psi and hold for 10 minutes

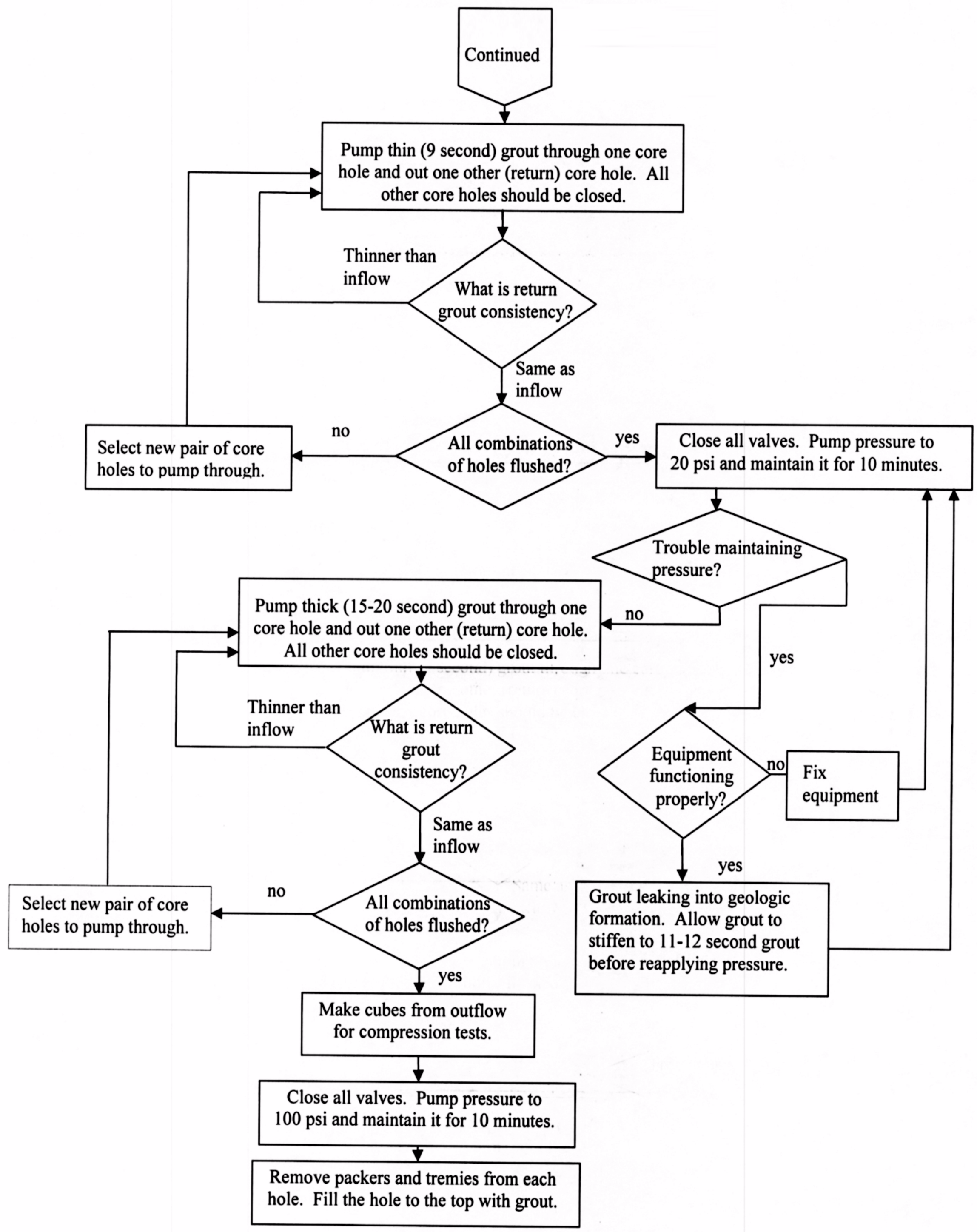
9)Make cubes from the outflow grout on the last core hole. These cubes are to be tested for compression strength.

10) Pull out packers and tremies from each hole. Fill the hole with grout until it reaches the top of the drilled shaft.

11)After the grout obtains 3000 psi on the cube compression test, perform the CSL tests again. If anomalies are found, it may be necessary to re-core the shaft.
The Contractor must submit a detailed alternate repair procedure for KDOT to review if they plan to deviate from the specified procedure.

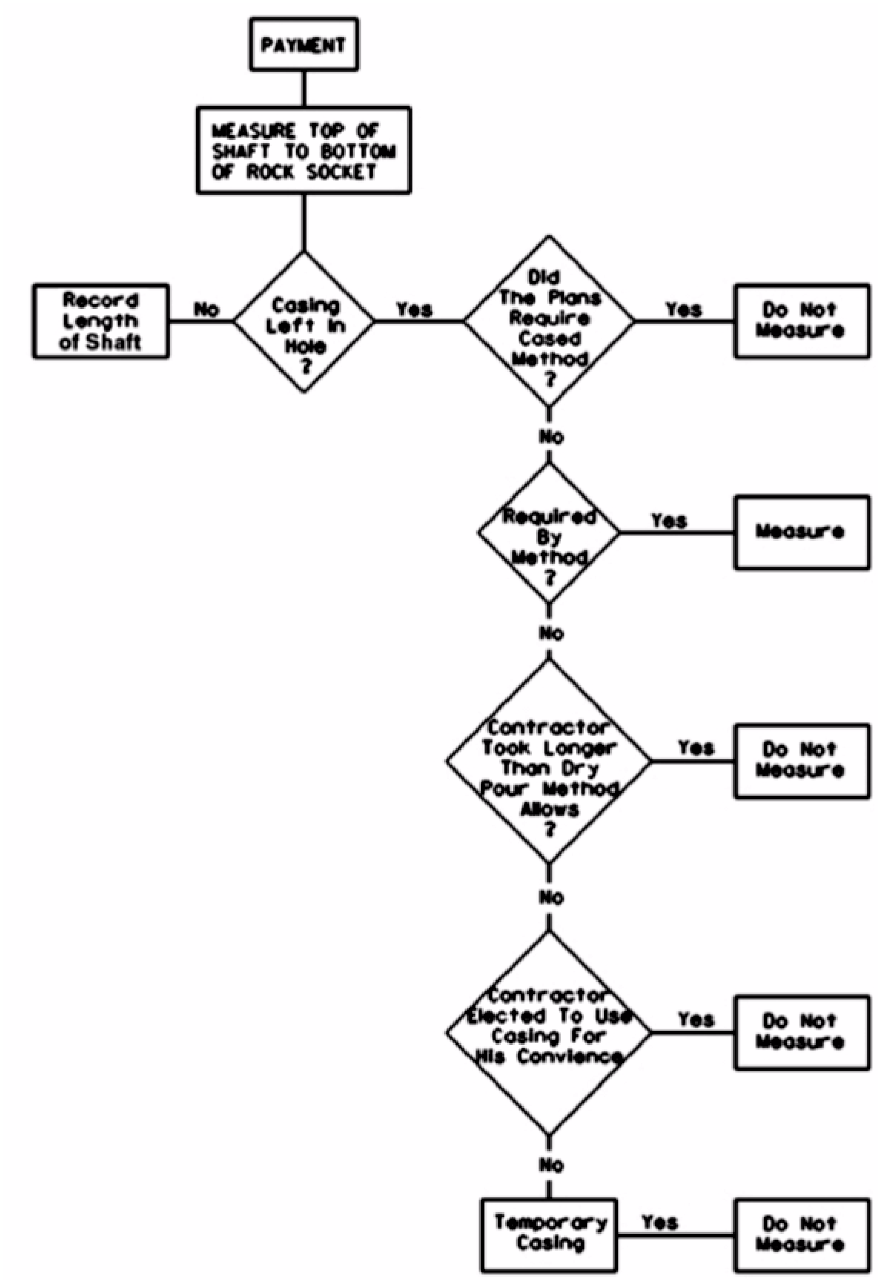
DRILLED SHAFT REPAIR FLOWCHART




Continued
Pump thin (9 second) grout through one core hole and out one other (return) core hole. All other core holes should be closed.
Thinner than inflow
What is return grout consistency?
Same as inflow
All combinations of holes flushed?
no
Select new pair of core holes to pump through.
yes
Close all valves. Pump pressure to 20 psi and maintain it for 10 minutes.
Trouble maintaining pressure?
no
yes
Pump thick (15-20 second) grout through one core hole and out one other (return) core hole. All other core holes should be closed.
Thinner than inflow
What is return grout consistency?
Same as inflow
All combinations of holes flushed?
no
Select new pair of core holes to pump through.
yes
Make cubes from outflow for compression tests.
Close all valves. Pump pressure to 100 psi and maintain it for 10 minutes.
Remove packers and tremies from each hole. Fill the hole to the top with grout.
Equipment functioning properly?
no
Fix equipment
yes
Grout leaking into geologic formation. Allow grout to stiffen to 11-12 second grout before reapplying pressure.

5.4.13 Measurement:

Drilled Shafts are bid as either cased or uncased. The bid item includes all materials and labor required to complete the shaft. The unit of measure is per foot measured to the nearest 0.01 ft. Drilled shafts are paid to the nearest 0.1 ft. If the cased method is required in the plans, the casing is not paid for directly. If the plans do not require casing, but the field conditions make casing necessary, then casing is paid for at the set price.



Sonic testing is paid at a set price. If sonic logging indicates a problem the Contractor will core the shaft (NX size) and the cores will be evaluated. If the cores reveal sound concrete, the Engineer will pay for the cores as "Extra Work" according to Standard Specification 104.6.

APPENDIX

Key Questions to ask the Contractor, Prior to Placing Concrete in a Drilled Shaft by the Wet Pour Method

1. Q. How is the Contractor going ensure the bottom of the excavation is clean?

- The Contractor can clean the bottom of the excavation by using an airlift and monitoring the clarity of the water at the discharge end of the airlift. Once the water is clear, the shaft should be sufficiently clean. Another method is to use a mucker bucket to lift the material out of the shaft once sediments have settled to the bottom. Upon approval from the Bridge Office in the Bureau of Design, coagulates may be used to speed up the settling of sediments. Coagulates may NEVER be used on shafts that are designed to account for skin friction, ALWAYS check with the Bridge Office in the Bureau of Design.

2. Q. Is the Contractor going to let the water level in the shaft reach its normal static elevation or pump the shaft full of water?

- After cleaning the bottom of the shaft and prior to placing concrete, the water level in the shaft must, at a minimum, reach its normal static elevation. This minimizes the flow of ground water into the shaft. However, the best approach is to fill the shaft full of water, to ensure any flow of water is away from the shaft.

3. Q. How is the Contractor going to place the concrete: pump it through an extension tube or place through a tremie?

- Either method is acceptable; however, the Contractor must implement other measures to satisfactorily separate the ground water and fresh concrete.

4. Q. Is the tremie/extension tube watertight?

- The tremie/extension tube MUST be watertight, so the cement paste is not washed off of the aggregate.

5. Q. How will the tremie/extension tube be sealed (separate the ground water and concrete), a "pig" or flap gate on the tremie?

- Either device; "pig" or flap gate, is acceptable. The deciding factor is ensuring the ground water and concrete don't come into contact with one another until the initial surge of concrete comes from the tremie/extension tube.

6. Q. What material is being used for the pig?

- When using a tremie, the "pig" MUST be an inflatable ball such as a soccer ball. The ball may be slightly under inflated to allow it to fit in the tube, but still large enough to not allow ground water to rise past the "pig" and mix with the concrete. A dense foam commercially available pig may also be used. NEVER allow the use of a soft foam ball, such as a Nurf ball, because the ball may collapse to the side and allow the concrete to free fall through the ground water in the tremie. If a pump and extension tube are used, a commercially available foam pig must be used.

7. Q. Where is the "pig" going to be placed in the tremie/extension tube or pump?

- Place the "pig" at the highest elevation inside the tremie/extension tube so the air gap between the "pig" and concrete is as small as possible. Thus, in a tremie place the "pig" just below the hopper at the top of the tube. In an extension tube, place the "pig" at the top of the tube just below the coupler. Immediately above the coupler there should be a device called a Portland cement concrete (PCC) brake, which allows the tube to be fully charged before any concrete is discharged.

8. Q. How is the Contractor going to fully charge the pump pipes or tremie before any concrete is discharged into the shaft?

- Prior to any concrete being discharged into the shaft, the Contractor MUST be prepared to deliver a continuous surge of concrete to develop a seal between the ground water and the concrete.
- If a tremie is being used, it is first lowered into the shaft so it is resting on the bottom of the shaft. The "pig" is then placed at the top of the tube directly beneath the hopper. Second, the hopper is filled, so the "pig" is forced to the bottom of the tremie. Third, the pump line or concrete bucket is placed into position directly above the hopper. Finally, the tremie is lifted one tremie diameter off the bottom of the shaft, and as the concrete level starts to drop in the hopper, the concrete bucket or pump is used to maintain concrete flow through the tremie. The tremie should not be raised until 10’-0" of head has been achieved, and then a minimum head of 7’-0" should be maintained throughout the pour.
- If a pump truck and extension tube are used, the extension tube is lowered into the shaft so it is resting on the bottom of the shaft. The "pig" is then placed into the top of the extension tube (just below the coupler). To fully charge the pump tube, the Contractor must use a PCC brake (attached to the top of the extension tube) which prevents the concrete from free falling to the bottom of the extension tube when it passes the peak of the arc made by the pump tube. Three fairly common devices are a "French horn", bladder valve or a pull gate. A "French horn" is an offset 360 degree tube made with four "elbow" fittings that are slightly turned so the exit end is offset from the inlet (see the photo below). A bladder valve is a valve that bleeds off air pressure as concrete is delivered to the top of the valve, and when a certain pressure level is achieve the valve opens to deliver the continuous surge of concrete. A pull gate is a manual gate that the Contractor pulls to open the tube once the pump tube is fully charged.

French horn

9. Q. How is the Contractor going to ensure the initial seal (discharge end in fresh concrete) is achieved?

- To ensure the initial seal is achieved, a continuous surge of concrete must exit the discharge pipe when it is lifted (one tremie diameter) from the bottom of the rock socket. This is accomplished by fully charging the tremie tube and hopper (or extension tube) with concrete, and not lifting the tube from the bottom of the rock socket until either another bucket of concrete is ready to be dumped in the hopper, or the pump truck is ready to continuously pump concrete. Once the Contractor is prepared to deliver a continuous surge of concrete, they will raise the tube one tremie diameter, the concrete will force the pig out and concrete will exit.

10. Q. How is the Contractor going to ensure the discharge end of the tremie/extension tube is sufficiently embedded in the fresh concrete?

- If the tremie/extension tube is not sufficiently embedded in the fresh concrete, the water in the shaft will flow into the tremie/extension tube; consequently mixing ground water, any remaining sediment and fresh concrete. To ensure the discharge end of the tremie/extension tube is sufficiently embedded in fresh concrete, the Contractor must know the top elevation of fresh concrete in the shaft. The most common way is to use a weighted tape to "feel" the top of the fresh concrete. Another method is to calibrate the pump and count strokes as described above, or count trucks.

11. Q. Is the tremie/extension tube marked in 1'-0" increments?

- The tremie/extension tube MUST be marked in 1 foot increments to accurately determine the embedment (difference between the elevation of the discharge end of the tube and the top of the fresh concrete) of the extension tube in the fresh concrete.

12. Q. When and how much is the Contractor going to lift the tremie/extension tube?

- After the initial seal is achieved, it is imperative that the discharge end of the tube is ALWAYS embedded at least 7'-0" into the fresh concrete. If the tremie/extension tube is not sufficiently embedded in the fresh concrete, the water in the shaft will flow into the tremie/

extension tube; consequently mixing ground water, any remaining sediment and fresh concrete. The tremie/extension tube may be lifted any distance; however, it is preferable to raise it in small increments, so as to ensure it is not lifted too high. Regardless of the amount of the incremental lifts, the elevation of the top of the fresh concrete must be known. This elevation should never be less than about 7'-0" above the end of the tremie.

13. Q. How is the Contractor going to over pump the shaft to displace the questionable (i.e. poor quality or frothy) concrete that has risen to the top of the shaft?

- Over-pumping of the shaft is required to remove questionable concrete that has mixed with the ground water (changing the water cement ratio) and has been contaminated with any debris that was in the shaft. A common problem with over-pumping that must be resolved is whether the questionable concrete is allowed to fall between the temporary and permanent casing. If allowed, it may cause problems when removing the temporary casing. In addition, if the Contractor tries to break the temporary casing lose by rocking it back and forth, the shaft could be severely damaged by cracking at the top of the rock socket. One solution is to cut a small vertical slot at least 6" wide, out of the permanent casing extending down to the final plan elevation for the top of the shaft. This will allow an outlet for the questionable concrete to escape.
- Attach a waste chute to the permanent casing to span the gap between the temporary and permanent casing. However, if the top elevation of the permanent casing is lower than the top elevation for the temporary casing, and the waste chute is not possible, the other acceptable approach is to extend the height of the shaft by one shaft diameter and chip down to good concrete. It is best to have the permanent casing above the temporary casing. Mucking out or shoveling out the questionable concrete is NOT an acceptable option, because of possible mixing of good and questionable concrete. ALWAYS remind the Contractor that KDOT is going to make a set of cylinders from the concrete at the top of the shaft.