SPECIFIC TASK TRAINING PROGRAM

DRILLED SHAFT FOUNDATION CONSTRUCTION INSPECTION

S32

CLASS REFERENCE GUIDE

Prepared and Published
by
Bureau of Construction

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Training Date: ____________________

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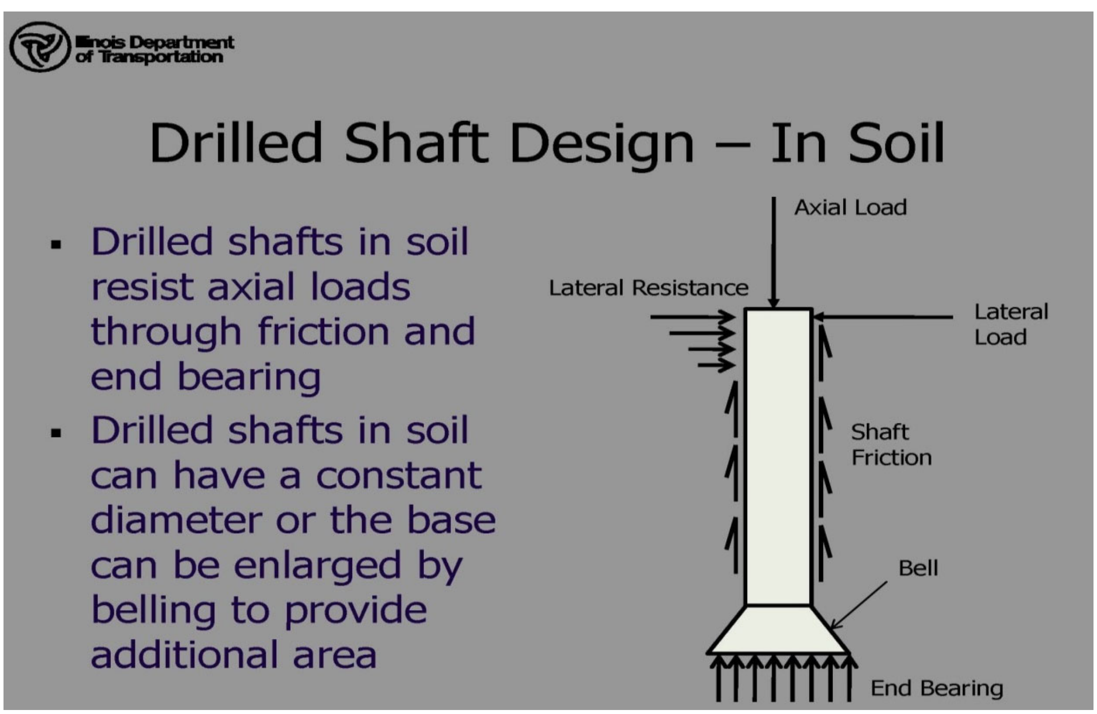
1 INTRODUCTION TO DRILLED SHAFT INSPECTION

1.1 – Role and Responsibilities of the Inspector

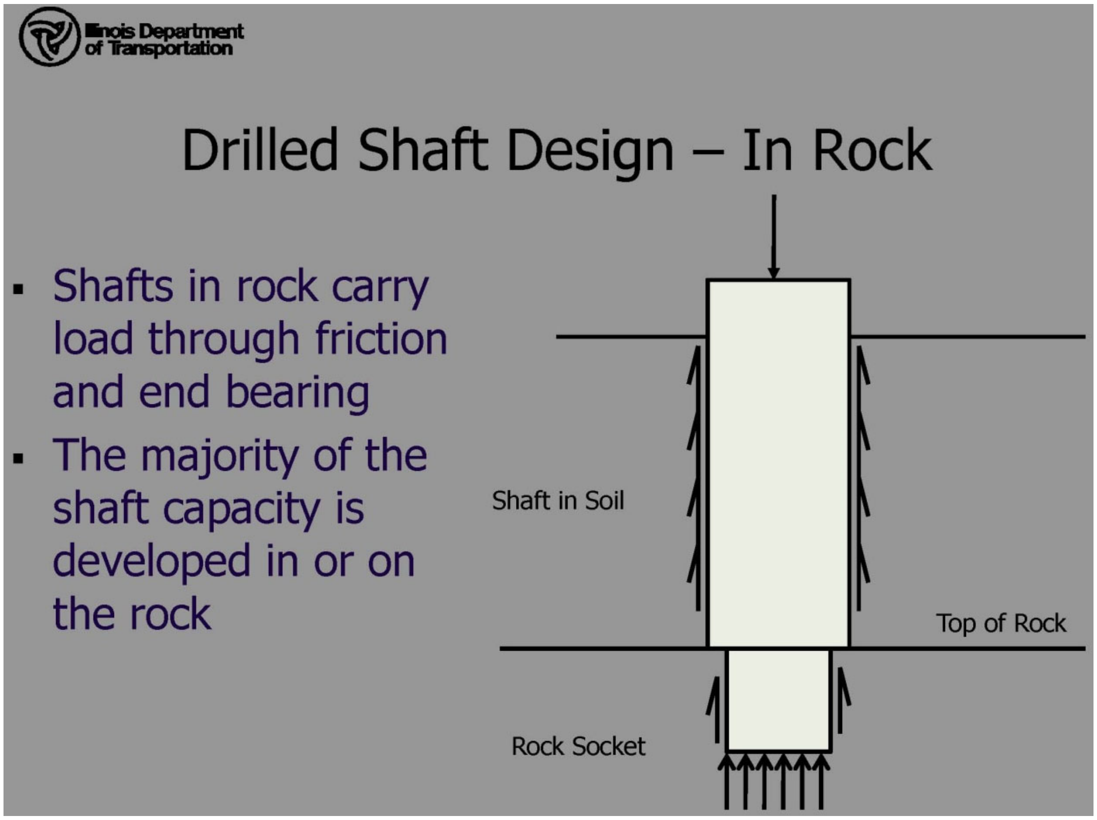
The role of the inspector is to observe and report on the construction activities at the site. This is especially important for drilled shafts since their construction is more susceptible to defects that result from poor construction techniques. As the inspector, it is your responsibility to confirm that the drilled shaft construction was performed in accordance with the plans and specifications. This task is completed through a combination of observations, recording and testing. The inspector is responsible for recording the means and methods by which a drilled shaft is constructed. In effect, the inspector will create an as-built plan of the foundations at the site. It is also the responsibility of the inspector to measure and record the soil and rock conditions which support the drilled shaft. The drilled shaft inspector is the eyes and ears of the geotechnical and structural engineers who designed the drilled shaft foundations for the project. The inspector has the responsibility to report any deviations from the plans and specifications or deviations from the contractor's approved work plan to their supervisor. The inspector should realize they have the authority and responsibility to observe every aspect of the foundation construction process. The inspector has the authority to not accept work if construction is not being performed in accordance with the plans or specifications.

1.2 – Introduction to Drilled Shafts

A drilled shaft is a foundation element composed of cast-in-place reinforced concrete that is placed into an open drilled excavation. Drilled shaft foundations are specified to address vertical and lateral load capacity concerns resulting from large scour depths, high seismic loadings, potential liquefaction, low soil strengths, and inadequate pile embedment. In general, drilled shafts will have a higher resistance against axial and lateral loads than driven piles. The additional capacity is a result of the size of the drilled shaft. Drilled shaft diameters can range from 1 to 10 feet, and lengths up to 150 feet can be achieved using common drilled shaft construction equipment. Even larger shafts are possible with specialized equipment. An additional benefit of drilled shafts is the less noise, and relatively low vibration levels during construction when compared to driven pile installation.



Drilled shafts can be constructed in soil or in rock. For drilled shafts in soil, the resistance to load is developed along the perimeter of the shaft through friction and also bearing on the end of the shaft. In certain situations, the capacity of the shaft can be increased by increasing the size of the base of the drilled shaft. Increasing the size of the base is commonly referred to as under-reaming or belling. Bells can be constructed at 45 degree or 60 degree angles. For higher bearing stress applications, a 60 degree bell is required. Bells can be up to three times the diameter of the shaft.



Drilled shafts in rock are constructed similarly to drilled shafts in soil. The drilled shaft extends through the overburden soils to the surface of the rock. A rock socket is excavated to a diameter and length necessary to meet the required design. The rock socket will generally be a slightly smaller diameter than the portion of the shaft in the soil. In some cases no socket will be constructed and the drilled shaft can bear on the surface of the rock after it has been cleaned. Shafts in rock support load similarly to shafts in soil. Loads are resisted by a combination of friction along the shaft in the soil and the shaft in the rock. End bearing resistance is also developed in the rock. In most cases, the majority of the load will be supported by shaft friction and end bearing in the rock socket and the contribution of the soil above may be ignored.

1.3 – <u>Plans, Specifications and Reports</u>

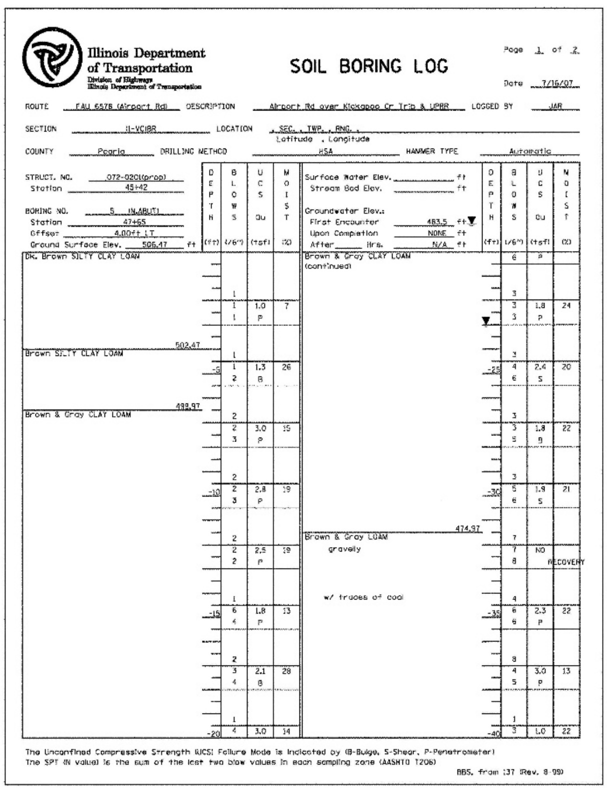
The construction of drilled shafts is controlled by IDOT plans and specifications. The geotechnical aspects of the drilled shaft design are controlled by the Structure Geotechnical Report.

When preparing for a drilled shaft inspection, the inspector must review the plans before the start of the project. From the plan drawings, important information such as drilled shaft diameters, rock socket diameter, drilled shaft length and rock socket length can be obtained. The plan drawings will also give information related to the type and configuration of reinforcing steel which will be installed.

The specifications provide details regarding the drilled shaft construction process. Before arriving on site, the inspector should be familiar with the specifications. Refer to 1.5 – Applicable Specifications and Forms for applicable specifications to review.

Before arriving on-site, the inspector should also review the Structure Geotechnical Report for the project. The inspector should review the entire report to become familiar with the site conditions. The inspector should pay special attention to the soil conditions section which will provide a general description of the soil conditions at the site. The inspector should also pay special attention to the design recommendations section as this may be the only source for information related to the bearing pressure assumed in the design. Finally, the inspector should pay special attention to the construction considerations section of the report. The construction considerations section may provide valuable information related to the use of temporary or permanent casing for the shafts and provide information on potential drilled shaft construction problems like caving soils and water infiltration.

After reviewing the text of the report, the inspector must carefully review the soil boring log (Form BBS 137) and rock core log (Form BBS 138). The logs will be included in the attachments to the Structure Geotechnical Report and should also be included in the plans. Important items to note on the soil boring logs include the soil types and strengths which will be encountered especially at the bearing level. The inspector should also pay close attention to the water levels encountered during drill operations. Two soil types which may be of concern during construction are soft clays and granular soil below the groundwater table.


Illinois Department of Transportation
Division of Highways
Illinois Department of Transportation

SOIL BORING LOG

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Date 7/16/07

ROUTE FAU 6578 (Airport Rd) DESCRIPTION Airport Rd over Kickapoo Cr Trib & UPRR LOGGED BY JAR

SECTION 11-VCIBR LOCATION , SEC. , TWP. , RNG. , Latitude , Longitude

COUNTY Peoria DRILLING METHOD HSA HAMMER TYPE Automatic

STRUCT. NO. 072-0201(prop)
Station 45+42

BORING NO. 5 (N.ABUT)
Station 47+65
Offset 4.00ft LT
Ground Surface Elev. 506.47 ft

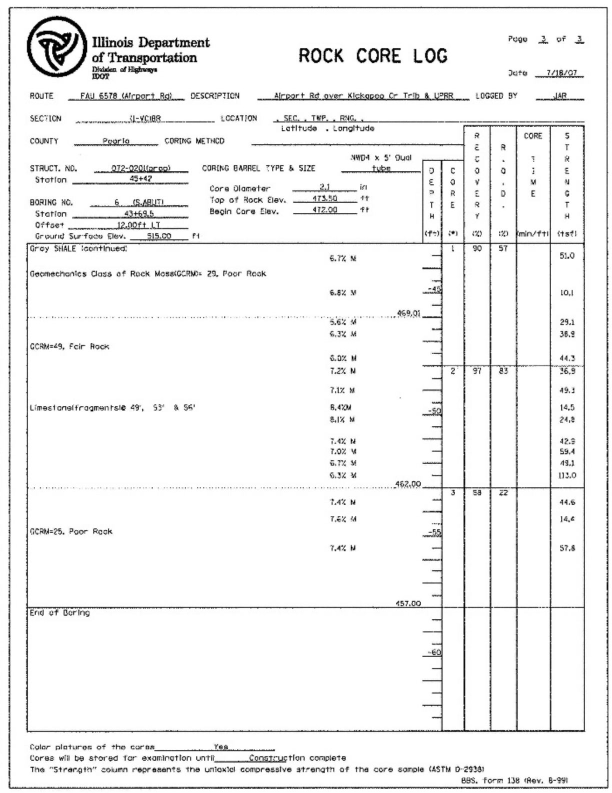
Surface Water Elev. ft
Stream Bed Elev. ft

Groundwater Elev.:
First Encounter 483.5 ft
Upon Completion NONE ft
After Hrs. N/A ft

Dk. Brown SILTY CLAY LOAM
502.47
Brown SILTY CLAY LOAM
498.97
Brown & Gray CLAY LOAM
Brown & Gray CLAY LOAM (continued)
474.97
Brown & Gray LOAM gravelly
w/ traces of coal

The Unconfined Compressive Strength (UCS) Failure Mode is Indicated by (B-Bulge, S-Shear, P-Penetrometer)
The SPT (N value) is the sum of the last two blow values in each sampling zone (AASHTO T206)

BBS, from 137 (Rev. 8-99)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IDOT

ROCK CORE LOG

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Date 7/18/07

ROUTE FAU 6578 (Airport Rd) DESCRIPTION Airport Rd over Kickapoo Cr Trib & UPRR LOGGED BY JAR

SECTION 11-VCIBR LOCATION , SEC. , TWP. , RNG. , Latitude , Longitude

COUNTY Peoria CORING METHOD

STRUCT. NO. 072-0201(prop)
Station 45+47

BORING NO. 6 (S.ABUT)
Station 43+69.5
Offset 12.00ft LT
Ground Surface Elev. 515.00 ft

CORING BARREL TYPE & SIZE NWD4 x 5' Dual tube
Core Diameter 2.1 in
Top of Rock Elev. 473.50 ft
Begin Core Elev. 472.00 ft

Grey SHALE (continued)
Geomechanics Class of Rock Mass(GCRM)= 29, Poor Rock
469.01
GCRM=49, Fair Rock
Limestonelfragments)@ 49', 53' & 56'
462.00
GCRM=25, Poor Rock
457.00
End of Boring

Color pictures of the cores Yes
Cores will be stored for examination until Construction complete
The "Strength" column represents the uniaxial compressive strength of the core sample (ASTM D-2938)

BBS, form 138 (Rev. 8-99)

When exploratory soil borings are extended into rock, coring is generally completed to evaluate the type, strength and consistency of the rock. The findings of the rock coring are summarized on rock core logs. The rock core logs will also be included in the attachments to the Structure Geotechnical Report and should be included in the plans as well. When reviewing the rock core logs the inspector should check which type of rock will be encountered at the site. Two common rock types encountered in Illinois are shale and limestone. Limestone is sometimes referred to as dolomite when the MgO is ≥ 11.0%. Shale is a relatively soft rock; it should be excavated relatively easily with rock excavation equipment. Limestone tends to be a much harder rock; excavation in limestone will be a slower process. It is also important to note the Rock Quality Designation (RQD) on the rock core log. The RQD is a measure of the quality of rock that was encountered. The RQD, expressed in percent, is the sum of the lengths of all pieces of sound core over 4 in. long, recovered from a core run, divided by the total length of the core run. For example, if the core length is 40 in. and there are 10 rock pieces, 7 of which with lengths less than 4 in. and 3 pieces with lengths of 4 in., 5 in. and 6 in., respectively, the RQD for this core is 37.5%. When the RQD is high (greater than 50 percent) the rock will be fairly solid and massive. Low RQD indicates the rock is weathered and fractured.

The core recovery ratio is the length of rock core recovered from a core run, divided by the total length of the core run. This ratio, expressed in percent, provides indications regarding the presence of weathered zones.

The rock compressive strengths should also be reviewed. Shale strength may be on the order of 750 psi while limestone or dolomite may exceed 10,000 psi. Fractured rocks with unconfined compressive strengths below 1000 psi may be excavated with rock augers, while hard rocks greater than 3000 psi may require coring.

1.4 – Equipment and Safety

Job site safety is beyond the scope of this document, but all normal safety procedures for construction sites shall apply. Personal Protective Equipment (PPE) is required on drilled shaft construction sites. Required safety equipment includes hard hat, safety glasses, high visibility vest, steel toed boots, and hearing protection. Gloves may also be required depending on the job site requirements. A life preserver is also required when working around water.

An inspector shall never perform an inspection activity which places them in an unsafe situation. All inspection work will be completed from the ground surface for the drilled shaft. Entry into the excavation is not necessary or recommended for the inspector. Any entry into a drilled shaft will require installation of steel casing, and compliance with Occupational Safety & Health Agency (OSHA) requirements for confined spaces in construction. For confined spaces, air quality testing for such things as oxygen content, flammable gases, and toxic air contaminants are required.

Before drilling begins, utilities within the work area must be located and staked. Also, look for any overhead conflicts. Plenty of headroom is needed when constructing deep drilled shafts because the crane will be lifting the rebar cage or tremie for construction of the drilled shaft.

When drilling next to an underground utility, the contractor should pothole first to locate the utility. During drilling, caving may expose the utility. If this occurs, the inspector should verify that the utility is well supported, if needed, and that the contractor does not entomb it in concrete when the shaft is poured.

With some types of soils, there is the danger of the soil collapsing near the surface as the driller advances the hole. Usually a surface (a.k.a. starter) casing will be placed around the hole to protect workers from cave-ins. The casing may extend above ground (recommended), but is inserted well into the ground. The casing serves as a guide for drilling tools, and will help prevent enlargement of the hole at the surface due to tools being in and out of the hole for excavation of the shaft. The surface casing will also prevent soil from falling back into the excavation after it has been cleaned. The inspector is cautioned that it is possible for a starter casing to slide down the shaft if soil sloughing or caving is occurring below the casing.

The inspector is required to follow OSHA regulations for fall protection. When a worker is exposed to vertical drops of more than 6 feet, which is typical for drilled shafts, fall protection is required. Fall protection may include such things a platform with a guardrail, or safety harness and lifeline connected to a fixed object. Thus, the contractor shall take into consideration the inspection activities of the inspector when constructing the drilled shaft.

Another hazard to consider is the open hole when unattended. Safety measures are required to protect the general public. Holes need to be covered with a protective covering, or a fence may need to be erected around the hole.

Additional safety risks peculiar to drilled shaft construction also exist and the inspector must be aware of these. When drilling tools are in and out of the hole, the rig will swivel side to side. Do not stand at the side of a drill rig or behind the operator's cab in a position where the operator cannot see you. Also, when spoil is spun off an auger, flying debris can be a hazard. Large chunks of clay could weigh hundreds of pounds and would break bones if they hit you. An end loader will constantly be working at the side of the rig to remove spoil. Stay out of its way. When approaching the top of the shaft to look into the shaft, be sure that the operator sees you. Also, be careful when a belling tool is being lowered into the shaft. If the tool hits the surface casing, the wings will spring out and if you are standing at the side of the shaft you could be severely injured. Do not stand next to the shaft when tools are being lowered into the hole. When a reinforcement bar cage, casing or tremie pipe are lifted the inspector is advised to stand away and to the side. Anticipate where the object will fall if a cable breaks and be elsewhere.

Since the role of the inspector is to observe and report, some of the most important pieces of equipment for the inspector are the field book, checklist and forms. Refer to 5 Inspector's Checklist and Documentation for more information. Without these tools it will not be possible to document the construction completed at the site. To accurately fill out the forms and field notes, it will be necessary for the inspector to measure the lengths and diameters of the shaft and rebar cage. A 25 foot tape measure is useful to measure diameters and check the rebar. In many cases, the length of the shaft will be longer than 25 feet so a 100 foot tape measure should also be available for the inspector. Since the shaft will be measured from the surface and in some cases, water may be present in the excavation, it is necessary to provide a weight on the 100 foot tape. A small piece of rebar, a heavy bolt, or a drilling tooth taped to the end of the tape measure is generally sufficient.

For drilled shafts bearing in clayey soils, it is necessary to measure and record the strength of the materials encountered at the base of the excavation. The strength will be measured on auger cuttings recovered from the base of the excavation. An initial check of the unconfined compressive strength of the soil can be performed using a hand penetrometer. Most hand penetrometers can only measure up to an unconfined compressive strength of 4.5 tsf, though some are available that extend to 7 tsf, and some dial gauge penetrometers reach as high as 14 tsf. When high bearing pressures are utilized, a RIMAC unconfined compression testing device may be able to check the unconfined compressive strength of the soil. The inspector should have a calculator to aid in computing the unconfined strength as well as for volume calculations. A camera is useful for documenting field conditions, and a plumb bob is beneficial for checking vertical plumbness.

When inspecting shafts in rock, a rock probe should be utilized. A rock probe consists of a piece of round steel or rebar attached to the end of a cable. The rock probe will be heavier than the weighted tape so that the rock surface can be probed and sounded.

Frequently when inspecting the base of the excavation it can be lit by using a high lumen flashlight, reflecting sunlight with a mirror, or by lowering an explosion proof light. In some instances the bottom of the drilled shaft can only be inspected by using an explosion proof camera. Frequently for deep holes and belled shafts a camera is lowered to the base of the shaft to evaluate the bottom condition and cleanliness.

1.5 – <u>Applicable Specifications and Forms</u>

The intent of this manual and course is to provide an introduction to the construction and inspection of drilled shafts. Refer to 8.1 – Additional References for more comprehensive information on the proper construction of drilled shafts.

This manual is applicable to the January 1, 2022 Standard Specifications for Road and Bridge Construction. It shall be noted the Drilled Shafts Guide Bridge Special Provision # 86 contains revisions to Section 516. The inspector should be familiar with the following specifications and forms when constructing drilled shafts.

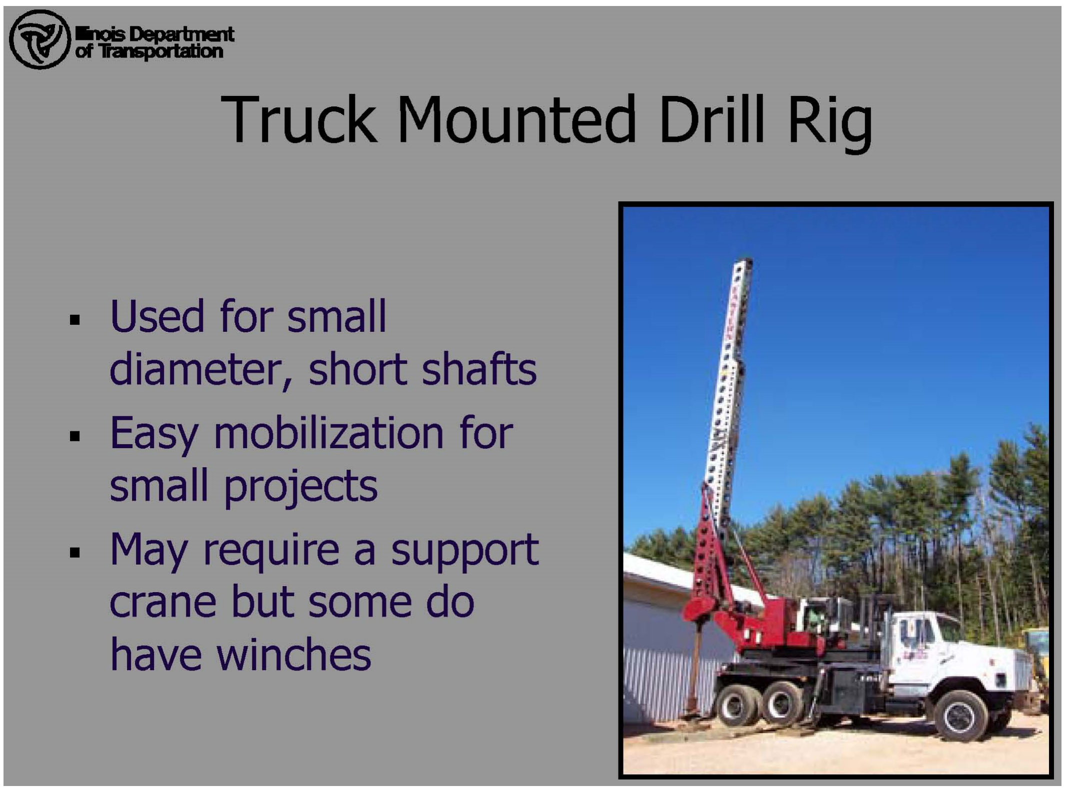
- IDOT Standard Specifications for Road and Bridge Construction:
  Section 508 – Reinforcement Bars (Construction Requirements)
  Section 516 – Drilled Shafts (Construction Requirements)
  Section 1020 – Portland Cement Concrete (Class DS Requirements)
  Section 1006.05 – Steel Casing (Material Requirements)
  Section 1006.10 – Reinforcement Bars (Material and Condition Requirements)

- Bureau of Bridges and Structures (BBS)Forms:
  BBS 133 – Drilled Shaft Qualification and Installation Plan
  BBS 134 – Drilled Shaft Excavation and Inspection Record
  BBS 135 – Drilled Shaft Concrete Placement Log/Drilled Shaft Concrete Curve

2 Shaft Excavation Tools and Methods

2.1 – Drill Rigs

Drill rigs used for construction of drilled shafts come in many types and sizes; however, they all have common components which are used for the drilled shaft excavation process. The power unit is the engine which powers the drilling equipment. In some cases, the power unit can be hydraulically powered off of the main engine for the equipment. In other cases, dedicated engines are provided for the drilling equipment. For large drilling equipment, two engines may be provided. The energy developed by the power unit is transferred to the drilling tools through the Kelly bar. Kelly bars can be round or square in section and are generally composed of multiple telescoping sections to minimize the overhead requirements of the equipment and maximize the drilling depths. The excavation is performed by tools connected to the end of the Kelly bar. Tools can consist of augers, core barrels, hammers or buckets. The type of tool utilized is dependent on the drilling conditions. All the drilling equipment is mounted to a body or carrier. The body can consist of a truck, crawler body or for large drilling equipment an attachment to a crane.



Truck mounted drilling equipment is generally used for small diameter short shafts. The truck carrier provides easy mobilization to sites and moves easily between widely spaced foundation locations. Truck mounted equipment is often self-servicing as winches are generally attached for lifting and placing rebar cages.

Illinois Department of Transportation

Crawler Body Mounted Drill Rig

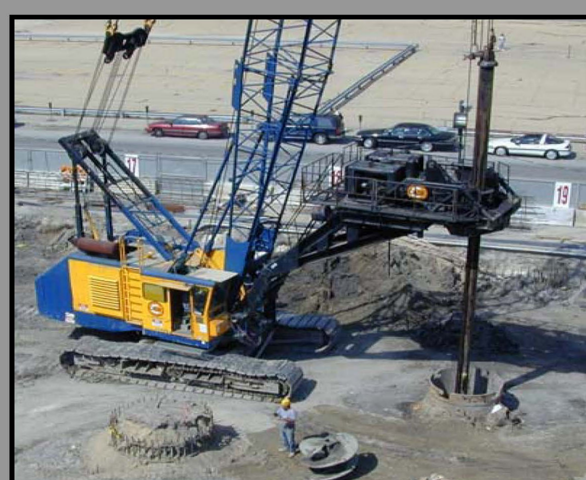
- Higher capacity than truck rigs
- Provides highest downward pressure (crowd)
- Better for difficult access conditions due to tracks
- Mobilize to site on flatbed trailer
- Largest rigs equal the torque of crane-mounted rigs

Crawler-body-mounted drill rigs are suited for larger diameter and deeper shafts than truck mounted equipment. The Kelly bar is generally larger diameter and often has more telescoping sections. Crawler mounted equipment is usually capable of providing downward pressure on the drilling tools through hydraulic rams acting on the Kelly bar. This additional pressure often referred to as "crowd", can be useful when drilling on rock or in hard soils. Another benefit of crawler mounted equipment is the body is track mounted which can be beneficial in difficult site conditions. Service winches are generally attached to crawler mounted equipment so they can place rebar cages and do other lifting.

Illinois Department of Transportation

Crane Mounted Drill Rigs

- Largest capacity, for diameter and length
- Crowd pressure limited to Kelly weight
- Highest torque
- Require large foot print to work in
- Mobilize to the site in multiple pieces
- Casing length that can be handled effectively is limited to the clearance below the "bridge"



The largest piece of drilling equipment available is a crane mounted drill rig. The power unit is attached to the body of the crane by a cable. The Kelly bar is then controlled via the boom and cables of the crane. Crane mounted equipment provides the largest amount of torque and can excavate the largest diameter shafts. The crowd of crane mounted equipment is limited to the weight of the Kelly bar and drilling tools. Weighted Kelly bars are available for rock drilling applications. Crane mounted equipment mobilizes to the site in multiple pieces and sections and requires assembly once on site. Service cranes for lifting and setting rebar cages are also required as crane mounted drilling equipment is not equipped with service winches. The size of the drilling equipment along with the requirement for a service crane creates the need for a large working footprint. If the project site is small and congested, crane mounted drilling equipment may not fit on the site.

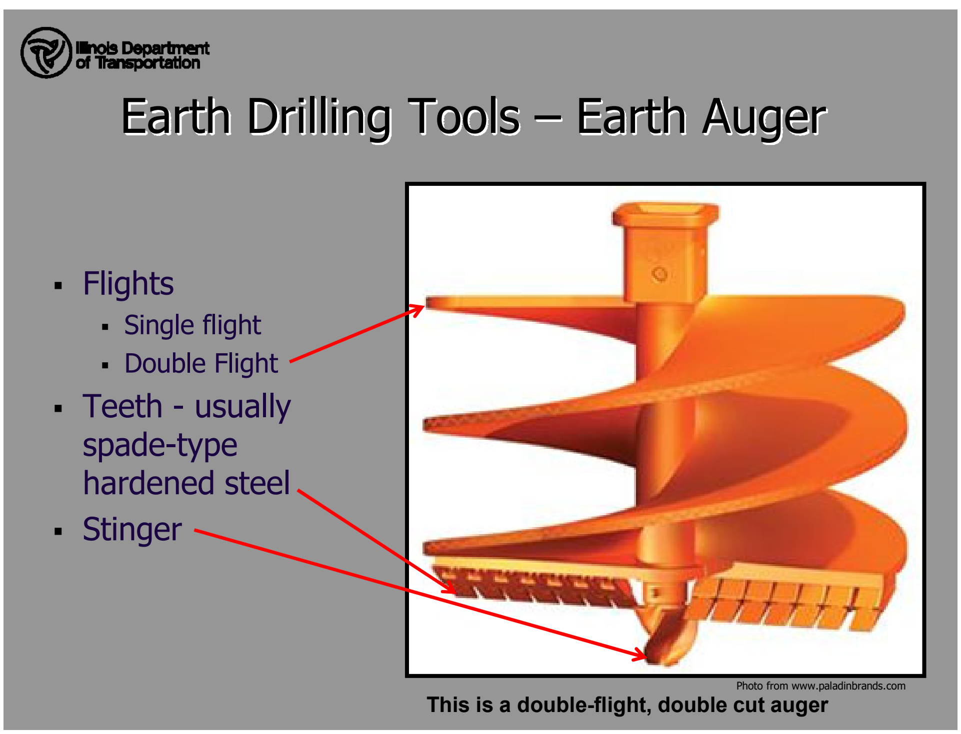
2.2 – Drilling Tools

The inspector should document the equipment on site and the tools used as well as their condition.

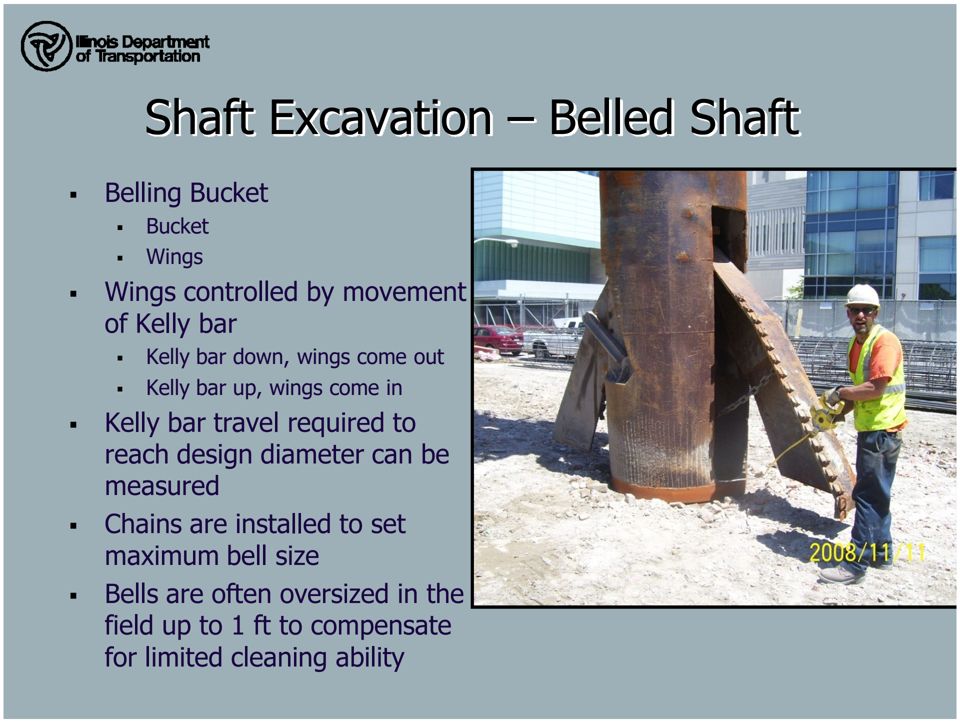
Drilling tools can be lumped into three broad categories including earth drilling tools, rock drilling tools and cleanup tools. The use of earth and rock drilling tools is fairly self-explanatory. Clean up tools are used for final bottom clean up. Earth and rock drilling tools are efficient at removing large amounts of soil or rock; however, they often leave thin layers of sediment and loose soil or rock at the base of the excavation. Earth and rock tools are also incapable of removing any standing water from the base of the excavation. For these final clean up tasks, clean up tools are required.

2.2.1 – Earth Drilling Tools

The most common earth drilling tool is the earth auger. Earth augers are available in single and double flight (cut) varieties. A single flight auger contains a single helix up the stem of the auger. A double flight auger has two helixes up the stem of the auger. Single cut augers only have teeth on one side of the center of the auger stem while double cut augers have two sets of cutting teeth at the base of the auger. Double cut augers are frequently used for hard drilling and large diameter shafts. The auger shown in the picture is a double flight, double cut auger. The stinger is located below the center of the auger stem to create a pilot hole for the auger and to help prevent the auger from walking along the bottom when drilling in hard soil.



When creating an enlarged base for a shaft bearing on soil a belling bucket or under-reamer is required. The belling bucket consists of two pieces: the bucket and the wings. The movement of the wings is controlled by the Kelly bar. As the Kelly bar is pushed downward the wings extend out of the bucket creating the enlarged base, when the Kelly bar is pulled up, the wings retract. As the wings cut the bell, the spoil collects in the bucket and is removed when the bucket is pulled out of the shaft. Prior to excavation, the bell size is set by attaching a chain to prevent over-excavation. To ensure the proper bell size is constructed, it is important to measure the travel of the Kelly bar which is required to achieve the design diameter. Alternatively a marker bar on the side of the belling bucket will indicate how far the wings opened. If no marker bar is available, heavy grease can be placed on the bucket in the wing slot. When the wings open, the grease will be smeared to the maximum opening point and will indicate the size of the bell.



Because, the quality of cleaning is limited with a belling tool, bells are often over-sized 1 foot to provide additional bearing area. Refer to 3.7.4 – Bottom Flatness and Cleanliness for additional information.

2.2.2 – Rock Drilling Tools

Augers can also be used for rock excavations. The primary differences between a rock auger and an earth auger are the teeth and flights. An earth auger will usually have spade-shaped hardened steel teeth. A rock auger will often have carbide-tipped, bullet-shaped or chisel-shaped teeth which are better suited for rock excavation than the spade-shaped teeth generally utilized on an earth auger. Rock auger teeth that are worn need to be replaced. Since rock drilling is harder than excavation in soil, the flights of a rock auger are thicker, heavier and often harder than those on an earth auger and may also be tapered. Rock augers can be used in any rock type but are most efficient in soft rocks such as shale or highly fractured and weathered rocks. Rock augers are also used to grind the surface of harder rock like dolomite when little penetration is required. When large sockets are required in harder rock such as dolomite, specialized equipment such as a core barrel or a downhole hammer are required. A core barrel consists of heavy casing with carbide teeth attached to the bottom, and frequently used for rock with greater than 3,000 psi compressive strength. A core the diameter of the rock socket is created and then the rock remaining in the center is removed with augers or broken up with a drop chisel. A downhole hammer is a hydraulic or pneumatic powered piece of equipment that consists of multiple cutting heads and a hammer. The cutting heads combined with the hammer effect break and crush the rock at the base of the excavation and remove the small rock fragments that remain. Downhole hammers are relatively rare and will only be used on large rock sockets in hard rock with compressive strengths up to

50,000 psi. Downhole hammers are used with reverse circulation or air circulation drilling processes which are unlikely to be encountered on IDOT projects.

For removal of boulders, a downhole hammer can be used but is unlikely. Refer to 3.3 – Obstructions and Differing Site Conditions for more information on equipment to remove boulders.

<u>2.2.3 – Clean Up Tools</u>

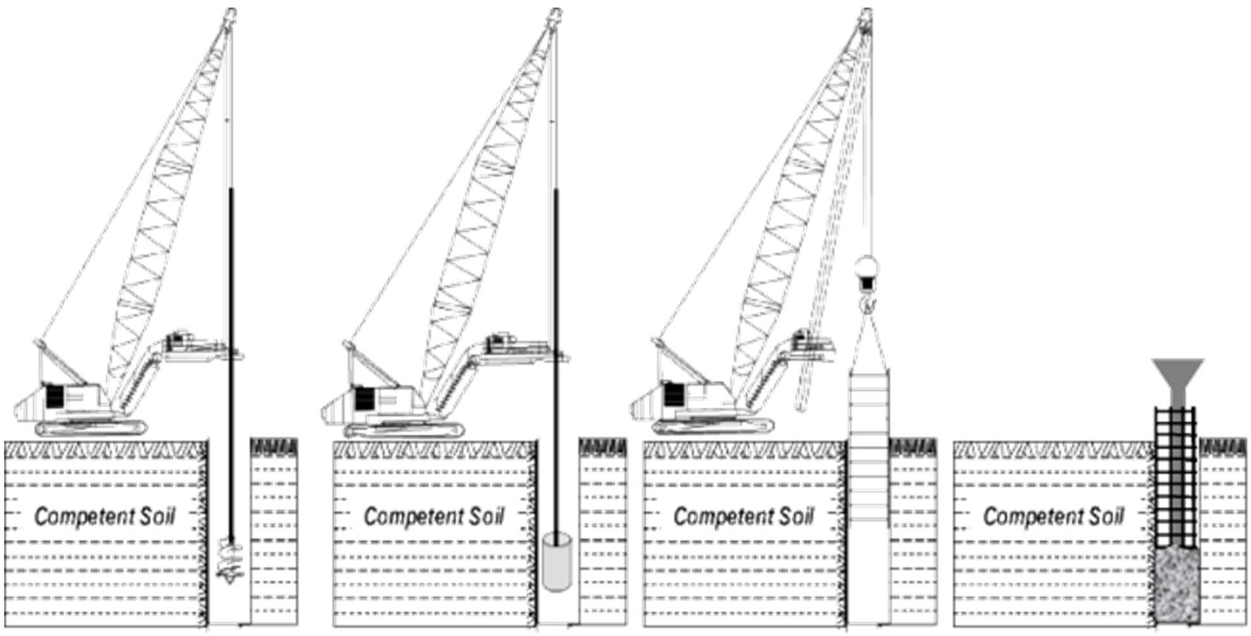
The best clean up tool for a dry shaft or shaft with a small amount of water is a clean-out bucket. Clean-out buckets are also commonly referred to as a one-eye bucket or a muck bucket. The clean out bucket has a flat bottom with an opening which is covered by a sliding plate. The bucket is lowered to the bottom of the excavation and rotated in the normal direction to collect any water and loose material off the bottom of the excavation. The bucket is then rotated in the opposite direction which slides the plate across the opening to close the bottom. This will capture soil and water inside. The captured soil will also help seal any gaps, and thus prevent leakage of water. If the bucket leaks water, this is a possible indication the bottom is clean since there is no soil to seal the gaps. Clean-out buckets can also be used to clean the base of excavations filled with water.

Two other options exist for excavations which are full of water or fluid. The two options are an airlift pump and a downhole pump. These tools are typically only recommended in rock sockets since they can cause excavation and erosion of the side walls or bearing soil if used in a shaft founded in soil. A downhole pump is lowered to the base of the excavation. The pump forces fluid and sediment at the base of the excavation up a hose to the surface. The pump should be lifted and moved around the base of the excavation to help ensure the entire shaft base is cleaned.

An airlift pump is more effective than a downhole pump and works like a giant vacuum. The airlift pump consists of a steel lift pipe 6 to 12 inches in diameter which is lowered to the base of the shaft. Compressed air is blown into the side of the lift pipe near the base of the excavation. The upward movement of the air creates suction in the lift pipe which pulls water and sediment from the base of the excavation up to the surface. The pipe must be lifted and moved around the entire shaft base until no more sediment (only fluid) comes to the surface.

2.3 – Shaft Excavation Methods

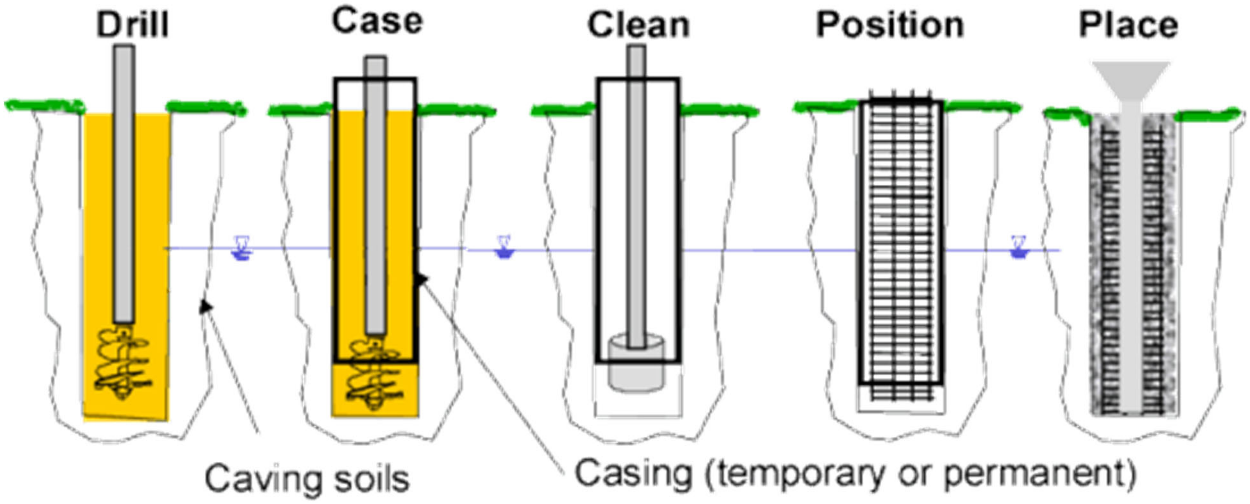
The excavation method for drilled shaft construction is dependent on a combination of factors. The following figures from the FHWA Drilled Shaft Tutorial illustrate the most common combinations.



Drill the shaft to the designed depth | Cleanout accumulated water and loose material | Positioning the reinforcement cage. | Concrete placed

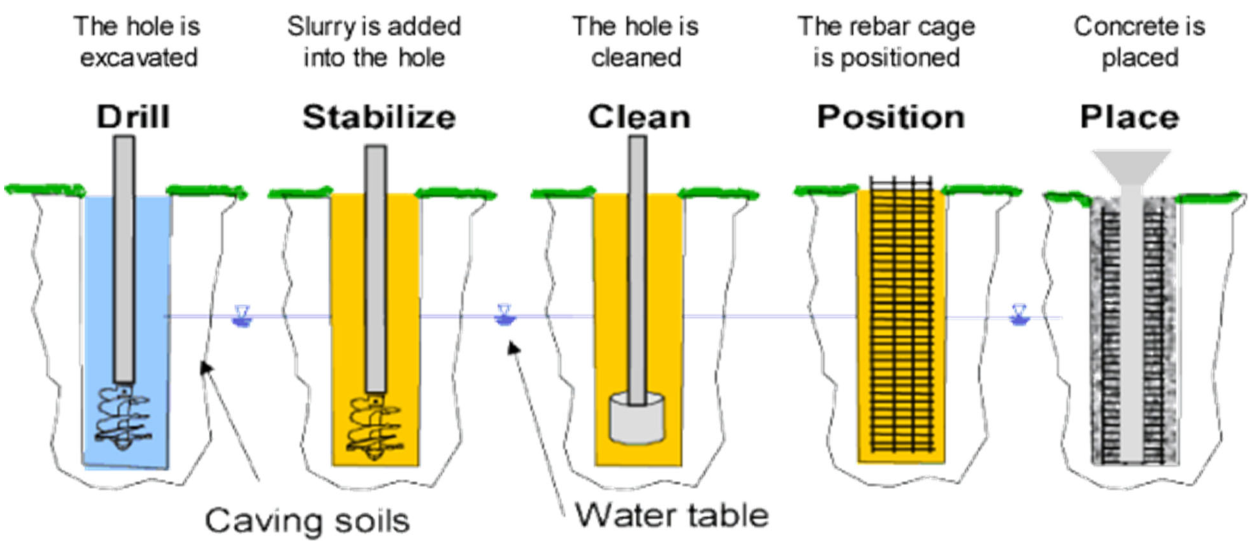
Dry hole excavations (a.k.a. Dry Method) are the simplest option for drilled shaft construction. Only a surface (a.k.a. starter) casing is utilized if any casing at all. Surface casings protect workers and provide additional benefits. Refer to 1.4 – Equipment and Safety for more information on surface casings. The Dry Method is suited for stiff to hard clayey soils which can stand vertically without sloughing or bulging. This method may also work in cemented sands or rock above the water table. Concrete placement in dry hole excavations is by freefall methods and is discussed in 4.2.2 – Concrete Placement.

Cased excavation methods (a.k.a. Casing Method) can be used for wet or dry hole excavations. Casing is used to prevent unstable soils from caving in and can also be used as a groundwater cutoff for intermediate water bearing granular layers. Casing can be temporary or permanent. Temporary casing (a.k.a. Temporary Casing Method) is installed to stabilize the excavation, and is typically 6 inches larger than the specified drilled shaft diameter to allow passage of the drilling tools. The temporary casing is removed after placing sufficient concrete in the shaft excavation. Permanent casing becomes a part of the final drilled shaft. Permanent casing is often used adjacent to critical structures or structures supported on shallow footings. The permanent casing reduces the risk of damage to these structures by preventing ground movement caused by the excavation process. Permanent casing may also be used to extend the shaft above the ground surface or the water surface if constructing in a river. Other subsurface conditions may also require permanent casing.



When temporary casing is used, another reason the diameter of the cased length will be enlarged is to set the casing in the excavation. The temporary casing can also be pushed or twisted into the soil ahead of the excavation. When permanent casing is used, the casing should be twisted into the soil so that it is tight against the excavation. The permanent casing must be a tight fit to provide lateral load transfer.

When temporary casing is used and the top of the shaft is within an unstable layer, a liner may be installed within the temporary casing. The diameter of the liner is selected to be the design diameter of the shaft. The liner will also be a minimum of 6 inches smaller diameter than the temporary casing it is placed within. A liner is generally thinner steel than permanent steel casing and is usually constructed from corrugated metal pipe. Once the shaft excavation is completed, the corrugated liner is set to the appropriate level and should extend a minimum of 2 feet below the base of the temporary casing. The shaft and liner are then filled with concrete to the design level. The shaft concrete should be allowed to set overnight and the following day the space between the liner and the temporary casing (annulus) is backfilled with a cement-sand grout mixture. The temporary casing can then be removed while the grout is still fluid. Backfilling the annulus with grout and pulling the casing while the grout is fluid helps prevent a gap from developing between the liner and the surrounding soil. This also limits surface settlement which would occur over time if the annulus is left unfilled. Direct contact between the shaft or grout and the surrounding soils is imperative when shafts will support lateral loads.



The most complicated construction method for drilled shafts for both the contractor and the inspector is wet hole excavations (a.k.a. Wet Method or Slurry Method). For the Slurry Method, construction is being completed in the blind. The fluid in the shaft prevents direct observation of the base and sides of the shaft. Careful construction and detailed inspection is required for successful shaft construction.

The Slurry Method is used when the excavation extends into water bearing granular soils. The shaft excavation progresses to, or slightly above the water bearing layer using either a cased hole or an open hole. The shaft is then flooded with water or slurry mixture. The level of the drilling fluid (water or slurry) in the excavation is maintained above the surrounding groundwater level. By maintaining this higher fluid level, groundwater infiltration into the excavation is prevented. Infiltration into the excavation is undesirable as it can soften and loosen the material at the base and on the side walls of the excavation. The pressure of the drilling fluid acting on the walls of the excavation stabilizes the excavation and limits the material from sloughing or caving into the excavation.

The use of solely water as the drilling fluid is rare and will require a review by the design engineer. The presence of free water against some clayey soils and rocks such as shale can cause the materials to soften. A soft layer along the shaft will reduce the amount of friction that is developed in the shaft and reduce the axial load resistance. To prevent this softening from occurring additives are introduced to the water which will create the slurry mixture. The two most common additives are bentonite clay and polymer.

When a slurry mixture is introduced into a drilled shaft excavation, the slurry will provide stability of the excavated hole by forming a filter cake (a.k.a. mudcake or slurry cake) which effectively acts as a membrane on the walls of the shaft. This membrane requires the slurry head pressure to exceed the fluid pressure resulting from the in situ formation. Thus, a stable hole will be maintained. For the slurry head pressure to exert this positive pressure on the wall, the slurry has a density higher than the groundwater, and the slurry elevation in the hole is higher than the surrounding groundwater elevation. Refer to 4.2.2 – Concrete Placement for additional information on head pressure.

Polymer is becoming more common in drilling as it is easier to handle, and requires less equipment for cleaning and reusing the slurry, than bentonite slurry. One advantage of polymer over bentonite is that sand will settle out of the polymer slurry while sand and silt become suspended in bentonite slurry. It is important to control the sand content of the slurry mixture especially prior to concrete placement. High sand content will affect the quality of the concrete and integrity of the shaft. Slurry with a high sand content will often be too dense or too viscous to be displaced by the concrete placement operations which can create voids in the shaft. In addition, the high sand content can settle in the concrete and create soil inclusions or contaminate the surface of the concrete during the pour which can affect the compressive strength of the concrete. Over the course of three to four hours, sand will settle out of polymer slurry and can be removed from the base of the excavation using clean up tools. To remove the sand from bentonite slurry, the fluid must be circulated with pumps through screens and a centrifuge (de-sanding unit) to remove the sand particles and then be pumped back into the shaft excavation.

Strict quality control of the drilling fluid is required for water or the slurry mixture. The drilling fluid is tested for density, viscosity, pH, and sand content. The drilling fluid properties should be discussed prior to construction. A discussion of slurry disposal is also required since it is considered a pollutant. The contractor is required by specification to provide a technical representative at the jobsite for a slurry additive, and testing the water or slurry is their responsibility. However, the inspector must record test results and compare to specifications.

The density of the drilling fluid is checked with a mud balance. The viscosity of the drilling fluid is determined by measuring the amount of time required for a quart of drilling fluid to flow through a specially sized (Marsh) funnel. The pH of the drilling fluid is used to determine how acidic or basic the drilling fluid is in the shaft. Digital pH meters or test strips are common methods used to evaluate the pH of the fluid.

The sand content of the drilling fluid is determined by passing a specific volume of drilling fluid through a screen which captures all sand sized and larger particles. The volume of sand retained is then determined using a measuring cylinder. When sampling slurry from a shaft excavation, it is important to sample slurry within 24 inches of the base of the excavation just before the concrete is placed. Specially designed slurry samplers are available for bottom sampling.

If the sand content fails for bentonite slurry, the drilling fluid from the bottom must be circulated through the de-sanding unit and added back into the top of the shaft. Another sand content sample is taken and the test repeated. If the sand content fails for polymer slurry, wait one to two hours for additional sand to settle out. After the waiting period, the contractor will need to clean the shaft bottom again and the test is repeated.

3 Shaft Excavation Inspection

3.1 – Work Plan

The Contractor is required to submit a drilled shaft installation plan (Form BBS 133) at least 28 days prior to drilled shaft construction according to Section 516. Thereafter, a pre-drill meeting is held with the Contractor before construction. The goal of the meeting is to have a clear understanding of the Contractor's plan to construct the drilled shafts. At the same time, the Contractor should have an understanding of how the inspector intends to inspect the shafts and the need to work together. Refer to 8.2 – Example of Drilled Shaft Pre-Drill Meeting Agenda for assistance with developing an agenda.

3.2 – Excavation

When shaft excavation is ready to proceed, it is recommended to notify the District Geotechnical Engineer. The District Geotechnical Engineer can provide assistance with testing of the soil excavation material as discussed in 1.4 – Safety and Equipment. It is also recommended to have the contact information of the design engineer. Once the shaft excavation process begins, it is important for the inspector to record construction as it proceeds. Accurate records are essential if any design changes are required. To accomplish this, the drilled shaft excavation and inspection record (Form BBS 134) is completed. During shaft excavation, the inspector needs to observe and record the soil conditions which are encountered. It is important to compare these conditions to the soil boring logs in the vicinity to confirm that the encountered soil conditions match the conditions that were used to develop the design of the shaft. The drilled shaft Inspector will record the soil type, depth, strength, and any other observations that help identify the soil, and will note any groundwater or caving conditions. If there are significant deviations in soil types, soil stratum depths, soil strengths, or other ground conditions encountered by the driller when compared to the soil boring logs, the inspector is required to notify the design engineer.

It is also important to record the dimensions of the excavation. In cased excavations, the diameter of the shaft may vary with depth. The inspector needs to record the levels at which the casings extend to and the depths and diameters of the casings. If any other changes in diameter occur, such as a rock socket, they must also be recorded.

The length of the shaft in the soil and the rock also needs to be recorded accurately. If the lengths are different than those indicated on the design drawings, the inspector needs to notify the design engineer.

Once the shaft excavation has reached the design depths the inspector needs to confirm that the material at the base of the excavation meets the requirements of the design, the base of the shaft is sufficiently clean, and the shaft meets the specified vertical plumbness. To determine vertical plumbness of the shaft, compare the location of the top of shaft to the bottom of shaft. Take the difference in top and bottom location divided by shaft length to determine percent out of plumb.

The inspector should be aware of the smearing of medium to soft clays on the walls of the excavation. If the contractor is not careful about how these materials are removed, they can adhere to the sides of the excavation and act as a lubricant between the shaft concrete and soils surrounding the shaft. If the inspector suspects that the sides of the shaft have been slickened by auger trimmings, then the contractor should ream the hole until the sides are returned to their original condition. A shaft may also need to be reamed if the sidewall has softened, swelled, or has a buildup of slurry cake.

When excavating while using the Slurry Method, the augers should enter and exit the excavation slowly. Any fast movements may cause turbulence and possibly erode the sides of the excavation.

The inspector should also record any observations that water has softened the soil or rock as discussed in 2.3 – Shaft Excavation Methods.

3.3 – Obstructions and Differing Site Conditions

During the course of the excavation process obstructions may be encountered, and the contractor may be entitled to additional compensation. IDOT specifications define an obstruction as “an unknown isolated object that causes the shaft excavation method to experience a significant decrease in the actual production rate and requires the contractor to core, break up, push aside, or use other means to mitigate the obstruction. Subsurface conditions such as boulders, cobbles, or logs and buried infrastructure such as footings, piling, or abandoned utilities, when shown on the plans, shall not constitute an obstruction”. When an obstruction is encountered, the contractor is to notify the inspector for concurrence that an obstruction has been encountered. Thereafter, the work effort to remove the obstruction is recorded by the inspector, which will allow additional compensation to the contractor. In addition, there is no deduction to the measured shaft length when measuring for payment.

In regards to obstructions, a boulder or cobble is one of the more common since a small diameter boring could easily miss it. Per AASHTO M 146, a boulder is defined as a rock fragment with an average dimension of 12 inches or more, and a cobble has an average dimension between 3 and 12 inches. A boulder or cobble may be removed by a downhole hammer as discussed in 2.2.2 – Rock Drilling Tools, but this is uncommon. Other more common methods include a grab bucket or clamshell, boulder rooter (basically a tapered auger), or a hammergrab. A hammergrab is a percussion tool that both breaks and lifts rock. Hammergrabs are heavy and the jaws are closed when the tool is dropped to break the rock. The jaws are then used to pick up the broken rock. A rock breaker/drop chisel (heavy object to break rock) in combination with a grab bucket or clamshell may be used in lieu of a hammergrab. The disadvantage is the need to make a tool change, whereas a hammergrab can do it in one operation.

A differing site condition is different from an obstruction, and may be one of two types. The first type is defined in Article 104.03 as subsurface or latent physical conditions encountered at the site differing materially from those indicated in the contract. One example would be larger rock, such as encountering cobbles and boulders instead of sand in a soil boring strata. Another example would be rock that is harder to drill, such as granite instead of limestone was encountered. For the Contractor to receive additional compensation, the contractor must prove the following:

1. The contract documents must have affirmatively indicated or represented the subsurface or latent physical conditions.
2. The contractor must have acted as a reasonably prudent contractor in interpreting the contract documents.
3. The contractor must have reasonably relied on the indications of the subsurface or latent physical conditions in the contract.
4. The subsurface or latent physical conditions actually encountered within the contract area must have differed materially from the conditions indicated in the same contract area.
5. The actual subsurface conditions or latent physical conditions encountered must have been reasonably unforeseeable.
6. The Contractor’s claimed excess costs must be shown to be solely attributable to the materially different subsurface or latent physical conditions within the contract site.

The second type is defined in Article 104.03 as unknown physical conditions of an unusual nature, differing materially from those ordinarily encountered and generally recognized as inherent in the work. An example of this would be a hazardous waste deposit. For the Contractor to receive additional compensation, the contractor must prove the following:

1. That it did not know about the condition
2. That it could not have reasonably anticipated the condition after a review of the contract documents, a site inspection, and the contractor's general experience in that area.
3. That the condition was unusual because it varied from the norm in similar construction work.

When a differing site condition is encountered, the compensation for a portion of the measured length of the shaft may be adjusted according to Article 104.02. When a differing site condition occurs, the inspector should notify their supervisor and the design engineer.

3.4 – Shaft Sizes and Tolerances

During construction it is important to record the length and diameter of the shaft. In some cases, the diameter of the shaft may be slightly larger than the diameter indicated on design drawings. When telescoped casing sections or a casing with a liner is installed some portions of the shaft may be larger than the design diameter of the shaft. Oversizing the diameter of the top of the shaft is required so that the base of the shaft meets the minimum design diameter requirements.
The length of the shaft may vary slightly from the design length. Shafts are often designed to bear at or near the top of a hard layer. Slight over excavation is sometimes necessary to meet the required bearing condition. For rock socketed drilled shafts, the constructed length of the rock socket must be at least the length indicated on the design drawings regardless of the overall shaft length.

Section 516 provides the specific requirements regarding construction tolerances and should be reviewed by the inspector.

3.5 – Squeezing, Necking and Cave-Ins

A contractor using the proper size excavation equipment does not necessarily insure that the shaft excavation will be the required diameter. A number of problems can occur during the excavation process that will provide a larger or smaller shaft. In soft cohesive soils, squeezing or necking of the shaft can occur if the shear strength of the soft clay is not sufficient to support the weight of the overburden soils at the free face of the excavation. The weight applied to these low strength soils could cause the clay wall to squeeze into the shaft creating a smaller diameter. Squeeze is more likely to occur the longer a shaft is kept open. To preventing necking, casing or slurry should be extended into the soft layer to provide stability.

A simple formula for predicting clay squeeze relates the clay unconfined strength to the depth of the excavation:

$$Q_u \text{ required (tsf)} \geq H \text{ (ft)} / 50$$

If the measured unconfined compressive strength of a clay sample taken off an auger flight is less than the depth of the shaft divided by 50, there is a risk of squeeze occurring. Clay with a water content that exceeds 30% is also an indicator of potential squeeze problems.

Example: A boring log shows soft clay with an unconfined strength of 0.4 tsf at a depth of 40 ft below grade. The contractor intends to open drill through the material. The water content of the soft clay is 35%. Based on the formula, the necessary unconfined strength to resist squeeze at 40 ft would be 40/50 or 0.8 tsf. The strength shown on the boring log is 0.4 tsf or ½ that predicted for stability. Also the high water content (> 30%) is an indicator of potential squeeze. Thus, squeeze is likely if casing or slurry is not used.

In some soils, typically more granular materials, caving and sloughing of material off the sides of the excavation can occur. Caving of clayey soils can also occur when excavations are left open for long periods of time. The excavation process disturbs the soils on the shaft walls which loosens them. As the auger comes in and out of the excavation, or if groundwater flow is present, these loosened soils will slough off the side of the excavation and fall in.

To identify if necking or caving is occurring it is necessary to pay close attention during excavation especially as the excavation tools are entering and leaving the excavation. If the shaft is experiencing necking the auger will consistently hang up at the same depth. If caving is occurring, materials from the upper parts of the shaft will fall onto the auger, drilling bucket or belling bucket as they enter and leave the excavation. Also, after the tool is out of the hole, the inspector will be able to hear caving soils falling into the base of the excavation.

If necking is occurring, casing should be installed into the excavation to below the level experiencing squeezing. Casing should also be installed when sloughing soils are encountered. The alternative to casing is slurry. If squeezing soils are not supported by casing or slurry, the shaft section could be inadvertently reduced which will lower the capacity of the shaft. If caving occurs during concrete placement, the resulting soil inclusions would represent a major defect and the shaft capacity would be reduced.

3.6 – <u>Rock Sockets</u>

As previously discussed, rock socketed drilled shafts often develop the majority of their capacity in the rock socket. Therefore, it is very important to make sure the rock socket is the proper length and diameter. The rock socket length is measured from the rock surface to the bottom of the rock socket. To accurately determine the socket length, it is necessary to accurately determine the location of the top of rock. Section 516 defines rock as “bedded and conglomerate deposits exhibiting the physical characteristics and difficulty of rock removal”. Essentially, the top of rock surface is defined when the excavation can no longer proceed using conventional earth excavation equipment. When refusal is encountered with an earth auger and rock drilling equipment such as rock augers or coring equipment is required to continue the excavation, rock has been encountered.

When rock is encountered, the elevation of the top of rock should be compared to the elevation rock was encountered at in the nearby soil borings. If the rock is encountered higher than expected the shaft excavation may be resting on shelf rock or a boulder. The inspector should observe that the degree of drilling difficulty does not reduce substantially while drilling the rock socket.

For end bearing drilled shafts on the top of rock, confirmation that the shaft is supported on bedrock and not just a boulder or shelf rock over soil is even more important. The inspector may ask the contractor to use a core barrel to extend a shaft deeper into bedrock when unusual conditions are encountered or when doubt exists.

If the top of rock elevation differs from that shown on the plans by more than 10 percent of the length of the drilled shaft above the rock, the inspector is required to notify the design engineer. Refer to 3.7.3 – Rock Socket Shafts and Top of Rock Shafts for additional information.

3.7 – <u>Shaft Acceptance</u>

<u>3.7.1 – Friction Shafts</u>

The first step in evaluating the acceptance criteria for a shaft is determining if the shaft develops its capacity through skin friction or end bearing. If this cannot be determined from the Structure Geotechnical Report or the plans, the inspector should contact the design engineer. For friction shafts, it is necessary to evaluate the soil profile over the entire shaft length as explained in 3.2 - Excavation. If the conditions don’t match nearby soil borings or if the inspector is unsure about the conditions, contact the design engineer immediately. Be prepared to provide the conditions encountered.

3.7.2 – End Bearing Shafts in Soil

For end bearing shafts in soil two essential items need to be checked. First, the inspector needs to determine if the materials encountered at the base of the excavation are strong enough to support the loads that will be imposed by the shaft. Second, the inspector needs to determine if the soil is the correct material based on the design assumptions. If the shaft bears in sand or silt, it is not possible to test the base material other than confirming that the material type is correct. In clayey soils the unconfined compressive strength of the base material can be estimated by testing the auger cuttings from the bottom of the shaft. A number of tools are available for the testing including hand penetrometers and a RIMAC. The allowable bearing resistance can be approximated as 1.5 times the unconfined compressive strength.

If the bearing soil is not strong enough, contact the design engineer. The design engineer may extend the shaft deeper to find suitable bearing soils, require a larger diameter shaft, or require a larger diameter bell.

3.7.3 – Rock Socket Shafts and Top of Rock Shafts

As previously discussed for shafts bearing in or on rock, the majority of the shaft resistance is developed within or on the rock. The following items are to be checked for rock shafts.

- Confirm the top of rock elevation compares to soil boring and rock core logs as discussed in 3.6 – Rock Sockets.
- Confirm the encountered rock type matches the rock core logs.
- Confirm that there were no voids or weak seams encountered when excavating the rock socket. If voids or weak seams are encountered, contact the design engineer.
- Confirm the bottom is clean. Refer to 3.7.4 – Bottom Flatness and Cleanliness for additional information.

3.7.4 – Bottom Flatness and Cleanliness

For shafts bearing on soil or rock, specifications require excavation equipment to have a nearly planar bottom. The specifications further state that for shafts bearing on rock the cutting edges of excavation equipment used to create the bottom of shafts in rock shall be normal to the vertical axis of the shaft within a tolerance of 6.25 percent. Thus, when using a rock auger for soft rock, the bottom must be completed with a flat bottomed auger and a stinger is not allowed. The alternative to the flat bottomed auger is to allow the rock auger create a pilot hole with the stinger. A core barrel is then used, and the pilot hole provides some stress relief for final excavation. Bottom flatness is a key factor to facilitate the cleaning of the shaft. Contact the design engineer if there are concerns with the bottom flatness.

For all shafts which are supported partially or entirely supported by end bearing, bottom cleanliness is a critical issue. Loose auger cuttings at the base of the excavation create a compressible layer which is not suitable to support the foundation loads. For open dry shafts, visual inspection of the base of an excavation is often possible. The base of the excavation can be lit when necessary by using a high lumen flashlight, reflecting sunlight with a mirror, or by lowering an explosion proof light to the base of the excavation. For extremely deep excavations or excavations with an enlarged base, an explosion proof camera with a visual depth measurement gauge can be lowered to the base of the excavation for direct observation of the base cleanliness. When direct observation of the base of the excavation is not possible because of the use of drilling slurry, sounding the base of the excavation with a weighted tape or rock probe is necessary.

The base of the excavation should be sounded at five locations. Check the center of the hole, which is usually the cleanest. Then check the sides of the hole at four locations around the circumference of the shaft. If the weight strikes the bottom and stops immediately, the drilled shaft has little or no sediment and debris. Lifting and dropping the feeling device should produce the same feel everywhere if the bottom is firm, flat and uniform. If there is any doubt, perform additional cleaning of the hole. Refer to Section 516 for the depth of sediment or debris allowed for a drilled shaft terminating in soil or rock.

For shafts bearing on soil, a clean-out bucket should be sufficient. Check that the clean-out bucket has a flat bottom, and also check that the bucket is not riding up and down on a boulder or uneven rock when cleaning the hole. Refer to 2.2.3 – Clean Up Tools for more information on knowing when the hole is clean. For shafts bearing on rock, an airlift pump or downhole pump is frequently required to get the shaft bottom sufficiently clean. Refer to 2.2 – Clean Up Tools for more information on airlift and downhole pumps. For belled shafts on soil, clean the bottom with a belling bucket as best as possible. The remaining spoils can be back-bladed to the bell periphery with a 1 foot over-sized bucket.

4 Rebar and Concrete Inspection and Installation

Once the shaft excavation is completed the role of the inspector is not completed. The inspector also needs to confirm that the concrete and reinforcing steel are placed properly in the drilled shaft and meet the project requirements.

4.1 – Rebar

The contract documents will show the reinforcing steel details for each drilled shaft. Fabrication usually occurs at the project site, but can be prefabricated in some cases. When the cages are fabricated at the project site, they are built on the ground giving the inspector ample opportunity to observe the fabrication process. Reinforcing steel (rebar) for drilled shafts is typically tied in a circular cage. The cages consist of vertical reinforcing bars tied together with circular hoop ties or spiral ties. The following items need to be checked when inspecting a rebar cage.

- Check the grade of steel shown on the plans matches the mill certificate.
- Check the rebar number, sizes, spacing, lengths, and clearances match the plans. The vertical spacing for the spiral bar is sometimes referred to as pitch.
- Check the cage diameter matches the plans and the cage length meets field drilled lengths. A sizing hoop (a.k.a. gauge hoop) may be used to aid in the fabrication of the rebar cage with the approval of the design engineer. The gauge hoop is located within the interior of the cage.
- Check proper rebar lap lengths. When mechanical splicers are specified, lap splices are not to be substituted. Lab or mechanical splices should be staggered to prevent an obstruction to concrete flow, and for structural considerations. The inspector should contact the design engineer if there are any questions.
- Refer to Section 508 and Article 1006.10 for additional rebar requirements.

After the inspector has confirmed the rebar cage meets the design requirements, additional considerations related to the installation are required. It is important the rebar is free from mud and debris when placed in the hole. It is also important the cage is lifted and installed properly. The cages should be picked up and moved from multiple lifting points. Cross bracing should be installed within the cage to prevent deformation. In some cases, a lifting cradle (a.k.a. as a strong-back) can be attached to the cage to prevent the cage from deforming.

When the cages are lifted, the inspector must look for any twisting or distortions that may have bent bars. Rebar cages are built horizontally on the ground and then lifted vertically for lowering into the hole. The cages themselves are long, slender and flimsy. The process of lifting a cage to a vertical position can severely distort and bend portions of the rebar cage. High stress concentrations can develop in a drilled shaft when distorted cages are used. Closely examine the rebar cage as it is lowered into the hole. If the inspector notices significant bending or distortion of the bars that affects bar straightness, spiral pitch, bar spacing, or cage shape and diameter, the cage should be lifted from the hole and the bent bars replaced. Once the cage has been lifted and set in place, no visual permanent deformation should be noted. The specified vertical plumbness of the rebar cage is then checked. To determine vertical plumbness of the rebar cage, compare the location of the top of rebar cage to the bottom of rebar cage. Take the difference in top and bottom location divided by cage length to determine percent out of plumb.

Cage centralizers (a.k.a. rolling spacers) are also required for drilled shaft construction. Centralizers ensure that the minimum rebar concrete cover is provided around the perimeter of the cage, and they keep the rebar cage properly aligned in the hole until the concrete is placed. Centralizers should be round and roll freely around the bars when they are attached to the reinforcement. If they can turn freely as the cage is lowered into the hole, they will minimize the amount of loose material that falls into the hole if the cage hits the side of the excavation. The centralizers should be attached to the hoop or spiral ties so that they roll vertically along the shaft wall. Centralizers are required to be constructed from a non-corrosive material. Two examples are a concrete ring or plastic wheel. The centralizers should be attached at multiple points around the perimeter of the cage, at the maximum vertical spacing, and near the top and bottom of the cage as specified in Section 516.

To prevent rebar corrosion, the design drawings may require concrete cover between the base of the drilled shaft and the rebar cage. Plastic chairs or other devices may be used for this purpose. The devices may also be called clearance boots.

Rebar spacing must be designed to work with the concrete mix design. It is recommended the clear spacing between rebar should not be less than 5 times the nominal maximum aggregate size for concrete placement in a dry shaft, and 8 times the nominal maximum aggregate size for concrete placement underwater. It is also recommended the nominal maximum aggregate size does not exceed two-thirds the clear distance between the reinforcement bar and the permanent casing or shaft wall. Nominal maximum aggregate size is defined as the largest sieve which retains any of the aggregate sample particles. IDOT Class DS concrete mix designs typically use a nominal maximum aggregate size of ½ inch or less.

When non-destructive testing tubes are added to a cage as explained in 6 Non-Destructive Testing and Loading in this manual, they would typically be placed midway between vertical bars. However, if the clear spacing between the tube and bar drops below the recommended spacing, concrete placement problems could occur. If this occurs, contact the design engineer.

One final comment on rebar consists of the term “bundled” bars. The inspector should be familiar with this term. In some cases two or three vertical bars are placed next to each other to increase the steel percentage, and to maintain appropriate rebar spacing for concrete placement.

4.2 – Concrete

Multiple items need to be checked and monitored for concrete, and are discussed in the following sections.

4.2.1 – Concrete Mix Design Slump and Slump Retention

As previously discussed, one crucial issue in the concrete mix design is the acceptable nominal maximum aggregate size for the rebar spacing. Another important issue is maintaining proper slump. According to Article 1020.04, the slump is to be 6 – 8 inches. If concrete is placed to displace drilling fluid (water or slurry), or against temporary casing, the slump shall be 8 – 10 inches at the point of placement. This fluid concrete is required since vibrators are not used to consolidate the concrete around the rebar, and to fill any voids along the wall of the excavation. Filling the voids will enhance the skin friction of the shaft.

Section 516 has additional requirements for slump which involves slump retention. Temporary casing is to be withdrawn before the slump of the concrete drops below 6 inches. The higher slump will make it easier to remove the casing. It will also ensure the concrete will displace any drilling fluid, and will flow out and fill any voids behind the casing during the removal process. Another requirement is the slump of all concrete placed shall be a minimum of 6 inches at the end of concrete placement for the Slurry Method. This is required to ensure the initial concrete placed and pushed up and out of the shaft is fluid, and will not entrap laitance or sediment in the concrete and thus the shaft itself. In order to know how long the mix will provide a slump of at least 6 inches, a trial batch of the concrete mixture is required for these two situations. A simple method for performing the trial batch is as follows:

- Batch four cubic yards of concrete. It is important to batch at the approximate concrete and air temperatures anticipated in the field.
- Obtain a sample of the concrete by filling up a five gallon bucket. The remaining concrete is available for use on the project.
- Perform a slump test every 15 minutes until it at least falls below 6 inches. No additional testing is recommended if the slump reaches 4 inches. It is suggested to plot the results with slump on the vertical axis and time on the horizontal axis. This will help to interpolate the time when the slump reaches 6 inches. After the test is completed, the concrete is put back in the bucket.
- During the interim between slump tests, put a lid on the bucket and place the bucket in a wheelbarrow filled with water. The lid will prevent evaporation, and the water should help minimize heat gain between tests. It is also important to keep the bucket in the shade.

For a mix design, slump retention can be maximized by batching the maximum water, using a retarder, and using a long lasting superplasticizer. Certain retarders known as hydration stabilizers will work a little better to retain slump because the delay in set is a very linear relationship. However, any retarder is acceptable. In regards to a long lasting superplasticizer, the polycarboxylate type superplasticizer has the longest retention time.

4.2.2 – Concrete Placement

Concrete placement is a critical stage of shaft construction, and the shaft needs to be ready before concrete arrives to facilitate a quality concrete pour. Holes normally are not left open overnight because of the risk of a major collapse. IDOT specifications require concrete placement to begin within 1 hour of shaft cleaning and inspection. As soon as the hole is accepted for cleanliness, the Contractor shall begin to set the rebar cage. This rapid sequence of events will minimize the chance of shaft material sloughing or caving in the hole, which would require it to be cleaned again.

Once concrete placement begins, it is important to record concrete placement as it proceeds. To accomplish this, the drilled shaft concrete placement log (Form BBS 135) is completed. This form provides a log of key information that should be recorded on the job. Any problems encountered while placing the concrete such as movement of rebar cage or loss of concrete slump retention is recorded.

For open dry shafts, concrete can often be placed by free fall. A critical issue with free fall placement is not allowing the concrete to fall through standing water. Free fall placement is allowed if there is a small amount of standing water present in the base of the excavation and water infiltration is low. IDOT specifications require the rate of water infiltration into the shaft to be less than 12 inches per hour, and the depth of water in the shaft excavation to be less than 3 inches at the time of concrete placement. Research has shown that concrete falling through as little as 6 inches of water can reduce the unconfined compressive strength of the concrete by half. If the water depth is more than 3 inches, the Contractor may use a small diameter cleanout bucket, air lift pump, or dewatering pump to remove the water. If the water infiltration rate into the shaft is greater than 12 inches per hour, free fall is prohibited because poor quality concrete may occur despite efforts to dewater the hole immediately before concrete placement.

Another important consideration during free fall placement is placing the concrete down the center of the excavation. Concrete should not hit the side walls of the excavation or the rebar cage as it falls down the excavation. This will segregate the coarse aggregate from the mortar within the concrete mixture. IDOT specifications state that concrete shall not be allowed to fall more than 60 feet for conventional concrete and 30 feet for self-consolidating concrete. If the shaft length is greater than the allowable free fall height, a drop chute can be used to decrease the free fall height to within allowable limits.

When concrete must be placed in an excavation with more than 3 inches of standing water or the infiltration rate is greater than 12 inches per hour, concrete must be placed by tremie or concrete pump. A tremie or pump is also used for the Slurry Method of construction. The purpose is to prevent intermingling of the concrete with the drilling fluid (water or slurry). Concrete placed by tremie or pump should have a slump at the upper limit of the allowable slump range.

For many shafts, it will not be possible to visually monitor the excavation as the concrete placement continues. This is especially true for concrete placement when displacing drilling fluid. The shaft and top of concrete will be obscured from view for the majority of the pour. To monitor the integrity of the shaft, which should be done for dry or wet shafts, the volume of concrete placed is monitored along with the height of the concrete in the shaft. A theoretical line relating volume to depth is created and compared to the recorded values. Normally a measurement is taken after discharge of each truck, and this information is recorded by the inspector on the front and back of the drilled shaft concrete placement log (Form BBS 135). An explanation for calculating the theoretical line follows:

- For a straight shaft, the total volume is the shaft area times the shaft length. Be careful about units, since concrete is measured in cubic yards. The shaft dimensions are measured in feet, and the calculated cubic feet volume is divided by 27 to get cubic yards.
- The formula is $((\pi r^2)X(\text{shaft length}))\div 27$.
- Example:
  Shaft Diameter = 4.0 feet
  Shaft Radius = 4.0 feet ÷ 2 = 2.0 feet
  Shaft Length = 60.0 feet
  $\pi = 3.14$
  $((3.14 \text{ X } 2.0^2)X(60.0))\div 27 = 27.9$ cubic yards
- Straight shafts may vary in diameter over the length. For example, the diameter of a rock socket is normally smaller than the shaft. In this case, compute the volume for each segment and add the segments together to get the total volume.
- Note: There is an alternate formula that may be used and is explained in 8.3 – Drilled Shaft and Belled Concrete Volume Calculation Tables.

When comparing the theoretical concrete volume to be placed with the actual concrete volume placed, this is done after discharge of each truck. If the actual amount of concrete placed is larger, this can be an indication there was a void or cavity in the wall of the shaft. If the actual amount of concrete placed is smaller than the theoretical volume, this can be an indication of a void in the shaft. A void may occur from pulling the casing (Refer to 4.2.3 – Removal of Temporary Casing), shaft squeeze or necking because of soft soils, side wall caving or sloughing of the excavation, or the concrete did not flow through the rebar cage due to slump.

At the beginning of tremie or pump placement, the initial concrete flow must be in a manner that will not cause contamination of the concrete with the drilling fluid. IDOT specifications require a "closed" tremie or pump system to be used. For this system, the discharge end will use a steel pipe with a steel or wood flap gate that has gaskets. Another option is a wood plug which may float to the surface. The wood plug is beveled to hold it in place, or it may be tied to the steel pipe to keep it in place. The wood plug is covered with a sheet of plastic or shall have a gasket. The inspector is advised that aluminum or plastic pipe is not allowed as a substitution for steel pipe. Aluminum will react with the concrete and plastic pipe has been known to break. Steel pipe has the additional advantage of being heavier and will counteract buoyancy.

IDOT specifications do not allow an "open" tremie or pump to be used. A traveling plug (a.k.a. as a pig or rabbit) constructed of polystyrene, closed cell foam, or foam rubber is inserted ahead of the concrete. A similar plug is the go-devil, which is a ball of rolled-up burlap or specially fabricated material. The traveling plug displaces the water inside the tremie pipe or pump line as the concrete falls or is pumped, which will prevent intermingling of water and the concrete. The plug normally floats to the surface once it has exited the discharge end. The disadvantage of the plug is the concern it will compress as it moves against the hydrostatic pressure from the drilling fluid, allowing the concrete to mix with the drilling fluid. Also, a traveling plug is not to be used after the loss of seal, where the discharge end of the tremie or pump becomes separated from the concrete. Once concrete flow is initiated, IDOT specifications require the discharge end to remain embedded in the concrete. If the traveling plug is used to restart concrete placement, it will push out water out of the pipe. This will wash cement and cementitious materials out of the previously placed concrete.

During the initial placement of concrete with a tremie or pump, the discharge end shall be kept within a few inches of the bottom until the discharge end of the tremie or pump is a minimum of 10 feet below the concrete surface. This will ensure there is no breach of the seal created by embedding the end into the concrete. A breach can occur when there is not a sufficient head of concrete when raising the tremie or pump pipe. If the drilling fluid (water or slurry) head pressure is higher, it is possible for the drilling fluid to “back-surge” or enter the discharge end. This will cause the concrete and drilling fluid to intermix. IDOT specifications require a minimum of 10 feet of embedment throughout concrete placement. It is not recommended to have excessive embedment. Excessive embedment into the concrete can cause the reinforcing cage to lift along with the rising column of concrete. The inspector must monitor the embedment of the tremie or pump into the concrete at all times throughout the pour.

As previously discussed in 4.2.1 – Concrete Mix Design Slump and Slump Retention, it is important for all concrete to have a minimum 6 inches of slump at the end of the pour for the Slurry Method. Therefore, for concrete being placed it is recommended to monitor slump loss as explained in 4.2.1.

At the completion of the concrete pour, there will be contaminated concrete at the surface since it was in contact with the drilling fluid. Shaft material such as soil and debris will also be mixed in with the concrete. Even a dry excavation can have contamination because of accumulated bleed water. IDOT specifications require concrete placement to continue until 18 inches of good quality, uncontaminated concrete is expelled at the top of the shaft. The inspector has the option and is encouraged to take a strength sample to ensure the concrete is of acceptable quality after the 18 inches is expelled. The inspector is also reminded that contaminated concrete must be expelled and disposed of in a proper manner.

If at any time the discharge end of the tremie or pump does not remain embedded in the concrete, restart the pour with the previously discussed “closed” system. Since there has been a break in the seal, the concrete may have to be over poured several feet to flush out the contaminated concrete.

4.2.3 – Removal of Temporary Casing

A common technique during drilled shaft construction is the removal of temporary casing during concrete placement. This technique is often referred to as the “pour and pull” method. The method can be used with single temporary casing or multiple, telescoped casings. The temporary casing was installed to retain a squeezing layer, water bearing layer or caving layer. The casing for these layers cannot be removed until the concrete level is above the layer of concern a sufficient level to maintain the stability of the layer. As the concrete level rises in the shaft and into the casing, the casing is generally broken loose to relieve some of the friction along the side of the shaft. During removal of the casing, the level of concrete in the casing shall be maintained at a level such that the head pressure inside the casing is a minimum of 1.25 times the head pressure outside the casing. The purpose of this head pressure is to prevent breach of the casing and inflow of drilling fluid. The drilling fluid will most likely be mixed with soil. This pressure head will also help fill surface voids in the wall, and compact loose soil material to ensure a tight fit for friction purposes. In no case shall the concrete be less than 5 feet above the bottom of the casing when the casing is broken loose to ensure this tight fit. It is possible for the casing to jump 3 or 4 feet when it is broken loose. An example of inside and outside head pressure when removing casing follows.

- Concrete head is calculated as unit weight of concrete times the depth of concrete in feet within the shaft. Assume the unit weight of concrete is 145 pounds per cubic feet.
- Drilling fluid head (water or slurry) is calculated as drilling fluid unit weight times the depth of drilling fluid in feet within the shaft. Assume the unit weight of drilling fluid (in this case water) is 62.4 pounds per cubic feet.
- Outside head pressure is calculated as unit weight of groundwater times the depth of groundwater in feet, which is measured from the bottom of the casing to the groundwater elevation. Assume the unit weight of groundwater is 62.4 pounds per cubic feet.
- Example:
  Assume the depth of concrete inside the casing is 5 feet. The 5 feet is measured up from the bottom of the casing.
  Concrete Head Pressure = 145 X 5 = 725 pounds per square feet
  Assume the depth of drilling fluid inside the casing is 10 feet above the concrete.
  Drilling Fluid Head Pressure = 62.4 X 10 = 624 pounds per square feet
  Total Head Pressure Inside the Casing = 725 + 624 = 1,349 pounds per square feet
  Assume the depth of groundwater measured from the bottom of the casing to the groundwater elevation is 20 feet.
  Total Head Pressure Outside the Casing = 62.4 X 20 = 1,248 pounds per square feet
  Minimum Head Pressure Required Inside the Casing = 1.25 X 1,248 = 1,560 pounds per square feet
  The actual head pressure inside the casing is inadequate per specifications to begin removal of the casing.

When casing is used, it is important the interior of the casing is free from concrete to facilitate removal. It is also important the inspector measure the depth of concrete before and after the casing is broke loose. If the concrete has risen, this is an indication that soil or drilling fluid has been sucked into the shaft. This could result in necking of the shaft or complete loss of concrete in a section of the shaft. When the casing is pulled, the concrete will normally drop immediately because of voids behind the casing. In addition, it is essential to have a continuous supply of concrete to ensure the head pressure inside the casing exceeds the head pressure outside the casing.

Even with head pressure, it is also essential to have the slump of the concrete at least 6 inches. It is possible that the Contractor will not be able to remove the casing if too much slump is lost. Therefore, it is recommended the inspector select appropriate samples of concrete to monitor slump loss as explained in 4.2.1 – Concrete Mix Design Slump and Slump Retention. By having 6 inches of slump, the concrete will be able to flow and displace drilling fluid, as well as completely fill the excavation. If there is inadequate slump, problems may occur such as arching or lifting of the concrete when the casing is raised. This may then cause a “neck” to form below the casing or possibly lift and twist the rebar cage. The inspector should place a target on the rebar cage and monitor movement with a level at the time when the casing is broken loose.

To pull casing, normally a downward pressure is used to cause movement. Hammering, or vibrating the casing may also be used to facilitate extraction. After the casing is broken loose, concrete placement should then proceed up to or slightly above the design concrete level. Once the final concrete level is achieved, the casing can be removed provided the head pressure in the casing is 1.25 times the head pressure outside the casing. As the casing is removed, continue to check the concrete level. The concrete will fill any voids behind the casing, and thus the level will drop slightly. Therefore, make sure there is a continuous supply of concrete. If the concrete level rises, it would be an indication that soil or drilling fluid outside the casing has collapsed into the concrete forming a defect.

5 Inspector's Checklist and Documentation

IDOT's Bureau of Construction has developed Construction Inspector's Checklists to provide guidance on the required inspection for various categories of work. A Construction Inspector's Checklist for Drilled Shafts is available online at www.idot.illinois.gov/ and provides a list of items to inspect before, during, and upon completion of work.

In regards to documentation, accurate and timely documentation of the drilled shaft construction process is an essential part of the drilled shaft inspector's job. All forms and documentation should be performed as the work progresses and on a daily basis. All forms for the project must be filled out completely. Use the field book for inspection of construction tolerances, and to record any additional information.

There are a total of three documents which the inspector is required to complete. The first document to complete is the drilled shaft excavation and inspection record (Form BBS134) which is explained in 3.2 – Excavation. The second document to complete is the front of the drilled shaft concrete placement log (Form BBS 135) which is explained in 4.2.2 – Concrete Placement. The third document to complete is the drilled shaft concrete curve, which is located on the back of Form BBS 135, and is explained in 4.2.2 – Concrete Placement.

6 Non-Destructive Testing and Load Testing

To confirm the quality of construction of drilled shafts, post construction testing can be utilized. Testing can be performed to confirm the integrity of the shaft. Testing can also be performed to determine the capacity of a constructed shaft to confirm the design assumptions which were made.

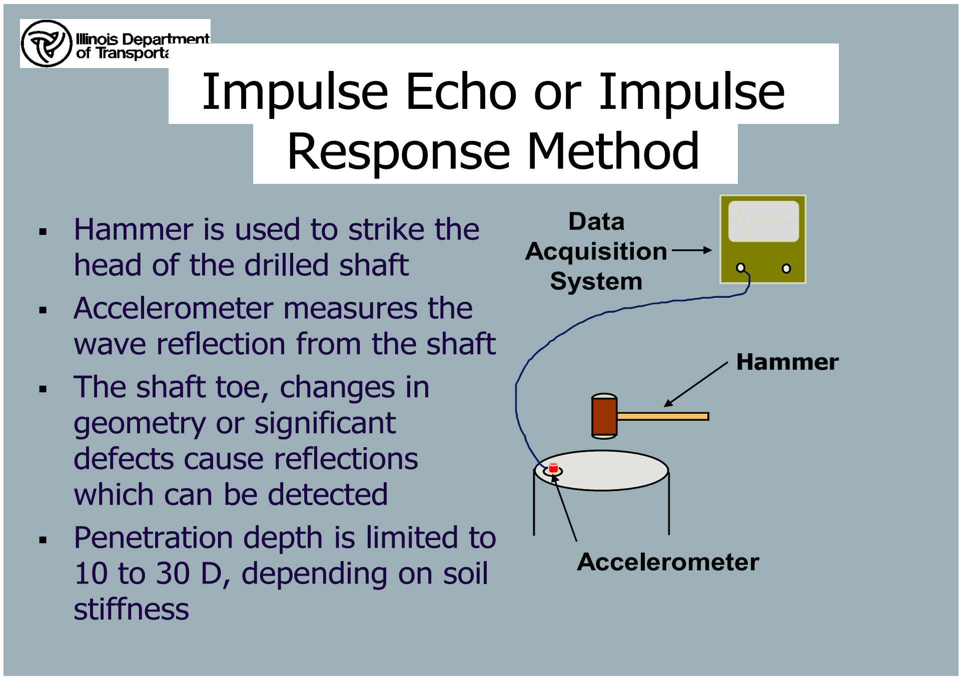
6.1 – Non-Destructive Testing

Non-destructive testing (NDT) is the general term used for a number of testing techniques which evaluate the condition of the drilled shaft without directly impacting the load carrying ability of the shaft. NDT is utilized to confirm the integrity of the constructed shaft. NDT can be performed on any type of shaft but is desirable for shafts where it is anticipated the Slurry Method will be employed. If NDT is used, there are five tests that are available. The most common test used on IDOT projects is cross-hole sonic logging (CSL). IDOT has also begun to evaluate thermal integrity profiling (TIP) on a limited basis for projects. For CSL and TIP, a Consultant that specializes in this area will evaluate the test results. The Drilled Shaft Excavation and Inspection Record (Form BBS 134) and Drilled Shaft Concrete Placement Log (Form BBS 135) should be provided to the Consultant to aid in their evaluation.

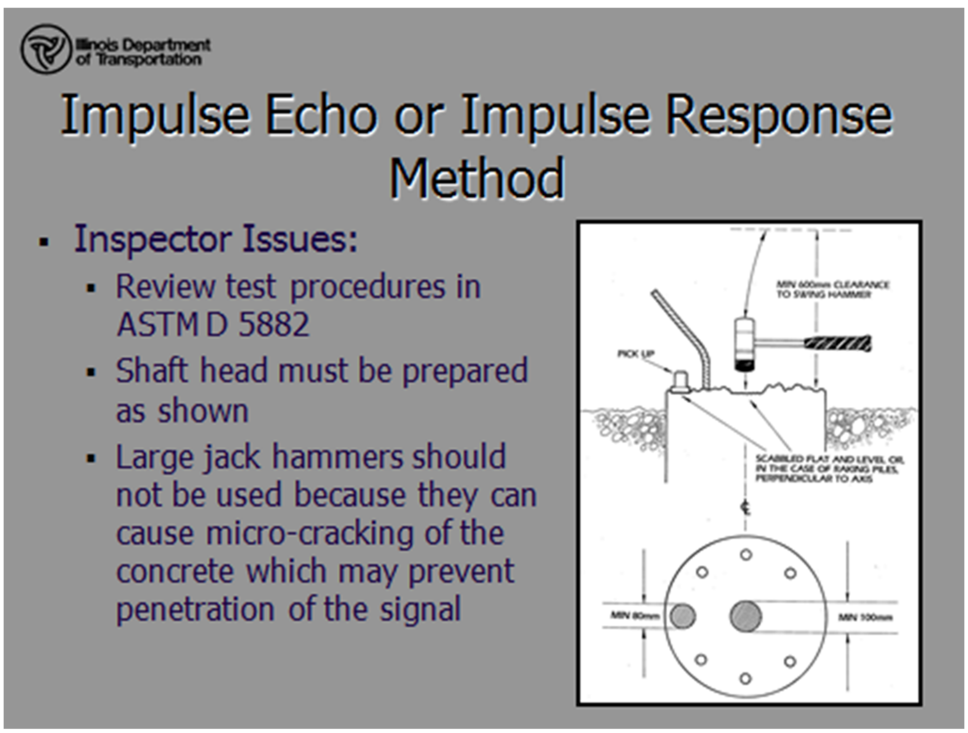
6.1.1 – Impulse Echo or Impulse Response

Impulse echo and impulse response are two tests for evaluating the length and condition of a drilled shaft. For both testing types, a hammer is used to strike the top of the drilled shaft. An instrument is attached to the top of the drilled shaft which measures the behavior of a wave, induced by the strike of the hammer, traveling through and reflecting off the base of the shaft. In the impulse echo method, an ordinary hammer is used for the testing; in the impulse response method, the hammer is instrumented to measure the force of the strike.

The data from a test generally consists of the initial strike, followed by a reflected wave. For an intact shaft, the reflection will be from the base of the shaft at the soil/concrete interface. If there is a defect in the shaft such as a void or reduction in section the reflection will occur at the defect. Based on the time required to measure the reflected wave, the depth to the point of reflection can be determined. The following slide presents a schematic of the test setup and some additional information related to the test.



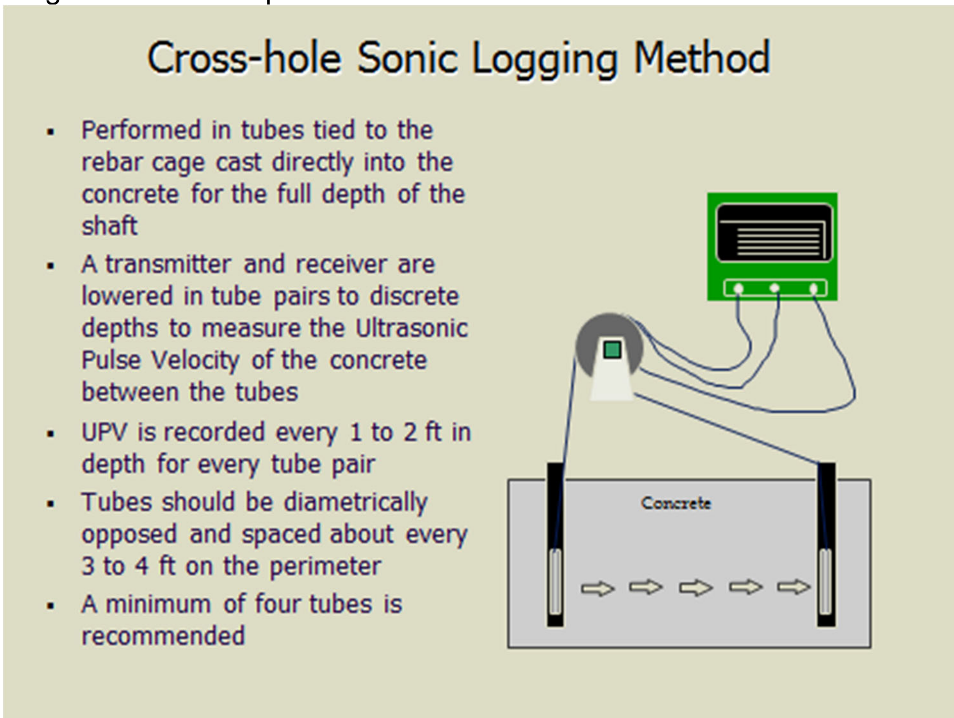
While the inspector does not generally perform the actual testing, there are a few items to be aware of, if impulse echo or impulse response will be used on the project.

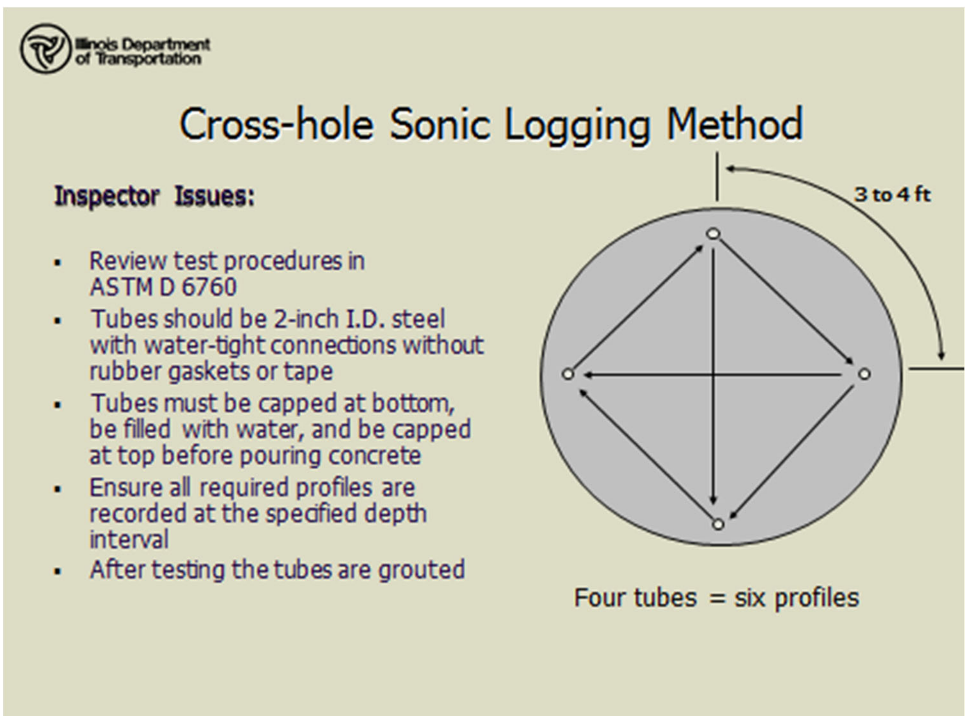


The results of impulse echo and impulse response testing are highly dependent on the size of the shaft and the soil conditions. These testing methods also only provide an estimate of the depth to a defect if one exists, but no information is provided on the type or size of the defect in the shaft. Other testing methods are available which can potential provide more detailed information.

<u>6.1.2 – Cross-Hole Sonic Logging</u>

Cross-hole Sonic Logging (CSL) is a non-destructive test method which can provide more detailed measurements of the shaft integrity and any defects which are encountered in the shaft. A brief description of the testing method follows. It shall be noted that IDOT specifications require steel tubes even though ASTM allows plastic tubes.





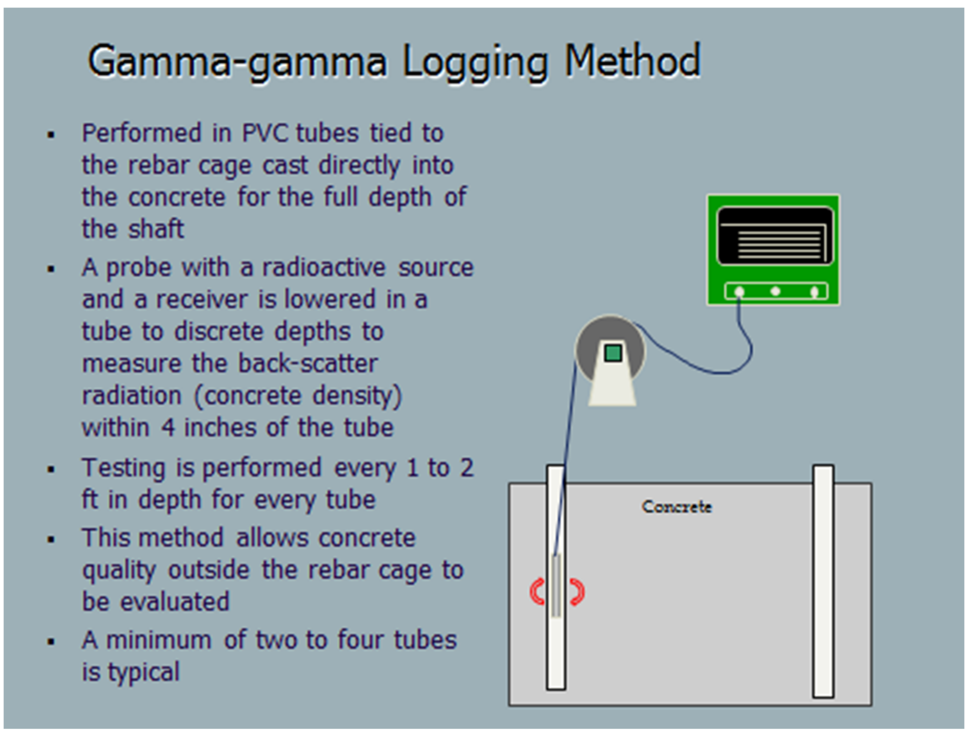
With the close testing increment along the length of the shaft and the multiple profiles developed across the shaft, more details on the size and the location of possible shaft defects can be determined. Tubes should extend all the way to the base of the shaft so that the bottom condition can also be assessed.

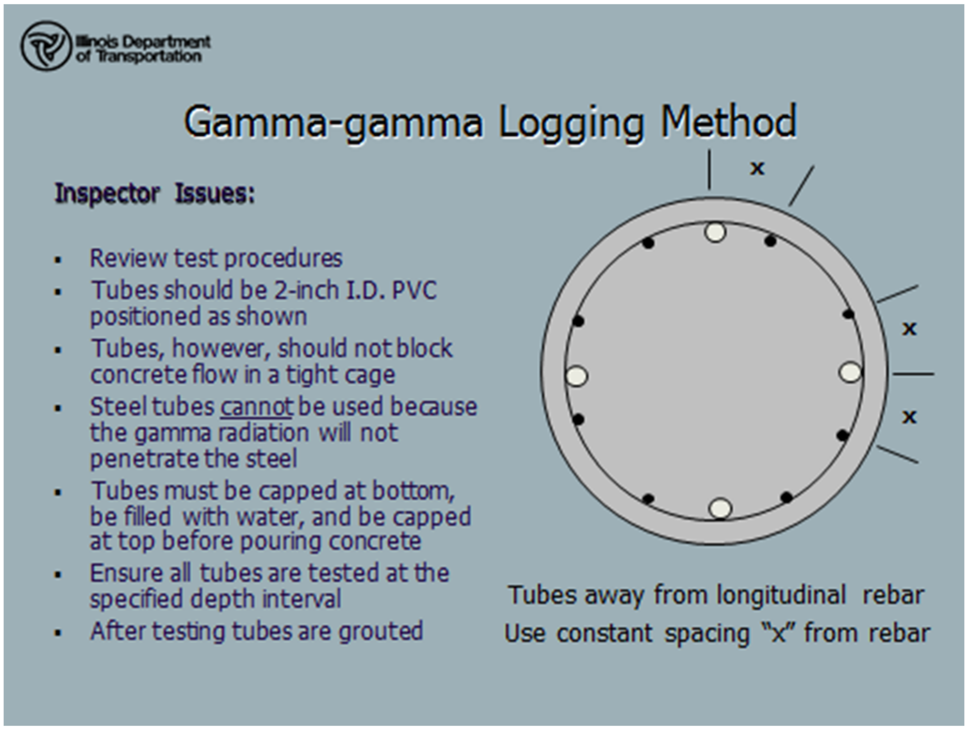
A few key inspection points for cross-hole sonic logging are as follows:

- Steel tubes are required because they provide the best bond to the concrete, and shall be installed on the inside of the rebar cage.
- The CSL tubes must be filled with water to ensure the tubes remain at the same temperature as the concrete. Concrete will hydrate and generate heat which will debond the tubes if water is not present. Check the tubes for water no more than one hour after completion of concrete placement.
- It is important the tubes are installed at the proper spacing and maintained in straight alignment for the full length of the shaft. Any deviations will affect the test results.

6.1.3 – Gamma-gamma Logging

Gamma-gamma logging (GGL) is a test which uses a technology similar to a nuclear density gage to measure the density of the concrete surrounding the test location. Low density measurements are an indication that a shaft defect is present. One advantage of this test method is it allows the concrete outside the rebar cage to be evaluated; however, the diameter of the tested zone is limited to only a few inches outside the access tube. Like CSL, gamma-gamma logging is performed inside full length tubes attached to the rebar cage. However, these tubes must be plastic (typically PVC) and not steel. Information on the testing method, and the issues the field inspector should watch for is as follows.





6.1.4 – Thermal Integrity Profile

Thermal integrity profile (TIP) testing is a recently developed non-destructive test. The test is based on measuring temperature during heat of hydration. If a relatively uniform and symmetrical temperature profile develops during hydration, it can be assumed there are no defects in the shaft.

TIP uses temperature sensors installed along the rebar cage. The temperature sensors record the temperature of the concrete throughout the hydration process. The relative difference in temperature from one side of the rebar cage to the other indicates the position of the rebar cage in the drilled shaft. In addition, low temperatures indicate the presence of soil, water, or aggregate within the drilled shaft.

The advantage of TIP is the ability to detect defects inside and outside the rebar cage. CSL and GGL are limited to the inside of the rebar cage.

6.1.5 – Non-Destructive Testing Limitations

NDT is used to evaluate the condition of the shaft but does not provide a direct measurement of the resistance of the shaft to axial or lateral loads. If the shaft resistance is in question, load testing needs to be performed. Also, when non-destructive testing indicates a defect or possible low strength zone, full length coring along with compressive strength testing of recovered cores will usually be performed to check the concrete and to compare to the NDT results.

It is important to know that NDT is intended to provide additional information on the quality of the drilled shaft constructed, but it can't replace the work of a well-trained inspector.

6.2 – Load Testing

Load testing is a direct measurement of the resistance that a drilled shaft can provide. In some cases, the load testing will be performed on a sacrificial test shaft so the ultimate load capacity can be determined. In other cases, a production shaft may be used and the load tests may extend to slightly above the working load applied to the shaft. When a test shaft (sacrificial or production) is utilized, it is critical that the inspector be present for the construction of that shaft to observe the construction procedures. A test shaft (sacrificial or production) must be constructed using the same procedures as the remaining shafts.

6.2.1 – Static Load Test

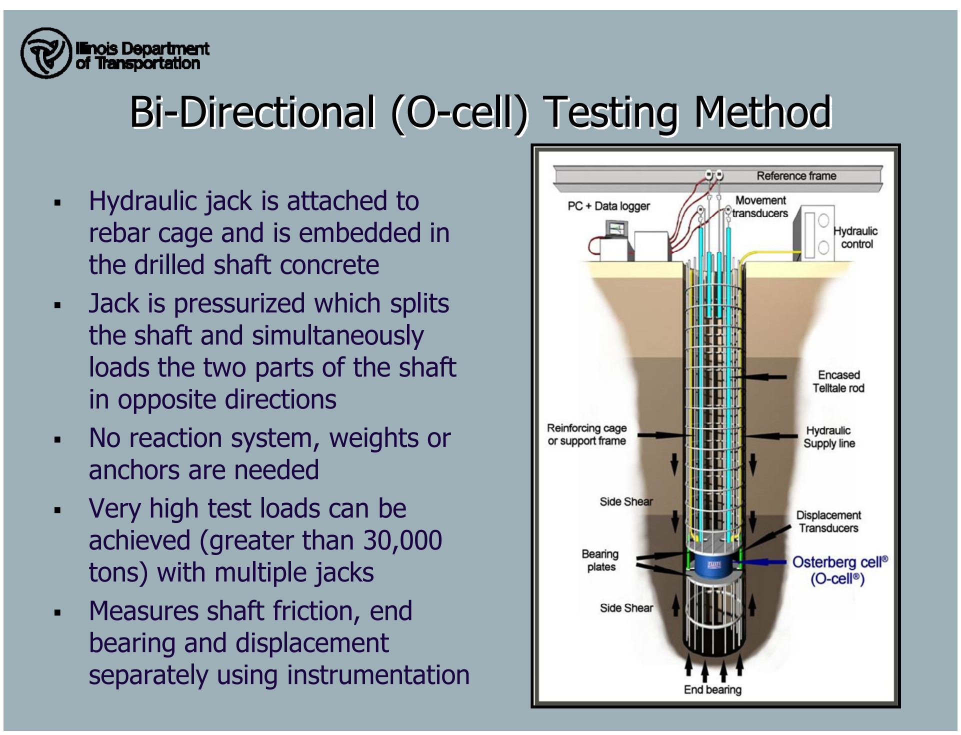
The simplest load test method is the static load test. The procedures for static load testing are described in ASTM standards D 1143 and D 3689 for compression and tension loading, respectively. For a static test, the load is applied via hydraulic rams resisted by reaction piles, shafts or anchors, dead weight or a combination of the two. Load increments are applied for a specified time increment and the deflection of the shaft under the load is measured and recorded.

6.2.2 – Lateral Load Test

Lateral load tests are similar to static load tests. The testing procedures are covered in ASTM standard D 3966. The load is again applied to the drilled shaft using hydraulic rams resisted by a reaction shaft, reaction piles, or a deadman cast into the soil.

6.2.3 – Bi-Directional Load Test

Bi-direction load testing, also referred to as Osterberg Cell or O-Cell testing, is a load testing procedure which does not require weights, reaction frames or reaction piles. The O-cell is a hydraulic jack which is cast directly into the shaft concrete, usually below the midpoint of the shaft. When the jack is pressurized it pushes up against the upper portion of the shaft and pushes down against the lower portion. At an intermediate level, the test has the effect of splitting the shaft at the cell location. The jacking forces applied in the cell are resisted by the weight of the shaft and the friction and end bearing resistance of the shaft. The capacity of resistance of a discrete portion of the shaft can be measured by installing cells at multiple levels. The following provides a schematic of a bi-directional load test.



6.2.4 – High Strain Dynamic Load Testing

High strain dynamic load testing is similar to the dynamic load testing performed during pile driving. The procedures are presented in ASTM standard D 4945. A large weight is dropped onto the top of the drilled shaft which is instrumented to measure the force imparted by the weight and the displacement of the shaft. Based on these measurements, the load carrying capacity of the drilled shaft can be calculated

6.2.5 – Role of the Inspector

In most cases the drilled shaft inspector will be present, but not be an active participant in the load testing process. The one crucial issue to be aware of is that the construction of the production shafts must follow the procedures used for constructing the test shaft. Other items for an inspector to be aware of are as follows.

- Review ASTM test procedures if available.
- Review specifications, loading schedule, and contractor's procedures.
- Confirm that all required instrumentation is installed.
- Record the load increments, time, and deflections.

7 Trouble Shooting

The following chapter presents some common construction issues which may arise on a drilled shaft project along with the potential cause. This information is reprinted from Table 19-2 in the FHWA publication "Drilled Shafts: Construction Procedures and LFRD Design Methods". Refer to 8.1 – Additional References for the link to this publication.

Problem: Shaft off location or out of plumb.
Cause: Improper set-up or poor alignment while drilling.

Problem: Shaft not based or with insufficient embedment in proper bearing stratum.
Cause: Bearing stratum misidentified or length not properly measured.

Problem: Crack in shaft
Cause: Shaft hit by construction equipment early in curing process.

Problem: Bulge or neck in the shaft.
Cause: Soft ground zones that were not cased.

Problem: Caving of shaft wall
Cause: Improper us of casing or slurry; failure to use weighting agent with slurry; casing not sealed in a stable stratum.

Problem: Reduction in side resistance due to excessive mudcake buildup.
Cause: Failure to agitate slurry or to place concrete in a timely manner.

Problem: Temporary casing cannot be removed
Cause: Crane for handling casing ineffective in squeezing ground; large set-up of soil friction after installing casing; causing wedged in rock or by boulder.

Problem: Horizontal separation or severe necking of shaft.
Cause: Pulling temporary casing with concrete adhering to it.

Problem: Horizontal sand lens in concrete.
Cause: Tremie or pump line pulled out of concrete in wet hole; insufficient head within casing when raising casing.

Problem: Soil intrusion on the side of the shaft.
Cause: Use of telescoping casing where concrete from inner casing spills into annular void behind the outer casing; low concrete slump; reinforcing bars too closely spaced.

Problem: Soft shaft bottom or CSL anomaly at/near bottom of shaft.
Cause: Incomplete bottom cleaning, side sloughing, or sedimentation of cuttings from slurry column.

Problem: Voids outside of cage.
Cause: Low concrete slump, aggregate too large, and/or reinforcing bars too closely spaced

Problem: Concrete defects.
Cause: Tremie pipe joints not watertight; tremie/pump line not at bottom of shaft at start of concrete placement; concrete flow into annular void between temporary and permanent casings; concrete slump inadequate for duration of concrete placement; excessive sediment in slurry.

Problem: Honeycombing, washout of fines or water channels in the concrete
Cause: Concrete placed directly into water; excessive groundwater head; excessive bleed water in concrete mix.

Problem: Folded-in debris.
Cause: Insufficient cleaning of shaft; excessive sand content in slurry.

Problem: Clogged tremie or pump line.
Cause: Concrete with insufficient slump or slump retention; interior of pipe not clean; segregation of concrete aggregates.

Problem: Rebar cage lifted during concrete placement.
Cause: Weight of rebar cage insufficient for rising concrete; tremie/pump line embedded too deep in concrete; rebar cage caught on tremie/pump line; concrete arch between casing/cage.

Problem: Rebar cage settles during concrete placement.
Cause: Missing inadequate number/spacing of rebar cage spacers; insufficient support of cage at bottom of shaft excavation; insufficient cage stiffness.

8 Appendix

8.1 – Additional References

The following additional references provide greater detail and explanation of the construction procedures and inspection requirements for drilled shafts. The inspector is encouraged to review the documents, especially the FHWA documents.

- Drilled Shaft Inspector Tutorial – Web Based (FHWA – Available online at no cost.)
  www.nhi.fhwa.dot.gov/home.aspx

- Drilled Shafts: Construction Procedures and LRFD Design Methods (FHWA – May 2010)
  www.fhwa.dot.gov/engineering/geotech/foundations/100521.cfm

- 336.1-01 Specification for the Construction of Drilled Piers (American Concrete Institute (ACI))
  Available on IDOT's intranet as follows:
  Click "Information Research Center"
  See Reference Collection and Click "View All"
  Click "ACI Manual of Concrete Practice"
  Select "336.1-01 Specification for the Construction of Drilled Piers"

- Various Publications (ADCS: The International Association of Foundation Drilling)
  www.adsc-iafd.com/

- Geotechnical Manual (IDOT)
  Available on the IDOT PowerDMS internal website.
- Bridge Manual (IDOT)
  Available on the IDOT PowerDMS internal website.

- Evaluating the Accuracy and Use of Drilled Shaft Integrity Testing Methods in Illinois, Illinois Center for Transportation Project R27-188 (October 2022)
  https://apps.ict.illinois.edu/projects/getfile.asp?id=10347

8.2 – Example of Drilled Shaft Pre-Drill Meeting Agenda

DRILLED SHAFT PRE-DRILL MEETING AGENDA

Date: ___________________
Time: ___________________
Contact: ____

1. CONSTRUCTION LAYOUT AND MEASUREMENTS

- a. 3 in. tolerance allowed from plan station and offset for center of shaft
- b. Top of drilled shaft elevation
- c. Will earth or seal coat excavation be necessary prior to start?
- d. What protection will be installed for workers around the excavation?
- e. Required documentation:
  - (1) Recording of soil excavated is required (BBS 134, or field book)
  - (2) Record all visually changing soils (clay, cobbles, rock, sand, silt, etc.)
  - (3) Record all moisture/water changes
  - (4) Record elevation of shaft when slurry was added
  - (5) Record all events throughout the day (weather, number of workers, equipment breakdowns, delays, important conversations, etc.)
- f. Setting top temporary casing
- g. Elevation of casing when fully installed (for use as a measuring point for determining depth)
- h. Survey check of top casing for layout of drilled shaft

2. CASING

- a. Temporary Casing
  - (1) When will temporary casing be installed?
  - (2) Method of removal and action to be taken if casing cannot be removed
- b. Permanent Casing
  - (1) When will permanent casing be installed (prior to, or after drilled shaft excavation)?
    - a. If installed after excavation, non-shrink grout will be required around the casing
  - (2) Full length or multiple sections

3. SLURRY

- a. Slurry type (mineral, polymer, water)
- b. Testing of slurry (density, viscosity, pH, sand content)
- c. Minimum level of slurry in excavation
- d. Clean up of slurry during excavation
- e. Method of slurry disposal upon completion

4. SHAFT EXCAVATION

- a. Erosion control should be installed
- b. Method to contain and stock pile dry excavation
- c. Method to contain and stock pile wet excavation
- d. Is non-special waste removal required?

5. OBSTRUCTIONS

a. Impediments encountered while drilling
   (1) Section 516
      a. Contractor must provide notice when obstruction is encountered
   (2) Paid under Article 109.04
   (3) Include entire crew and equipment
b. Check soil borings for types of soil at that elevation
   (1) Track time until impediment is removed or when plan bottom elevation is reached

6. TOP OF ROCK

a. Check plan for pay items (drilled shaft in soil, drilled shaft in rock)
b. Obstructions are different from rock. Obstructions are eventually removed or cut through.
c. Rock is continual to the bottom of the shaft (drilled shaft in rock)
d. When the plans call for “drilled shaft in rock”
   (1) “Non-fractured” rock must be achieved
      a. “Non-fractured” rock are large pieces of visibly non-rounded rock
      b. Rounded rock are “cobbles or boulders” that are embedded within soil
e. Top of rock
   (1) A determination of top of rock must be made for payment purposes
   (2) This elevation can be where fractured rock is encountered from a point all the way down the final rock socket
   (3) This elevation is the divider line between the two pay items (soil, rock)
   (4) Obtain top of rock elevation prior to drilling with rock drilling equipment

7. DRILLED SHAFT EXCAVATION INSPECTION

a. A dry hole may be visually inspected
b. A wet hole may need to be inspected using a weighted tape
c. A camera may be necessary
d. Bearing capacity method
e. Flatness of bottom
f. Cleaning of bottom

8. ASSEMBLY AND PLACEMENT OF REINFORCEMENT

a. Depending on length of drilled shaft, a planned splice may be required (lap or mechanical splices)
b. Rebar cages are assembled prior to excavation (assembly takes time; the cage must be ready when the shaft excavation is ready)
c. Adjustment of rebar cages due to modified length of excavation
   (1) Additional rebar will be paid by pay item (in the event of a longer cage)
      a. 50800105 Reinforcement Bars
      b. 50800205 Reinforcement Bars, Epoxy Coated
   (2) Only the reinforcing bars installed will be measured for payment.
d. Rebar clearance
   (1) Rebar centralizers are required along the length of the shaft
   (2) Rebar clearance boots are required at the base of the shaft
e. Reinforcement bar tolerances
   (1) 1.5 in. tolerance allowed from plan station and offset for center of cage
   (2) No more than 1 in. above and 3 in. below plan elevation for top of cage
f. Method of cage installation and cleaning debris from rebars
g. Cross-hole sonic logging tubes
   (1) Fill tubes with water after placement of rebar cage
   (2) Seal tubes and cap prior to placement of concrete

9. CONCRETE PLACEMENT

a. Recording of concrete placement is required (BBS 135, or field book)
b. Check for correct mix design number
c. Check for correct air, slump, and temperature
d. Free fall method of concrete placement (for dry excavation only)
   (1) Requires DS mix
   (2) Maximum 60 ft. drop height
   (3) Cannot impact rebar on the way down

e. Tremie method of concrete placement
   (1) Type of tremie (rigid steel pipe, ensure joints are sealed, etc.)
   (2) Dry method (see requirements for free fall concrete placement above)
   (3) Wet method
      a. Tremie must reach to the bottom of the shaft
      b. Tremie must be sealed before concrete placement begins
      c. Concrete must remain at least 10 ft. above the discharge end of the tremie throughout the pour
      d. Disassemble the tremie as concrete is placed
      e. Pump water/slurry from hole as concrete is placed (if necessary)
      f. Over-pour the top of the drilled shaft to remove any excess water/slurry in the concrete
      g. No more than 1 in. above and 3 in. below plan elevation for top of shaft
   (4) Concrete pump method
   (5) Protection of the top of the drilled shaft
      a. Consider weather (precipitation, temperature, etc.)
      b. Safety for construction personnel
      c. Fill CSL tubes with water

10. NON-DESTRUCTIVE TESTING

a. Cross-hole sonic logging testing
   (1) Test must be 3-40 days after placement (minimum 2/3 strength)
   (2) Uncap and test drilled shafts
   (3) Recap tubes
   (4) Review/analyze CSL report
      a. Acceptable
         1. Cut off tubes to top of drilled shaft
         2. Fill tubes with non-shrink grout from qualified list
      b. Unacceptable
         1. Require contractor to provide remedial measures
         2. Submit remedy procedures to IDOT BBS
         3. Repair drilled shaft as per approved method
         4. Cut off tubes to top of drilled shaft
         5. Fill tubes with non-shrink grout from qualified list

8.3 – Drilled Shaft Straight and Belled Concrete Volume Calculation Tables

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Shaft Volume

- For straight shaft the calculation is pretty simple, shaft area time shaft length equals the volume
- Be careful about units, concrete is usually measured by the cubic yard, you will measure the shaft dimensions in feet

$$Area = \frac{3.14}{4} \text{ x } (Diameter)^2$$

$$Volume = Area \text{ x } Length$$

- Divide the volume you calculate based on the measured dimensions in feet by 27 to get cubic yards

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Shaft Volume Calculation

- How about an example?
  - Diameter = 3.5′
  - Length = 35′

    $$\frac{3.14}{4} \text{ x } 3.5^2$$

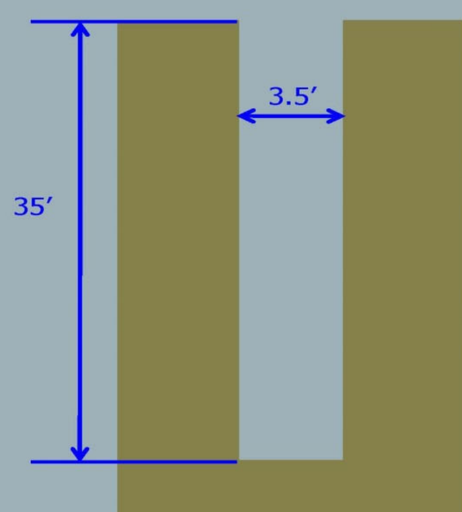
  - Area = 9.6 square feet

    $$9.6 \text{ x } 35$$

  - Volume = 336.6 cubic feet

    $$\frac{336.6}{27}$$

  - Volume = 12.5 cubic yards



STRAIGHT SHAFT VOLUME IN CUBIC YARDS

Shaft Length in Feet	Shaft Diameter in Inches																		
	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120
1	0.0	0.1	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.9	1.0	1.2	1.4	1.6	1.9	2.1	2.4	2.6	2.9
2	0.1	0.1	0.2	0.4	0.5	0.7	0.9	1.2	1.5	1.8	2.1	2.5	2.9	3.3	3.7	4.2	4.7	5.3	5.8
3	0.1	0.2	0.3	0.5	0.8	1.1	1.4	1.8	2.2	2.6	3.1	3.7	4.3	4.9	5.6	6.3	7.1	7.9	8.7
4	0.1	0.3	0.5	0.7	1.0	1.4	1.9	2.4	2.9	3.5	4.2	4.9	5.7	6.5	7.4	8.4	9.4	10.5	11.6
5	0.1	0.3	0.6	0.9	1.3	1.8	2.3	2.9	3.6	4.4	5.2	6.1	7.1	8.2	9.3	10.5	11.8	13.1	14.5
6	0.2	0.4	0.7	1.1	1.6	2.1	2.8	3.5	4.4	5.3	6.3	7.4	8.6	9.8	11.2	12.6	14.1	15.8	17.5
7	0.2	0.5	0.8	1.3	1.8	2.5	3.3	4.1	5.1	6.2	7.3	8.6	10.0	11.5	13.0	14.7	16.5	18.4	20.4
8	0.2	0.5	0.9	1.5	2.1	2.9	3.7	4.7	5.8	7.0	8.4	9.8	11.4	13.1	14.9	16.8	18.8	21.0	23.3
9	0.3	0.6	1.0	1.6	2.4	3.2	4.2	5.3	6.5	7.9	9.4	11.1	12.8	14.7	16.8	18.9	21.2	23.6	26.2
10	0.3	0.7	1.2	1.8	2.6	3.6	4.7	5.9	7.3	8.8	10.5	12.3	14.3	16.4	18.6	21.0	23.6	26.3	29.1
11	0.3	0.7	1.3	2.0	2.9	3.9	5.1	6.5	8.0	9.7	11.5	13.5	15.7	18.0	20.5	23.1	25.9	28.9	32.0
12	0.3	0.8	1.4	2.2	3.1	4.3	5.6	7.1	8.7	10.6	12.6	14.7	17.1	19.6	22.3	25.2	28.3	31.5	34.9
13	0.4	0.9	1.5	2.4	3.4	4.6	6.1	7.7	9.5	11.4	13.6	16.0	18.5	21.3	24.2	27.3	30.6	34.1	37.8
14	0.4	0.9	1.6	2.5	3.7	5.0	6.5	8.2	10.2	12.3	14.7	17.2	20.0	22.9	26.1	29.4	33.0	36.8	40.7
15	0.4	1.0	1.7	2.7	3.9	5.3	7.0	8.8	10.9	13.2	15.7	18.4	21.4	24.5	27.9	31.5	35.3	39.4	43.6
16	0.5	1.0	1.9	2.9	4.2	5.7	7.4	9.4	11.6	14.1	16.8	19.7	22.8	26.2	29.8	33.6	37.7	42.0	46.5
17	0.5	1.1	2.0	3.1	4.5	6.1	7.9	10.0	12.4	15.0	17.8	20.9	24.2	27.8	31.6	35.7	40.1	44.6	49.5
18	0.5	1.2	2.1	3.3	4.7	6.4	8.4	10.6	13.1	15.8	18.8	22.1	25.7	29.5	33.5	37.8	42.4	47.3	52.4
19	0.6	1.2	2.2	3.5	5.0	6.8	8.8	11.2	13.8	16.7	19.9	23.4	27.1	31.1	35.4	39.9	44.8	49.9	55.3
20	0.6	1.3	2.3	3.6	5.2	7.1	9.3	11.8	14.5	17.6	20.9	24.6	28.5	32.7	37.2	42.0	47.1	52.5	58.2
21	0.6	1.4	2.4	3.8	5.5	7.5	9.8	12.4	15.3	18.5	22.0	25.8	29.9	34.4	39.1	44.1	49.5	55.1	61.1
22	0.6	1.4	2.6	4.0	5.8	7.8	10.2	13.0	16.0	19.4	23.0	27.0	31.4	36.0	41.0	46.2	51.8	57.8	64.0
23	0.7	1.5	2.7	4.2	6.0	8.2	10.7	13.5	16.7	20.2	24.1	28.3	32.8	37.6	42.8	48.3	54.2	60.4	66.9
24	0.7	1.6	2.8	4.4	6.3	8.6	11.2	14.1	17.5	21.1	25.1	29.5	34.2	39.3	44.7	50.4	56.5	63.0	69.8
25	0.7	1.6	2.9	4.5	6.5	8.9	11.6	14.7	18.2	22.0	26.2	30.7	35.6	40.9	46.5	52.5	58.9	65.6	72.7
26	0.8	1.7	3.0	4.7	6.8	9.3	12.1	15.3	18.9	22.9	27.2	32.0	37.1	42.5	48.4	54.6	61.3	68.3	75.6
27	0.8	1.8	3.1	4.9	7.1	9.6	12.6	15.9	19.6	23.8	28.3	33.2	38.5	44.2	50.3	56.7	63.6	70.9	78.5
28	0.8	1.8	3.3	5.1	7.3	10.0	13.0	16.5	20.4	24.6	29.3	34.4	39.9	45.8	52.1	58.8	66.0	73.5	81.4
29	0.8	1.9	3.4	5.3	7.6	10.3	13.5	17.1	21.1	25.5	30.4	35.6	41.3	47.5	54.0	60.9	68.3	76.1	84.4
30	0.9	2.0	3.5	5.5	7.9	10.7	14.0	17.7	21.8	26.4	31.4	36.9	42.8	49.1	55.9	63.1	70.7	78.8	87.3
31	0.9	2.0	3.6	5.6	8.1	11.0	14.4	18.3	22.5	27.3	32.5	38.1	44.2	50.7	57.7	65.2	73.0	81.4	90.2
32	0.9	2.1	3.7	5.8	8.4	11.4	14.9	18.8	23.3	28.2	33.5	39.3	45.6	52.4	59.6	67.3	75.4	84.0	93.1
33	1.0	2.2	3.8	6.0	8.6	11.8	15.4	19.4	24.0	29.0	34.6	40.6	47.0	54.0	61.4	69.4	77.8	86.6	96.0
34	1.0	2.2	4.0	6.2	8.9	12.1	15.8	20.0	24.7	29.9	35.6	41.8	48.5	55.6	63.3	71.5	80.1	89.3	98.9
35	1.0	2.3	4.1	6.4	9.2	12.5	16.3	20.6	25.5	30.8	36.7	43.0	49.9	57.3	65.2	73.6	82.5	91.9	101.8
36	1.0	2.4	4.2	6.5	9.4	12.8	16.8	21.2	26.2	31.7	37.7	44.2	51.3	58.9	67.0	75.7	84.8	94.5	104.7
37	1.1	2.4	4.3	6.7	9.7	13.2	17.2	21.8	26.9	32.6	38.7	45.5	52.7	60.5	68.9	77.8	87.2	97.1	107.6
38	1.1	2.5	4.4	6.9	9.9	13.5	17.7	22.4	27.6	33.4	39.8	46.7	54.2	62.2	70.7	79.9	89.5	99.8	110.5
39	1.1	2.6	4.5	7.1	10.2	13.9	18.2	23.0	28.4	34.3	40.8	47.9	55.6	63.8	72.6	82.0	91.9	102.4	113.4
40	1.2	2.6	4.7	7.3	10.5	14.3	18.6	23.6	29.1	35.2	41.9	49.2	57.0	65.4	74.5	84.1	94.2	105.0	116.4
41	1.2	2.7	4.8	7.5	10.7	14.6	19.1	24.2	29.8	36.1	42.9	50.4	58.4	67.1	76.3	86.2	96.6	107.6	119.3
42	1.2	2.7	4.9	7.6	11.0	15.0	19.5	24.7	30.5	37.0	44.0	51.6	59.9	68.7	78.2	88.3	99.0	110.3	122.2
43	1.3	2.8	5.0	7.8	11.3	15.3	20.0	25.3	31.3	37.8	45.0	52.8	61.3	70.4	80.1	90.4	101.3	112.9	125.1
44	1.3	2.9	5.1	8.0	11.5	15.7	20.5	25.9	32.0	38.7	46.1	54.1	62.7	72.0	81.9	92.5	103.7	115.5	128.0
45	1.3	2.9	5.2	8.2	11.8	16.0	20.9	26.5	32.7	39.6	47.1	55.3	64.1	73.6	83.8	94.6	106.0	118.1	130.9
46	1.3	3.0	5.4	8.4	12.0	16.4	21.4	27.1	33.5	40.5	48.2	56.5	65.6	75.3	85.6	96.7	108.4	120.8	133.8
47	1.4	3.1	5.5	8.5	12.3	16.7	21.9	27.7	34.2	41.4	49.2	57.8	67.0	76.9	87.5	98.8	110.7	123.4	136.7
48	1.4	3.1	5.6	8.7	12.6	17.1	22.3	28.3	34.9	42.2	50.3	59.0	68.4	78.5	89.4	100.9	113.1	126.0	139.6
49	1.4	3.2	5.7	8.9	12.8	17.5	22.8	28.9	35.6	43.1	51.3	60.2	69.8	80.2	91.2	103.0	115.5	128.6	142.5
50	1.5	3.3	5.8	9.1	13.1	17.8	23.3	29.5	36.4	44.0	52.4	61.5	71.3	81.8	93.1	105.1	117.8	131.3	145.4

STRAIGHT SHAFT VOLUME IN CUBIC YARDS																			
	Shaft Diameter in Inches																		
Shaft Length in Feet	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120
51	1.5	3.3	5.9	9.3	13.4	18.2	23.7	30.0	37.1	44.9	53.4	62.7	72.7	83.4	94.9	107.2	120.2	133.9	148.4
52	1.5	3.4	6.1	9.5	13.6	18.5	24.2	30.6	37.8	45.8	54.5	63.9	74.1	85.1	96.8	109.3	122.5	136.5	151.3
53	1.5	3.5	6.2	9.6	13.9	18.9	24.7	31.2	38.5	46.6	55.5	65.1	75.5	86.7	98.7	111.4	124.9	139.1	154.2
54	1.6	3.5	6.3	9.8	14.1	19.2	25.1	31.8	39.3	47.5	56.5	66.4	77.0	88.4	100.5	113.5	127.2	141.8	157.1
55	1.6	3.6	6.4	10.0	14.4	19.6	25.6	32.4	40.0	48.4	57.6	67.6	78.4	90.0	102.4	115.6	129.6	144.4	160.0
56	1.6	3.7	6.5	10.2	14.7	20.0	26.1	33.0	40.7	49.3	58.6	68.8	79.8	91.6	104.3	117.7	131.9	147.0	162.9
57	1.7	3.7	6.6	10.4	14.9	20.3	26.5	33.6	41.5	50.2	59.7	70.1	81.2	93.3	106.1	119.8	134.3	149.6	165.8
58	1.7	3.8	6.7	10.5	15.2	20.7	27.0	34.2	42.2	51.0	60.7	71.3	82.7	94.9	108.0	121.9	136.7	152.3	168.7
59	1.7	3.9	6.9	10.7	15.4	21.0	27.5	34.8	42.9	51.9	61.8	72.5	84.1	96.5	109.8	124.0	139.0	154.9	171.6
60	1.7	3.9	7.0	10.9	15.7	21.4	27.9	35.3	43.6	52.8	62.8	73.7	85.5	98.2	111.7	126.1	141.4	157.5	174.5
61	1.8	4.0	7.1	11.1	16.0	21.7	28.4	35.9	44.4	53.7	63.9	75.0	86.9	99.8	113.6	128.2	143.7	160.1	177.4
62	1.8	4.1	7.2	11.3	16.2	22.1	28.9	36.5	45.1	54.6	64.9	76.2	88.4	101.4	115.4	130.3	146.1	162.8	180.4
63	1.8	4.1	7.3	11.5	16.5	22.4	29.3	37.1	45.8	55.4	66.0	77.4	89.8	103.1	117.3	132.4	148.4	165.4	183.3
64	1.9	4.2	7.4	11.6	16.8	22.8	29.8	37.7	46.5	56.3	67.0	78.7	91.2	104.7	119.1	134.5	150.8	168.0	186.2
65	1.9	4.3	7.6	11.8	17.0	23.2	30.3	38.3	47.3	57.2	68.1	79.9	92.6	106.4	121.0	136.6	153.2	170.6	189.1
66	1.9	4.3	7.7	12.0	17.3	23.5	30.7	38.9	48.0	58.1	69.1	81.1	94.1	108.0	122.9	138.7	155.5	173.3	192.0
67	1.9	4.4	7.8	12.2	17.5	23.9	31.2	39.5	48.7	59.0	70.2	82.3	95.5	109.6	124.7	140.8	157.9	175.9	194.9
68	2.0	4.5	7.9	12.4	17.8	24.2	31.6	40.1	49.5	59.8	71.2	83.6	96.9	111.3	126.6	142.9	160.2	178.5	197.8
69	2.0	4.5	8.0	12.5	18.1	24.6	32.1	40.6	50.2	60.7	72.3	84.8	98.3	112.9	128.5	145.0	162.6	181.1	200.7
70	2.0	4.6	8.1	12.7	18.3	24.9	32.6	41.2	50.9	61.6	73.3	86.0	99.8	114.5	130.3	147.1	164.9	183.8	203.6
71	2.1	4.6	8.3	12.9	18.6	25.3	33.0	41.8	51.6	62.5	74.4	87.3	101.2	116.2	132.2	149.2	167.3	186.4	206.5
72	2.1	4.7	8.4	13.1	18.8	25.7	33.5	42.4	52.4	63.4	75.4	88.5	102.6	117.8	134.0	151.3	169.6	189.0	209.4
73	2.1	4.8	8.5	13.3	19.1	26.0	34.0	43.0	53.1	64.2	76.4	89.7	104.1	119.4	135.9	153.4	172.0	191.6	212.3
74	2.2	4.8	8.6	13.5	19.4	26.4	34.4	43.6	53.8	65.1	77.5	90.9	105.5	121.1	137.8	155.5	174.4	194.3	215.3
75	2.2	4.9	8.7	13.6	19.6	26.7	34.9	44.2	54.5	66.0	78.5	92.2	106.9	122.7	139.6	157.6	176.7	196.9	218.2
76	2.2	5.0	8.8	13.8	19.9	27.1	35.4	44.8	55.3	66.9	79.6	93.4	108.3	124.4	141.5	159.7	179.1	199.5	221.1
77	2.2	5.0	9.0	14.0	20.2	27.4	35.8	45.4	56.0	67.8	80.6	94.6	109.8	126.0	143.3	161.8	181.4	202.1	224.0
78	2.3	5.1	9.1	14.2	20.4	27.8	36.3	45.9	56.7	68.6	81.7	95.9	111.2	127.6	145.2	163.9	183.8	204.8	226.9
79	2.3	5.2	9.2	14.4	20.7	28.2	36.8	46.5	57.5	69.5	82.7	97.1	112.6	129.3	147.1	166.0	186.1	207.4	229.8
80	2.3	5.2	9.3	14.5	20.9	28.5	37.2	47.1	58.2	70.4	83.8	98.3	114.0	130.9	148.9	168.1	188.5	210.0	232.7
81	2.4	5.3	9.4	14.7	21.2	28.9	37.7	47.7	58.9	71.3	84.8	99.5	115.5	132.5	150.8	170.2	190.9	212.6	235.6
82	2.4	5.4	9.5	14.9	21.5	29.2	38.2	48.3	59.6	72.2	85.9	100.8	116.9	134.2	152.7	172.3	193.2	215.3	238.5
83	2.4	5.4	9.7	15.1	21.7	29.6	38.6	48.9	60.4	73.0	86.9	102.0	118.3	135.8	154.5	174.4	195.6	217.9	241.4
84	2.4	5.5	9.8	15.3	22.0	29.9	39.1	49.5	61.1	73.9	88.0	103.2	119.7	137.4	156.4	176.5	197.9	220.5	244.3
85	2.5	5.6	9.9	15.5	22.3	30.3	39.6	50.1	61.8	74.8	89.0	104.5	121.2	139.1	158.2	178.6	200.3	223.1	247.3
86	2.5	5.6	10.0	15.6	22.5	30.6	40.0	50.7	62.5	75.7	90.1	105.7	122.6	140.7	160.1	180.7	202.6	225.8	250.2
87	2.5	5.7	10.1	15.8	22.8	31.0	40.5	51.2	63.3	76.6	91.1	106.9	124.0	142.4	162.0	182.8	205.0	228.4	253.1
88	2.6	5.8	10.2	16.0	23.0	31.4	41.0	51.8	64.0	77.4	92.2	108.2	125.4	144.0	163.8	184.9	207.3	231.0	256.0
89	2.6	5.8	10.4	16.2	23.3	31.7	41.4	52.4	64.7	78.3	93.2	109.4	126.9	145.6	165.7	187.0	209.7	233.6	258.9
90	2.6	5.9	10.5	16.4	23.6	32.1	41.9	53.0	65.4	79.2	94.2	110.6	128.3	147.3	167.6	189.2	212.1	236.3	261.8
91	2.6	6.0	10.6	16.5	23.8	32.4	42.4	53.6	66.2	80.1	95.3	111.8	129.7	148.9	169.4	191.3	214.4	238.9	264.7
92	2.7	6.0	10.7	16.7	24.1	32.8	42.8	54.2	66.9	81.0	96.3	113.1	131.1	150.5	171.3	193.4	216.8	241.5	267.6
93	2.7	6.1	10.8	16.9	24.3	33.1	43.3	54.8	67.6	81.8	97.4	114.3	132.6	152.2	173.1	195.5	219.1	244.1	270.5
94	2.7	6.2	10.9	17.1	24.6	33.5	43.7	55.4	68.4	82.7	98.4	115.5	134.0	153.8	175.0	197.6	221.5	246.8	273.4
95	2.8	6.2	11.1	17.3	24.9	33.9	44.2	56.0	69.1	83.6	99.5	116.8	135.4	155.4	176.9	199.7	223.8	249.4	276.3
96	2.8	6.3	11.2	17.5	25.1	34.2	44.7	56.5	69.8	84.5	100.5	118.0	136.8	157.1	178.7	201.8	226.2	252.0	279.3
97	2.8	6.3	11.3	17.6	25.4	34.6	45.1	57.1	70.5	85.4	101.6	119.2	138.3	158.7	180.6	203.9	228.6	254.7	282.2
98	2.9	6.4	11.4	17.8	25.7	34.9	45.6	57.7	71.3	86.2	102.6	120.4	139.7	160.4	182.4	206.0	230.9	257.3	285.1
99	2.9	6.5	11.5	18.0	25.9	35.3	46.1	58.3	72.0	87.1	103.7	121.7	141.1	162.0	184.3	208.1	233.3	259.9	288.0
100	2.9	6.5	11.6	18.2	26.2	35.6	46.5	58.9	72.7	88.0	104.7	122.9	142.5	163.6	186.2	210.2	235.6	262.5	290.9

BELL VOLUMES IN CUBIC YARDS, 45 DEGREE BELLS, HEIGHT INCLUDES 6" PAD, VOLUME INCLUDES PAD											
Shaft Diameter (in)	Bell Diameter (in)	Bell Height (ft)	Bell Volume (cy)	Shaft Diameter (in)	Bell Diameter (in)	Bell Height (ft)	Bell Volume (cy)	Shaft Diameter (in)	Bell Diameter (in)	Bell Height (ft)	Bell Volume (cy)
18	24	0.75	0.33	48	54	0.75	1.87	66	72	0.75	3.41
	30	1.00	0.57		60	1.00	2.73		78	1.00	4.81
	36	1.25	0.89		66	1.25	3.75		84	1.25	6.42
	42	1.50	1.33		72	1.50	4.95		90	1.50	8.25
	48	1.75	1.88		78	1.75	6.33		96	1.75	10.31
	54	2.00	2.56		84	2.00	7.93		102	2.00	12.63
24	30	1.00	0.68		90	2.25	9.74		108	2.25	15.21
	36	1.25	1.05		96	2.50	11.79		114	2.50	18.06
	42	1.50	1.53		102	2.75	14.09		120	2.75	21.21
	48	1.75	2.13		108	3.00	16.65		126	3.00	24.67
	54	2.00	2.87		114	3.25	19.50		132	3.25	28.45
	60	2.25	3.77		120	3.50	22.63		138	3.50	32.57
	66	2.50	4.83		126	3.75	26.07		144	3.75	37.04
	72	2.75	6.07		132	4.00	29.84		150	4.00	41.87
30	36	1.25	1.23		138	4.25	33.94		156	4.25	47.09
	42	1.50	1.76		144	4.50	38.40		162	4.50	52.70
	48	1.75	2.42	54	60	1.00	2.99		168	4.75	58.72
	54	2.00	3.22		66	1.25	4.09		174	5.00	65.16
	60	2.25	4.18		72	1.50	5.37		180	5.25	72.05
	66	2.50	5.31		78	1.75	6.84		186	5.50	79.38
	72	2.75	6.63		84	2.00	8.53		192	5.75	87.19
	78	3.00	8.15		90	2.25	10.44		198	6.00	95.47
	84	3.25	9.88		96	2.50	12.59	72	78	1.00	5.16
	90	3.50	11.85		102	2.75	15.00		84	1.25	6.87
36	42	1.50	2.03		108	3.00	17.67		90	1.50	8.80
	48	1.75	2.74		114	3.25	20.63		96	1.75	10.98
	54	2.00	3.61		120	3.50	23.89		102	2.00	13.40
	60	2.25	4.64		126	3.75	27.46		108	2.25	16.10
	66	2.50	5.85		132	4.00	31.35		114	2.50	19.08
	72	2.75	7.24		138	4.25	35.59		120	2.75	22.36
	78	3.00	8.85		144	4.50	40.19		126	3.00	25.95
	84	3.25	10.67		150	4.75	45.15		132	3.25	29.87
	90	3.50	12.73		156	5.00	50.50		138	3.50	34.13
	96	3.75	15.04		162	5.25	56.25		144	3.75	38.75
	102	4.00	17.61	60	66	1.25	4.45		150	4.00	43.73
	108	4.25	20.46		72	1.50	5.82		156	4.25	49.11
42	48	1.75	3.10		78	1.75	7.38		162	4.50	54.88
	54	2.00	4.04		84	2.00	9.17		168	4.75	61.07
	60	2.25	5.14		90	2.25	11.18		174	5.00	67.68
	66	2.50	6.43		96	2.50	13.44		180	5.25	74.74
	72	2.75	7.91		102	2.75	15.96		186	5.50	82.26
	78	3.00	9.60		108	3.00	18.75		192	5.75	90.25
	84	3.25	11.52		114	3.25	21.83		198	6.00	98.73
	90	3.50	13.68		120	3.50	25.21		204	6.25	107.71
	96	3.75	16.09		126	3.75	28.91		210	6.50	117.21
	102	4.00	18.78		132	4.00	32.94		216	6.75	127.23
	108	4.25	21.74		138	4.25	37.32				
	114	4.50	25.01		144	4.50	42.06				
	120	4.75	28.58		150	4.75	47.18				
	126	5.00	32.49		156	5.00	52.68				
					162	5.25	58.60				
					168	5.50	64.93				
					174	5.75	71.69				
					180	6.00	78.90				

BELL VOLUMES IN CUBIC YARDS, 60 DEGREE BELLS, HEIGHT INCLUDES 6" PAD, VOLUME INCLUDES PAD

Shaft Diameter (in)	Bell Diameter (in)	Bell Height (ft)	Bell Volume (cy)
18	24	0.93	0.39
	30	1.37	0.74
	36	1.80	1.23
	42	2.23	1.89
	48	2.67	2.74
	54	3.10	3.81
24	30	0.93	0.64
	36	1.37	1.14
	42	1.80	1.80
	48	2.23	2.66
	54	2.67	3.73
	60	3.10	5.05
	66	3.53	6.64
	72	3.96	8.52
30	36	0.93	0.95
	42	1.80	2.08
	48	2.23	3.02
	54	2.67	4.20
	60	3.10	5.62
	66	3.53	7.32
	72	3.96	9.33
	78	4.40	11.66
	84	4.83	14.34
	90	5.26	17.40
36	42	0.93	1.33
	48	1.37	2.19
	54	1.80	3.28
	60	2.23	4.61
	66	2.67	6.20
	72	3.10	8.09
	78	3.53	10.30
	84	3.96	12.86
	90	4.40	15.78
	96	4.83	19.10
	102	5.26	22.84
	108	5.70	27.03
42	48	0.93	1.76
	54	1.80	3.66
	60	2.23	5.10
	66	2.67	6.82
	72	3.10	8.84
	78	3.53	11.19
	84	3.96	13.90
	90	4.40	16.98
	96	4.83	20.46
	102	5.26	24.37
	108	5.70	28.74
	114	6.13	33.58
	120	6.56	38.93
	126	7.00	44.81
48	54	0.93	2.26
	60	1.37	3.60
	66	1.80	5.20
	72	2.23	7.10
	78	2.67	9.32
	84	3.10	11.89
	90	3.53	14.82
	96	3.96	18.15
	102	4.40	21.90
	108	4.83	26.09
	114	5.26	30.76
	120	5.70	35.92
	126	6.13	41.60
	132	6.56	47.83
	138	7.00	54.63
	144	7.43	62.02
54	60	0.93	2.82
	66	1.37	4.43
	72	1.80	6.33
	78	2.23	8.56
	84	2.67	11.13
	90	3.10	14.07
	96	3.53	17.40
	102	3.96	21.15
	108	4.40	25.35
	114	4.83	30.02
	120	5.26	35.19
	126	5.70	40.87
	132	6.13	47.11
	138	6.56	53.91
	144	7.00	61.31
	150	7.43	69.33
	156	7.86	78.00
	162	8.29	87.34
60	66	0.93	3.43
	72	1.80	6.87
	78	2.23	9.25
	84	2.67	11.98
	90	3.10	15.09
	96	3.53	18.60
	102	3.96	22.54
	108	4.40	26.93
	114	4.83	31.80
	120	5.26	37.18
	126	5.70	43.08
	132	6.13	49.54
	138	6.56	56.58
	144	7.00	64.22
	150	7.43	72.50
	156	7.86	81.43
	162	8.29	91.04
	168	8.73	101.35
	174	9.16	112.40
	180	9.59	124.20
66	72	0.93	4.12
	78	1.37	6.35
	84	1.80	8.93
	90	2.23	11.88
	96	2.67	15.22
	102	3.10	18.98
	108	3.53	23.19
	114	3.96	27.87
	120	4.40	33.05
	126	4.83	38.74
	132	5.26	44.98
	138	5.70	51.80
	144	6.13	59.21
	150	6.56	67.24
	156	7.00	75.91
	162	7.43	85.26
	168	7.86	95.31
	174	8.29	106.08
	180	8.73	117.60
	186	9.16	129.89
	192	9.59	142.97
	198	10.03	156.88
72	78	0.93	4.86
	84	1.37	7.44
	90	1.80	10.39
	96	2.23	13.74
	102	2.67	17.51
	108	3.10	21.73
	114	3.53	26.41
	120	3.96	31.59
	126	4.40	37.29
	132	4.83	43.54
	138	5.26	50.35
	144	5.70	57.77
	150	6.13	65.80
	156	6.56	74.49
	162	7.00	83.84
	168	7.43	93.89
	174	7.86	104.67
	180	8.29	116.19
	186	8.73	128.48
	192	9.16	141.57
	198	9.59	155.49
	204	10.03	170.25
	210	10.46	185.89
	216	10.89	202.42

Shaft Diameter (in)	Bell Diameter (in)	Bell Height (ft)	Bell Volume (cy)
78	84	0.93	5.66
	90	1.37	8.62
	96	1.80	11.97
	102	2.23	15.75
	108	2.67	19.96
	114	3.10	24.65
	120	3.53	29.84
	126	3.96	35.54
	132	4.40	41.79
	138	4.83	48.62
	144	5.26	56.04
	150	5.70	64.08
	156	6.13	72.76
	162	6.56	82.12
	168	7.00	92.18
	174	7.43	102.96
	180	7.86	114.48
	186	8.29	126.78
	192	8.73	139.88
	198	9.16	153.80
	204	9.59	168.57
	210	10.03	184.21
	216	10.46	200.75
	222	10.89	218.21
	228	11.33	236.63
	234	11.76	256.01
84	90	0.93	6.53
	96	1.37	9.88
	102	1.80	13.66
	108	2.23	17.89
	114	2.67	22.58
	120	3.10	27.77
	126	3.53	33.48
	132	3.96	39.74
	138	4.40	46.56
	144	4.83	53.99
	150	5.26	62.03
	156	5.70	70.72
	162	6.13	80.09
	168	6.56	90.15
	174	7.00	100.93
	180	7.43	112.46
	186	7.86	124.77
	192	8.29	137.87
	198	8.73	151.79
	204	9.16	166.57
	210	9.59	182.21
	216	10.03	198.76
	222	10.46	216.23
	228	10.89	234.65
	234	11.33	254.04
	240	11.76	274.43

Shaft Diameter (in)	Bell Diameter (in)	Bell Height (ft)	Bell Volume (cy)
90	96	0.93	7.45
	102	1.37	11.24
	108	1.80	15.46
	114	2.23	20.16
	120	2.67	25.36
	126	3.10	31.07
	132	3.53	37.33
	138	3.96	44.17
	144	4.40	51.59
	150	4.83	59.64
	156	5.26	68.34
	162	5.70	77.71
	168	6.13	87.78
	174	6.56	98.56
	180	7.00	110.10
	186	7.43	122.41
	192	7.86	135.52
	198	8.29	149.45
	204	8.73	164.22
	210	9.16	179.87
	216	9.59	196.42
	222	10.03	213.90
	228	10.46	232.32
	234	10.89	251.72
	240	11.33	272.12
	246	11.76	293.54
	252	12.19	316.01
	258	12.62	339.55
	264	13.06	364.20
	270	13.49	389.97

Shaft Diameter (in)	Bell Diameter (in)	Bell Height (ft)	Bell Volume (cy)
96	102	0.93	8.44
	108	1.80	16.32
	114	2.23	21.25
	120	2.67	26.68
	126	3.10	32.63
	132	3.53	39.15
	138	3.96	46.24
	144	4.40	53.94
	150	4.83	62.27
	156	5.26	71.25
	162	5.70	80.91
	168	6.13	91.28
	174	6.56	102.38
	180	7.00	114.24
	186	7.43	126.87
	192	7.86	140.32
	198	8.29	154.59
	204	8.73	169.72
	210	9.16	185.74
	216	9.59	202.66
	222	10.03	220.51
	228	10.46	239.32
	234	10.89	259.11
	240	11.33	279.91
	246	11.76	301.75
	252	12.19	324.64
	258	12.62	348.61
	264	13.06	373.70
	270	13.49	399.91
	276	13.92	427.29
	282	14.36	455.85
	288	14.79	485.62

Illinois Department of Transportation

SPECIFIC TASK TRAINING PROGRAM

DRILLED SHAFT CONSTRUCTION INSPECTION

S 32

Bureau of Construction

1

Illinois Department of Transportation

Course Goals

- Introduce you to the construction process.
- Introduce you to proper inspection.
- Introduce you to proper safety.

2

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Course Goals

- Know where to find more detailed information on the construction of drilled shafts.
  - FHWA
    Drilled Shafts : Construction Procedures and LRFD Design Methods (FHWA – May 2010)

3

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FHWA Process Review Results

- Good boring information is critical.
- Improved definition of obstruction needed.
- Encourage pre-drill meetings.
- Define excessive water infiltration.
- Emphasize importance of slump retention.

4

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FHWA Process Review Results

- Emphasize the concept of head pressure.
- Emphasize proper tremie concrete placement.
- Emphasize concrete containment at end of pour.
- Increase nondestructive testing.
- Emphasize fall protection safety.

5

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Course Outline

- Module 1 – Introduction to Drilled Shaft Inspection
- Module 2 – Shaft Excavation Tools and Methods
- Module 3 – Shaft Excavation Inspection
- Module 4 – Rebar and Concrete Inspection and Installation
- Module 5 – Inspector's Checklist and Documentation
- Module 6 – Non-Destructive Testing and Load Testing

6

Module 1
Introduction to Drilled Shaft Inspection

7

Role of the Inspector

- Verify soil conditions are comparable to borings and notify the design engineer of significant deviations.
- Ensure that construction is done in accordance with plans and specifications through observation and testing.
- Record the means and methods of construction using Bureau of Bridges and Structures forms, and document the as-built condition of the shaft.

8

Drilled Shaft Applications

- Bridges (Guide Bridge Special Provision #86 "Drilled Shafts")
  - Shafts over 100 feet deep possible.
  - District 8 (Chain of Rocks Canal Project)
    - Example of One Shaft:
      Portion of Shaft in Soil – 144 feet in length and 6 feet in diameter
      Portion of Shaft in Rock – 25 feet in length and 5.5 feet in diameter
- Noise Abatement Walls
- Concrete Foundations for Sign Structures (Section 734)
  - Overhead Sign Structures – Shafts 10 to 27 feet deep
  - Cantilever Sign Structures – Shafts 16 to 32 feet deep

9

Drilled Shaft Applications

- Light Pole Foundations (Section 836)
  - Highway Standard 836001 – Shafts 5 to 7 feet deep
  - Highway Standard 836011 – Shafts 3 to 5 feet deep
  - Possibly up to 15 feet deep
- Light Tower Foundations (Section 837)
  - Highway Standard 837001 – Shafts 11.5 to 30 feet deep
- Traffic Signal Foundations (Section 878)
  - Highway Standard 878001 – Shafts 10 to 25 feet deep

10

Advantages of Drilled Shafts

- Drilled shaft foundations are specified to address vertical and lateral load capacity concerns resulting from large scour depths, high seismic loadings, potential liquefaction, low soil strengths, and inadequate pile embedment.

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Advantages of Drilled Shafts

- Drilled shafts have a large capacity per element. A driven pile can support hundreds of tons, but a drilled shaft can support thousands of tons. Drilled shafts also have high lateral load capacity.
  - Why large capacity? Drilled shafts can be constructed 1 to 10 feet in diameter.
- Drilled shafts generally have less noise and vibration during construction than driven piles.

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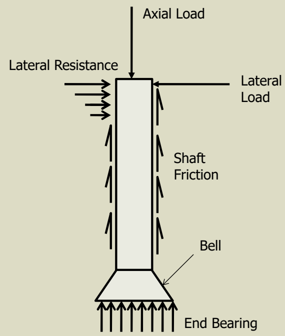
Drilled Shaft Design – In Soil

- Drilled shafts in soil resist axial loads through friction and end bearing
- Drilled shafts in soil can have a constant diameter or the base can be enlarged by belling to provide additional area



13

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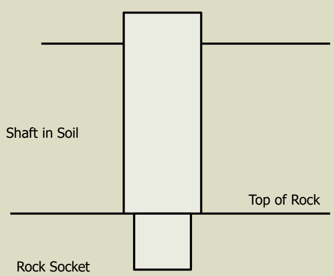
Drilled Shaft Design – In Rock

- Shaft excavation will extend through the overburden soil and then socket into rock
- Socket is generally a smaller diameter than the shaft
- Shaft can also extend to the top of rock with no socket



14

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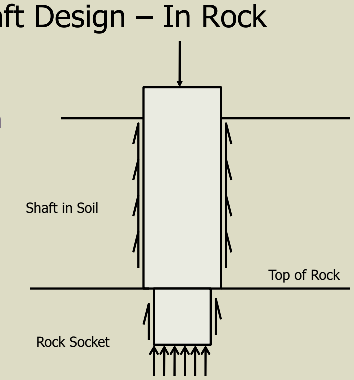
Drilled Shaft Design – In Rock

- Shafts in rock carry load through friction and end bearing
- The majority of the shaft capacity is developed in or on the rock



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Disadvantages of Drilled Shafts

- Drilled shafts are more susceptible to defects that result from poor construction techniques!
- Drilled shaft capacity is highly dependent on the Contractor's installation methods and experience.

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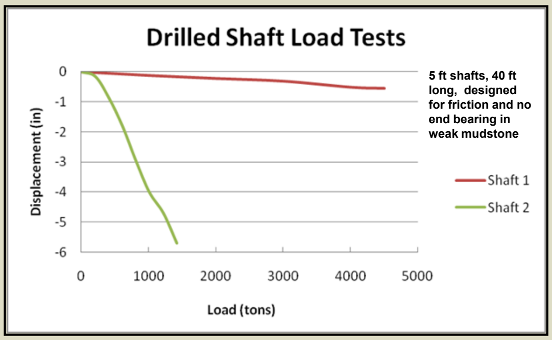
Load test results for two drilled shafts at a project site in the same ground.
Shaft 1 reached 4500 tons at ½ inch displacement
Shaft 2 failed, reaching only 1500 tons at 6 inches displacement
The test failed because of an interrupted tremie pour which apparently resulted in two cubic yards of leached concrete at the base of the shaft. The tremie was pulled out of the concrete and reinserted without a bottom plate. Contaminated concrete is assumed to line the side walls of the shaft.



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Example of Contaminated Concrete

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Disadvantages of Drilled Shafts

- A driven pile is a tested pile. The capacity of a drilled shaft can be uncertain without a load test.
- Soil or rock can be disturbed by drilled shaft installation.
- Installation in caving, saturated granular soil below the water table is difficult.
- Open excavations can result in loss of ground below neighboring structures.
- Poured concrete integrity can be uncertain especially for tremie pours. Testing is needed.

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Preparation for Drilled Shaft Inspection

- Review plans and specifications for the project.
- Review the Structure Geotechnical Report for the project. If applicable, discuss with District Geotechnical Engineer.
- Obtain design engineer contact information.
- Prepare your field tools and supplies.
- Collect forms for field documentation.

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Plans and Specifications

- The plans will indicate the type of shaft such as permanent casing or no casing.
- The plans will indicate the diameter of the shaft and the length of the shaft.
- The plans will provide important information regarding the reinforcing steel.

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Standard Specifications for Road and Bridge Construction

- Section 508 – Rebar (Construction)
- Section 516 – Drilled Shafts (Construction)
- Section 1020 – Portland Cement Concrete (Class DS Requirements)
- Section 1006.05 – Steel Casing (Material Requirements)
- Section 1006.10 – Rebar (Material and Condition Requirements)

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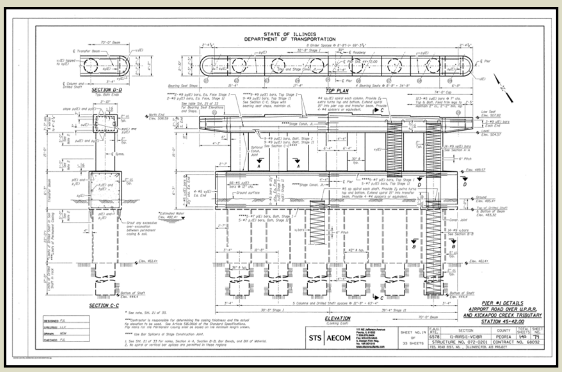
Typical Drilled Shaft Plans



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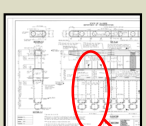
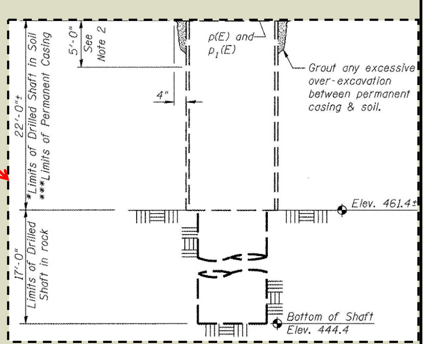
Shaft Length



Estimated elevation of rock, shaft length, required rock socket length and shaft bottom elevation are shown



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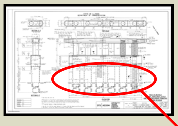
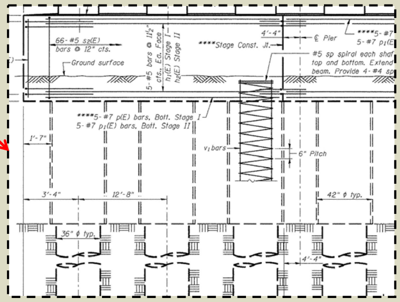
Shaft Diameter





Shaft and socket diameters are shown here

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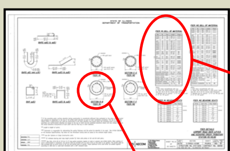
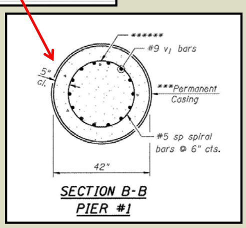
Rebar





PIER #1 BILL OF MATERIAL

Bar	No.	Size	Length	Shape
$h_1(E)$	10	#5	28'-7"	
$h_2(E)$	10	#5	37'-3"	
p(E)	10	#7	28'-7"	
$p_1(E)$	10	#7	37'-3"	
$p_2(E)$	13	#9	31'-3"	
$p_3(E)$	13	#9	39'-11"	
$p_4(E)$	9	#9	31'-3"	
$p_5(E)$	9	#9	39'-11"	
$s_2(E)$	66	#5	20'-6"	
$s_4(E)$	246	#5	9'-10"	
** sp	6	#5	40'-3"	
** $sp_1(E)$	6	#4	17'-6"	
u(E)	6	#9	20'-1"	
$u_1(E)$	14	#5	11'-9"	
v_1	84	#9	44'-9"	
$v_2(E)$	84	#9	24'-6"	
$v_3(E)$	8	#5	5'-11"	
Concrete Structures			Cu. Yd.	112.9
Reinforcement Bars			Pound	17,500
Reinforcement Bars, Epoxy Coated			Pound	20,020
Drilled Shaft in Soil			Cu. Yd.	47.0
Drilled Shaft in Rock			Cu. Yd.	26.7
Permanent Casing			Foot	132
Structure Excavation			Cu. Yd.	46

Type, size and arrangement or rebar are provided

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Structure Geotechnical Report

- Review soil conditions section for generalized soil description.
- Review design recommendations section to understand the desired bearing conditions and the nominal bearing pressure.
- Review construction considerations to understand type of construction which is anticipated, pay special attention to recommendations related to casing and groundwater control.

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Soil Boring Logs

- Should be included in the plans.
- Check the groundwater level.
- Review soil types. Granular layers below the water table (shaft water) and soft clay (shaft squeeze) can be problematic during construction.
- Compare boring log to design depth. What type of soil will the drilled shaft bear in?

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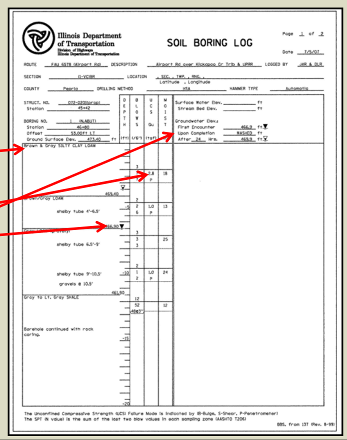
Soil Boring Logs

- Material type and color
- Material strength
- Groundwater elevations



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Rock Core Logs

- Do the drilled shafts extend into the rock?
- What type of rock will be encountered?
  - Shale is soft and easy to drill through – a rock auger may be adequate
  - Limestone or dolomite are much harder – coring may be required

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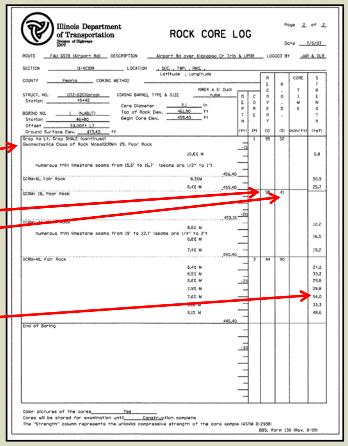
Rock Core Logs

- Rock type and quality
- Recovery
- RQD
- Unconfined Compressive Strength (UCS)



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Rock Core Logs

- What is Recovery?
  - The core recovery ratio is the length of rock core recovered from a core run, divided by the total length of the core run.
  - This ratio, expressed in percent, provides indications regarding the presence of weathered zones.

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Rock Core Logs

- What is the Rock Quality Designation (RQD)?
  - The RQD is a measure of the quality of rock.
  - High RQD (>50%) means fairly solid and massive rock.
  - Low RQD means weathered and fractured rock.
  - RQD is expressed in percent and is the sum of the lengths of all pieces of sound core over 4 in. long, recovered from a core run, divided by the total length of the core run. For example, if the core length is 40 in. and there are 10 rock pieces, 7 of which with lengths less than 4 in. and 3 pieces with lengths of 4 in., 5 in. and 6 in., respectively, the RQD for this core is (15 ÷ 40) X 100 = 37.5%.

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Rock Core Logs

- Check with District Geotechnical Engineer to see if rock cores were saved.
- Visual inspection of the rock cores will help the Resident determine if similar rock is encountered in the field.

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Inspector's Toolbox

- Safety Equipment
  - Hard Hat
  - Safety Glasses
  - High Visibility Vest
  - Steel Toed Boots
  - Hearing Protection
  - Gloves
  - Life Preserver

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Inspector's Toolbox

- Tools for Inspection
  - 25 foot tape measure
  - 100 foot weighted tape measure
  - Hand penetrometer
  - RIMAC
  - Field book and forms
  - Calculator
  - Camera
  - Plumb bob
  - High Lumen Flashlight or Mirror

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Inspector’s Toolbox – Advanced Tools

- Rock probe on a cable
- Explosion proof camera
- Explosion proof light

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Module 2
Shaft Excavation Tools and Methods

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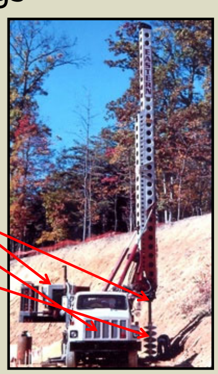
Drill Rigs

- Common Components
  - Power Unit
  - Kelly Bar
  - Body or Carrier
  - Tools



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Drill Rigs

- One of three types will usually be encountered
  - Truck mounted
  - Crawler body mounted
  - Crane mounted

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Truck Mounted Drill Rig

- Used for small diameter, short shafts
- Easy mobilization for small projects
- May require a support crane but some do have winches

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Crawler Body Mounted Drill Rig

- Higher capacity than truck rigs
- Provides highest downward pressure (crowd)
- Better for difficult access conditions due to tracks
- Mobilize to site on flatbed trailer
- Largest rigs equal the torque of crane-mounted rigs

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Crawler Body Mounted Rig

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Crane Mounted Drill Rigs

- Largest capacity, for diameter and length
- Crowd pressure limited to Kelly weight
- Highest torque
- Require large foot print to work in
- Mobilize to the site in multiple pieces
- Casing length that can be handled effectively is limited to the clearance below the "bridge"

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Drilling Tools

- Earth drilling tools
- Rock drilling tools
- Cleanup tools

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Earth Drilling Tools – Earth Auger

- Flights
  - Single flight
  - Double Flight
- Teeth - usually spade-type hardened steel
- Stinger

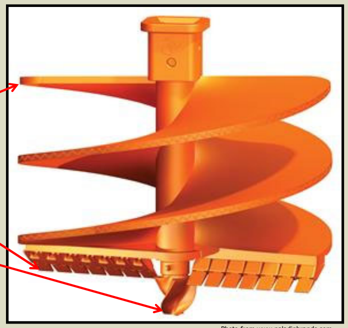

Photo from www.paladinbrands.com

This is a double-flight, double cut auger

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Earth Drilling Tools – Earth Auger Double Flight for Hard Drilling

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Earth Drilling Tools – Earth Auger Single Flight

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Earth Drilling Tools – Earth Auger

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Earth Drilling Tools – Digging Bucket

- For use in soil that does not stay on an open auger
  - Very soft clay
  - Saturated sand and silt
  - Drilling under slurry

Photo from www.nubeng.com

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Earth Drilling Tools – Belling Bucket

Wings Open

Wings Closed

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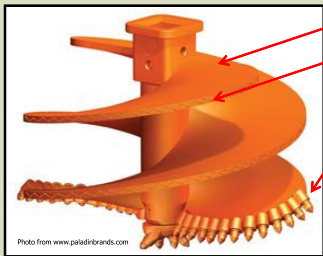
Rock Drilling Tools – Rock Auger



Heavier flights
Abrading "teeth"
Flights often tapered
Carbide-tipped bullet or chisel shaped teeth

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Rock Auger

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Rock Drilling Tools – Rock Auger

- Rock augers are mainly used for soft rock such as shale or highly fractured and weathered rock.
- Replace teeth that are worn down.

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Rock Drilling Tools

Core Barrel

Downhole Hammer

Photo from www.paladinbrands.com

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Rock Drilling Tools
Core Barrel and Downhole Hammer

- Core Barrel – Used for harder rock with a compressive strength greater than 3,000 psi.
- Downhole Hammer – Cutting heads combined with hammer to break rock. Used for rock compressive strength up to 50,000 psi.

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Core Barrel

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Core Barrel – Core Held by Friction

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Removal of Boulders

- Grab Bucket or Clamshell
- Boulder Rooter – Basically a tapered auger.
- Hammergrab – Jaws closed when tool is dropped to break rock. Jaws are then used to pick up broken rock.
- Rock Breaker/Drop Chisel – Heavy object to break rock.

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Clean up Tools

- Often referred to as a muck bucket, one-eye bucket or clean-out bucket
- Removes loose material and water from excavation

View of bottom of bucket

Emptying bucket into loader

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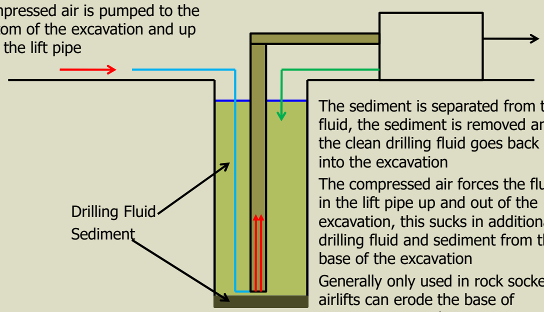
Clean Up Tools – Air Lift

Compressed air is pumped to the bottom of the excavation and up into the lift pipe



The sediment is separated from the fluid, the sediment is removed and the clean drilling fluid goes back into the excavation

The compressed air forces the fluid in the lift pipe up and out of the excavation, this sucks in additional drilling fluid and sediment from the base of the excavation

Generally only used in rock sockets, airlifts can erode the base of excavations in soil

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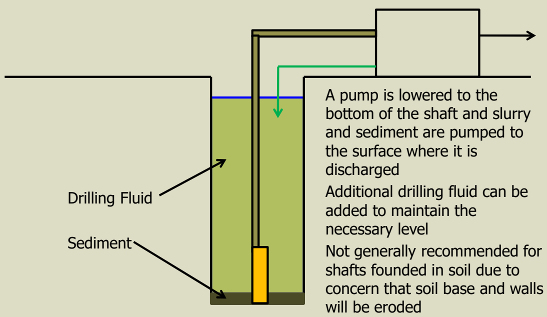
Clean Up Tools – Downhole Pump



A pump is lowered to the bottom of the shaft and slurry and sediment are pumped to the surface where it is discharged

Additional drilling fluid can be added to maintain the necessary level

Not generally recommended for shafts founded in soil due to concern that soil base and walls will be eroded

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Shaft Excavation Methods

- Dry Hole Excavations (a.k.a. Dry Method)
- Wet or Dry Hole Excavations (Casing Method)
  - Temporary (a.k.a. Temporary Casing Method)
  - Telescoping
  - Permanent Casing
  - Permanent Corrugated Liner
  - Removable Forms
- Wet Hole Excavations (a.k.a. Wet Method or Slurry Method)
  - Water
  - Bentonite
  - Polymer

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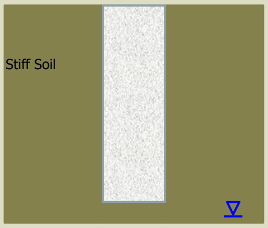
Shaft Excavation – Dry Method

- No casing except possibly at surface.
- Shaft must remain dry.
- Suited for stiff to hard clayey soils.
- Suited for cemented sands or rock above the water table.
- Allows the base to be enlarged (belled) by under-reaming.
- Concrete may be placed by free fall.



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Surface or Starter Casing

- Almost all shafts will have a starter casing at the ground surface to protect workers from cave-ins, and to prevent the top of the shaft from becoming enlarged due to tool removal and insertion.

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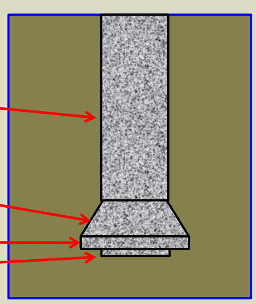
Shaft Excavation – Belled Shaft

- Belling can only occur in stiff soil
- Shaft
- Bell
  - Not larger than 3 x shaft diameter
  - Angle not flatter than 45 degrees
- Pad
- Pilot hole



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Shaft Excavation – Belled Shaft

- Belling Bucket
  - Bucket
  - Wings
- Wings controlled by movement of Kelly bar
  - Kelly bar down, wings come out
  - Kelly bar up, wings come in
- Kelly bar travel required to reach design diameter can be measured
- Chains are installed to set maximum bell size
- Bells are often oversized in the field up to 1 ft to compensate for limited cleaning ability

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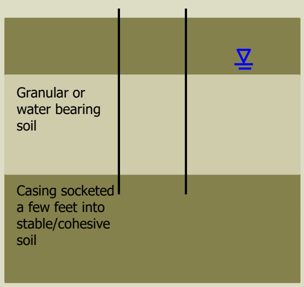
Shaft Excavation – Temporary Casing

- Casing used to stabilize sloughing soils.
- Typically 6 inches larger than design shaft.
- Hole can be completed wet or dry.



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Shaft Excavation – Temporary Casing

- When temporary casing is used, the diameter of the cased length is often enlarged to allow passage of the drilling tools and to set the casing in the excavation.
- The casing can also be pushed or twisted into the soil ahead of the excavation.

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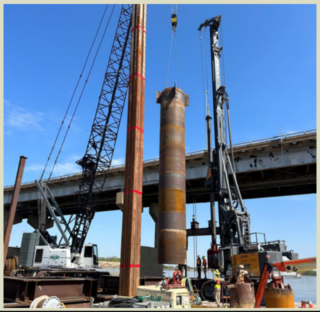
Temporary Casing



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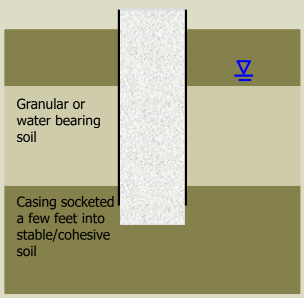
Shaft Excavation – Permanent Casing

- Used to reduce the risk of damage to adjacent structures by preventing ground movement caused by the excavation process.
- Used to extend the drilled shaft above the ground surface or water surface if constructing in a river.
- Other subsurface conditions may require its use.



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Shaft Excavation – Permanent Casing

- When permanent casing is used, the casing should be pushed or twisted into the soil so that it is tight against the excavation.
- The casing must be a tight fit to provide lateral load transfer.

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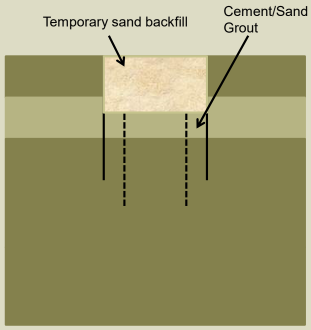
Shaft Excavation – Permanent Corrugated Liner

- Used with temporary casing when top of shaft is within an unstable layer.
- Wet or dry excavation.
- Liner extends minimum of 2 feet below temporary casing and must be design diameter.



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Installing Permanent Corrugated Liner

Corrugated Steel Liner

Installing blocks to center the corrugated steel liner

Temporary Casing
Permanent Corrugated Liner
Annulus

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Shaft Excavation – Permanent Corrugated Liner

- Before pulling the temporary outer casing, it is necessary to grout the annulus between the liner and the casing.
- Allow the shaft concrete to set overnight before pulling casing.
- Backfill the annulus between the permanent liner and casing with cement-sand grout mixture.
- Pull temporary casing while grout is still fluid.
- Temporarily backfill the excavation to grade with sand.

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Shaft Excavation – Removable Forms

- When shafts extend above the ground surface but are not permanently cased, removable forms are used.
- Some examples include
  - Sonotubes
  - Custom built wood forms
  - Reusable steel or timber forms
- Concrete must cure minimum of 72 hours and achieve a minimum compressive strength of 2,500 psi before forms are removed.

concreteforms-shoring.blogspot.com/

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Slurry Method

- Used in water bearing granular soils.
- Used when casing would be too large or too long to handle efficiently.
- Can use drilling fluid (water or slurry).
  - Slurry - bentonite or polymer
- Using only water is generally not recommended. Water may soften soils (clay) or rock (shale).

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Water Excavation Vs. Polymer Slurry

1) Samples are very weak limestone auger cuttings taken during shaft drilling.
2) Half the sample was placed in water and the other half in polymer slurry.
3) Even after 3 hours, both samples are essentially intact.

Conclusion: Water excavation does not degrade the limestone at this site.

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Water Excavation Vs. Polymer Slurry

1) Samples are very weak shale auger cuttings taken during shaft drilling.
2) Half the sample was placed in water and the other half in polymer slurry.
3) In less than one hour, the shale sample in water disintegrated to "mush"
4) Even after 3 hours, the shale sample in polymer slurry is intact

Conclusion: Shaft friction in the shale will be lost because of the water installation method. Polymer is required.

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Slurry Method

- Slurry provides stability of the excavated hole by forming a filter cake (a.k.a. mudcake or slurry cake) which effectively acts as a membrane on the walls of the shaft.
- The membrane requires the slurry head pressure to exceed the fluid pressure resulting from the in situ formation. This will stabilize the hole.

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Slurry Method

Example of head pressure from in situ formation.

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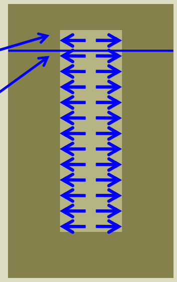
Slurry Method

- Shaft excavation is stabilized using water or slurry mixture.
  - Density of bentonite or polymer slurry is greater than density of water.
  - Elevation of drilling fluid (water or slurry) is greater than groundwater elevation.
- The fluid in the shaft applies pressure to the side walls stabilizing the excavation and preventing caving and sloughing.
- The fluid also balances water pressure from the groundwater table preventing seepage from entering the shaft.



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Polymer Slurry

- Polymer slurry is becoming more common than bentonite slurry.
  - Easier to handle.
  - Requires less equipment for cleaning and reusing the slurry.
  - Sand will settle out of the polymer slurry whereas sand and silt will become suspended in bentonite slurry.

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Sand in Slurry

- High sand content makes it more difficult for the concrete to displace the slurry. This can create voids in shaft.
- High sand content can settle in the concrete and can create soil inclusions or contaminate the surface of the concrete during the pour, ultimately affecting concrete compressive strength.

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Polymer Slurry

- Add polymer additive to water to create a slurry.
- Need to maintain a higher level (in shaft) than with bentonite slurry to provide equivalent pressures due to lower density of polymer slurry.
- Allow to 3-4 hours for sand to settle out of slurry.
- Slurry can be reused.
- Contractor tests slurry for density, viscosity, pH, and sand content .

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Polymer Slurry

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Polymer Slurry - Disposal

- Polymer slurry normally broken down with chemical oxidizer.
- After mixing chemical oxidizer, slurry may be disposed as follows:
  - Sewer System
  - Percolated Into the Ground
  - Evaporation

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Polymer Slurry – Improper Disposal

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Bentonite Slurry

- Add bentonite clay to water to create slurry.
- Bentonite slurry has higher density than polymer slurry.
- Fine sand and silt will become suspended in the slurry, need to circulate and de-sand the slurry during construction.
- Contractor tests slurry for density, viscosity, pH, and sand content.
- Slurry can be reused.

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Bentonite Slurry

- Slurry storage and cleaning system.
- Screens remove large particles.
- Centrifuge used to remove sand and silt particles.

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Slurry Method

Construction quality control is critical. Discuss slurry properties at preconstruction meeting.

Testing polymer slurry.

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Slurry Testing Equipment

Mud Balance – Density

Sand Content Set

Slurry Sampler

Marsh Funnel – Viscosity

pH Meter

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Module 3
Shaft Excavation Inspection

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Safety

- Employee Safety Code Manual
  - Chapter 8 Confined Space Entry
  - Chapter 11 Fall Protection Program – Working at Heights

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Safety

- Inspection – Will be completed from the ground surface.
  - Entry into Shaft – Entry into the excavation is not necessary or recommended.
  - Entry into Shaft (Confined Space)
    - Installation of steel casing required.
    - Testing required for oxygen content, flammable gases, and toxic air contaminants.

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Safety

- Inspection – Will be completed from the ground surface.
  - Fall Protection – Required when IDOT worker is working at height of four feet or greater above a lower level in the field per Employee Safety Code Manual.
  - Fall Protection Methods – Examples include platform with a guardrail, or safety harness and lifeline connected to a fixed object.
  - Starter Casing – Will protect workers, but can slide down shaft if soil sloughing or caving is occurring below the casing. The casing must be 42 inches plus or minus three inches above the walking or working level per Employee Safety Code Manual.

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Safety

Need fall Protection.

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Safety

Need fall protection and slope stability is a concern.

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Safety

Starter casing is too low and could slide down.

99

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Safety

Need better fall protection.

100

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Safety

Good Fall Protection - Full body harness attached to concrete deadman.

101

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Safety

Good fall protection.

Tremie Pipe

102

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Safety

Good fall protection.

103

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Safety

Good fall protection.

104

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Work Plan

- Drilled Shaft Installation Plan (Form BBS 133)
  - Bridges – Required
  - Noise Abatement Walls – See Specification
  - Concrete Foundations for Sign Structures – Required
    - Overhead or Cantilever
  - Light Pole Foundations – Not Required
  - Light Tower Foundations – Not Required
  - Traffic Signal Foundations – Not Required
- Drilled Shaft Pre-Drill Meeting - Encouraged

105

Shaft Excavations – Preparation

- Notify District Geotechnical Engineer as required by District practice.
- Obtain contact information of design engineer.
- Obtain copy of Drilled Shaft Excavation and Inspection Record (Form BBS 134)

106

Shaft Excavations – What to Watch

- Does the excavated material match the soil boring logs and rock core logs?
  - Record soil type, depth, and strength.
  - Perform soil testing when applicable.
    - Pocket Penetrometer
    - RIMAC unconfined compressive strength
  - Other Observations: Groundwater elevation, caving conditions, casing, slurry, etc. on BBS 134.

107

Shaft Excavation – Obstructions

- IDOT classifies an obstruction as "an unknown isolated object that causes the shaft excavation to experience a significant decrease in the actual production rate and requires the contractor to core, break up, push aside, or use other means to mitigate an obstruction".
- The contractor is required to notify the inspector for concurrence that an obstruction has been encountered.

108

Shaft Excavation – Obstructions

- A boulder or cobble is a common obstruction encountered during excavation.
  - Boulder - Average dimension 12 inches or more.
  - Cobble - Average dimension between 3 and 12 inches.
- The contractor is allowed additional compensation for mitigating an obstruction.
- There is no deduction to the measured shaft length when measuring for payment.

109

Shaft Excavation Differing Site Conditions

- First type per Article 104.03 – Subsurface or latent physical conditions encountered at the site differing materially from those indicated in the contract.
- Examples:
  - Larger rock such as encountering cobbles and boulders instead of sand in a soil boring strata.
  - Rock that is harder to drill, such as granite instead of limestone was encountered.

110

Shaft Excavation Differing Site Conditions

- Second type per Article 104.03 – Unknown physical conditions of an unusual nature, differing materially from those ordinarily encountered and generally recognized as inherent in the work.
- Example:
  - A hazardous waste deposit.

111

Shaft Excavation
Differing Site Conditions

- The contractor is allowed additional compensation for the differing site condition.
- The portion of the measured length of the shaft may be adjusted according to Article 104.02.

112

Shaft Excavation
Differing Site Conditions

- Is a groundwater elevation that is different from the elevation shown on the plans a differing site condition?
- Not normally, but refer to 3.3 – Obstructions and Differing Site Conditions for six conditions the contractor must prove.

113

Shaft Diameter and Length

- Diameter
  - The shaft needs to be at least as large as the diameter shown on the drawings.
  - The shaft can and often will be larger than design due to the need for temporary (oversized) casing.
- Length
  - The length may vary.
  - Make sure the bottom material meets the bearing requirements.
  - Make sure that the rock socket lengths match the plan dimensions.

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Construction Tolerances

- Inspect Construction Tolerances
  - Center of Shaft
  - Center of Reinforcement Cage
  - Vertical Plumbness of Shaft – Compare the location of the top of shaft to the bottom of shaft. Take the difference in top and bottom location divided by shaft length to determine percent out of plumb.

115

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Construction Tolerances

- Inspect Construction Tolerances
  - Vertical Plumbness of Reinforcement Cage – Compare the location of the top of rebar cage to the bottom of rebar cage. Take the difference in top and bottom location divided by cage length to determine percent out of plumb.
  - Top of Shaft
  - Top of Reinforcement Cage
  - Bottom of Shaft

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Squeeze, Necking and Cave-Ins

- Using the correct size auger doesn't guarantee the shaft will be the right diameter.
- Shafts in soft clays can squeeze creating a necked down shaft. Refer to 3.5 and use formula to determine which soils may squeeze.
  - Casing or slurry should be used.
- All materials are subject to cave-ins and sloughing if left open for a significant period of time.

117

Squeeze, Necking and Cave-Ins

- Pay close attention during excavation for squeeze/necking.
  - Watch to see if the auger consistently gets hung up at a certain depth.
- Pay close attention during excavation for cave-ins.
  - Watch when tools come out of the hole if there is material that fell from above.
  - When the tools are out of the excavation, listen for material caving into the excavation.

118

Cave-Ins and Sloughing

- Caution should be exercised when tools are entering and exiting the excavation.
  - When no starter casing is utilized, tools entering and exiting the holes can oversize the top and cause cave-ins from the surface.
  - When excavating under fluid, the augers should enter and exit the excavation slowly. Fast movements may cause turbulence and possibly erode the sides of the excavation.

119

Shaft Excavation – Rock Sockets

- Where does the rock socket start?
  - Refer to Section 516 of the specifications.
    - Rock is defined as bedded and conglomerate deposits exhibiting the physical characteristics and difficulty of rock removal.
  - When the excavation can no longer proceed using conventional earth excavation equipment. Rock has been encountered if rock augers or coring equipment is required.

120

Shaft Excavation – Rock Sockets

- If the rock elevation encountered during excavation is higher than the nearby borings there could be a problem.
  - Boulders and shelf rock may be present.
- Contractor should be able to use core barrel to obtain core at the base of the excavation and confirm solid rock.

121

Shaft Excavation – Acceptance

- Friction Shafts
  - Determine if this is a friction shaft or an end bearing shaft from the structure geotechnical report, plans, or design engineer.
  - Does the encountered soil profile match the soil boring logs? If the conditions don't match, contact the design engineer.

122

Shaft Excavation - Acceptance

- End Bearing Shafts in Soil
  - Is correct material confirmed?
  - Is the encountered material at the base strong enough to support the load?
  - Check the bottom cuttings with a pocket penetrometer or RIMAC. Bearing pressure = 1.5 X unconfined compressive strength.
    - It may not be possible to check with RIMAC.
    - If material is sand or silt, pocket penetrometer and RIMAC testing will not be possible.

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Shaft Excavation - Acceptance

- End Bearing Shafts in Sand or Silt
  - Confirm that the encountered soil conditions match the nearest soil borings.

124

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Shaft Excavation - Acceptance

- Rock Sockets and Top of Rock Shafts
  - Confirm top of rock elevation compared to boring and rock core logs.
    - If the top of rock elevation differs from that shown on the plans by more than 10% of the length of the drilled shaft above the rock, notify the design engineer.

125

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Shaft Excavation - Acceptance

- Rock Sockets and Top of Rock Shafts
  - Does the encountered rock type match the rock core logs?
  - Are any voids or weak seams encountered when excavating the rock socket? If yes, contact the design engineer.
  - Is the bottom clean?

126

Shaft Excavation - Acceptance

- Is the bottom flat for soil?
  - Does the excavation equipment have a nearly planar bottom?
    - A clean-out bucket with a planar bottom is used for soil.

127

Shaft Excavation - Acceptance

- Is the bottom flat for rock?
  - Does the excavation equipment have a nearly planar bottom?
  - Are the cutting edges normal to the vertical axis of the shaft within a tolerance of 6.25 percent?

128

Rock Auger – Bottom is Not Flat

129

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Shaft Excavation - Acceptance

- Is a flat bottomed rock auger being used without a stinger?
  - The alternative to this is to allow the rock auger create a pilot hole with the stinger. A core barrel is then used, and the pilot hole provides some stress relief for final excavation.

130

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Core Barrel

131

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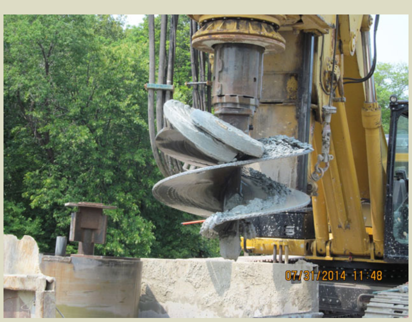
Removal of Cores



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Core

133

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Shaft Excavation – Acceptance

- Is the bottom clean?
  - In some cases visual inspection can be completed using a high lumen flashlight, reflecting sunlight with a mirror, or using an explosion proof light.
  - Otherwise you may have to use an explosion proof camera with visual depth measurement gauge.

134

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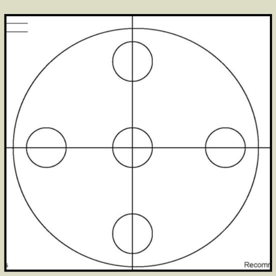
Shaft Excavation – Acceptance

- Is the bottom clean?
  - A weighted tape or rock probe can also be used to check the bottom.
  - Check at 5 points on the bottom.
  - If the weight strikes the bottom immediately, the drilled shaft has little or no sediment and debris.



135

Product to Help Clean Bottom

Flocculent for wet excavation.

136

Bottom Clean Up - Discussion

- For shafts bearing on soil, a clean-out bucket should be sufficient.
  - Make sure bucket is not riding up and down on a boulder or uneven rock.
  - If the bucket leaks water, this is an indication the soil is not sealing the gaps. Thus, the bottom is possibly clean.
- For belled shafts, clean with belling bucket as best as possible. The remaining spoils can be back-bladed to the bell periphery with a 1 foot over-sized bucket.
- For shafts bearing on rock, an airlift pump or downhole pump is frequently required to get the shaft bottom sufficiently clean.

137

Module 4
Rebar and Concrete Installation and Inspection

138

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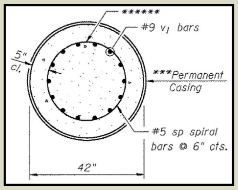
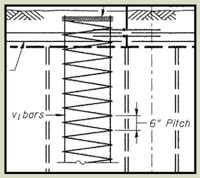
Rebar Inspection - General

- Check grade of steel on the plans matches the mill certificate.
- Check rebar number, sizes, spacing, lengths, and clearances match the plans.
- Check the cage diameter matches the plans and the cage length meets field drilled lengths.
- Check proper rebar lap lengths.
- Refer to Sections 508 and 1006.10 for additional rebar requirements.
- Discuss rebar cleanliness with Contractor.





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Rebar Cleanliness

Consider storage location and rebar must be off the ground.

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Rebar Cleanliness

Rebar must be off the ground after assembly.

141

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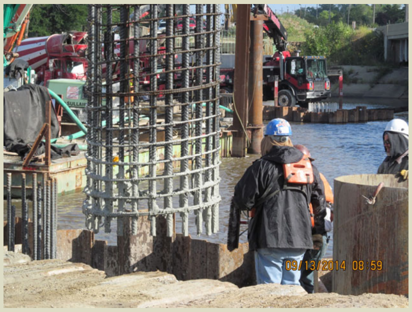
Rebar Cleanliness

Need water supply.



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Rebar Cleanliness

Consider location of cleaning.

143

Rebar Inspection – Drilled Shafts

- Ensure the cage is being lifted properly.
- Multiple lift points are required.
- Additional stiffeners (i.e. cross bracing) may be required.
- The cage should not acquire a permanent deformation
- A cradle (a.k.a. strong-back) may be needed.

144

145

146

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Improper Lifting

Need multiple lift points.
Risk of deformed rebar cage or damage to epoxy coating.

147

After Lifting

Crane will hold rebar cage in place.

Excavator Will Pull Casing

148

Rebar Inspection – Drilled Shafts

- Cage centralizers (a.k.a. rolling spacers) must be used to assure minimum rebar cover and to align rebar cage. Do not use metal chairs.
- Centralizers must be round and roll freely to minimize loose material falling in hole.
- Non-corrosive materials only such as concrete ring or plastic wheel.

149

Centralizers

150

Rebar Inspection – Drilled Shafts

- If required, the design drawings may require concrete cover between the base of the drilled shaft and the rebar cage.
  - Plastic chairs or other devices may be used for this purpose. The devices may also be called clearance boots.

151

Concrete Mix Design

- Check the concrete mix design nominal maximum aggregate size (usually ½ " or less). Nominal maximum aggregate size is the largest sieve which retains any aggregate.
- Rebar spacing should be 5 (dry shaft) to 8 (wet shaft) times the nominal maximum aggregate size.
- Nominal maximum aggregate size should not exceed 2/3 clear distance between rebar and casing or wall excavation.

152

Concrete Mix Design Slump

- Slump is 6 to 8 inches.
- Slump is 8 to 10 inches if displacing drilling fluid (water or slurry) or temporary casing is used.

153

Concrete Mix Design Slump Retention

- Temporary casing is to be withdrawn before slump drops below 6 inches.
  - Easier to remove casing.
  - Needed to displace any drilling fluid and fill void behind casing.
- Trial batch required.

154

Concrete Mix Design Slump Retention

- When concrete displaces drilling fluid, the slump of all concrete placed shall be a minimum of 6 inches at end of concrete placement.
  - To ensure initial concrete placed and pushed up and out of shaft is fluid, and will not entrap laitance or sediment in the concrete.
- Trial batch required.

155

Concrete Mix Design Trial Batch

- Batch 4 cubic yards.
- Obtain sample of concrete and fill up 5 gallon bucket. Remaining concrete can be used on project.
- Perform slump test every 15 minutes until it at least falls below 6 inches. No more testing is needed if it reaches 4 inches. Plot results.
- Between tests put lid on bucket and place in wheelbarrow filled with water. Move to shade.

156

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Concrete Mix Design Slump Retention

- Maximum Slump Retention
  - Use maximum water.
  - Use retarder (hydration stabilizers work a little better).
  - Use polycarboxylate superplasticizer if possible.

157

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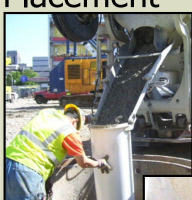
Free Fall Placement

- Check for standing water in shaft, must be less than 3” at beginning of placement.
- Check for water infiltration rate in shaft, must be less than 12 inches per hour.
- Note: Fall protection needed in picture.



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Free Fall Placement

159

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Free Fall Placement Maximum

60’ conventional concrete/30’ self consolidating concrete

160

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Free Fall Placement

Direct to center of shaft.

161

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High Water Infiltration Rate

Don’t try to pump out water immediately prior to concrete placement.
Example of contaminated concrete for free fall placement.

162

Tremie or Pump Placement

- Used for wet holes.
- Concrete is placed underwater.
- Initial flow of concrete must be in manner that will not cause contamination of concrete with drilling fluid (water or slurry).
  - "Closed" system versus "Open" system
- Tremie or pump pipe must remain embedded in concrete after flow is initiated to create "seal" from drilling fluid.

163

Pump Placement

Crane holding rebar cage in place and excavator will pull casing.

Tremie Pipe

164

Concrete Placement

Crane holding rebar cage in place and excavator will pull casing.

Concrete Pump

Tremie Pipe

165

"Closed" Tremie or Pump System

- Required by Specification
- Options:
  - Discharge end will have steel or wood flap gate with gaskets.
  - Discharge end will have wood plug which may float to surface.

166

"Closed" Tremie or Pump System

- Wood Plug
- Options:
  - Wood plug is beveled to hold it in place.
  - Wood plug may be tied to steel pipe to keep it in place.
  - For both options, wood plug is covered with plastic or shall have gasket.

167

"Open" Tremie or Pump System

- Prohibited by Specification
- Traveling plug prevents intermingling of water.
  - Also known as Pig or Rabbit – Polystyrene, closed cell foam, or foam rubber.
  - Also known as Go-Devil – Ball of rolled-up burlap or specially fabricated material.
  - Plug floats to surface.

168

Traveling Plug

169

"Open" Tremie or Pump System

- Why prohibited by specification?
  - Plug may compress as it moves against the hydrostatic pressure from the drilling fluid, allowing the concrete to mix with the drilling fluid.
  - A traveling plug can't be used when the "seal", that is the pipe separates from concrete. If the traveling plug is used, it will push out water and wash out cement and cementitious materials from previously placed concrete.

170

Tremie or Pump Placement

- Tremie or pump pipe must be steel.
  - Aluminum pipe will react with concrete.
  - Plastic pipe will break.
- Steel pipe has additional the advantage of being heavier and will counteract buoyancy.
- The steel pipe shall be clean, smooth, and shall have watertight connections.

171

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Broken Plastic Tremie Pipe

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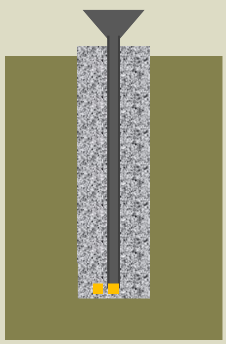
Tremie or Pump Placement

- After pour starts, keep discharge end a few inches off the bottom until the end is a minimum of 10 feet below the concrete. A breach can occur if there is not sufficient concrete head.
- Important to monitor concrete level and ensure continuous supply of concrete.



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Tremie Placement – What can go wrong?

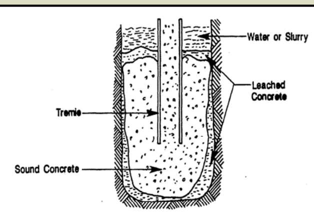

Figure 8.16. Potential distribution of leached concrete resulting from excessive initial lifting of gravity-fed tremie (from LCPC, 1986)

Possible zones of contaminated concrete resulting from inadequate bottom cleaning, lack of separator or improper lifting of tremie. (FHWA, "Drilled Shafts: Construction Procedures and Design Methods," O'Neill and Reese, 1999)

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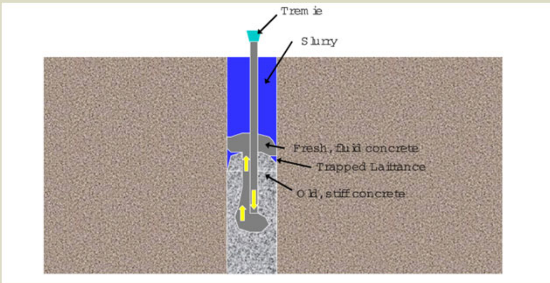
Tremie Placement – What can go wrong?



Effects of Loss of Workability During Concrete Placement

175

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Tremie Placement – What can go wrong?

Tremie Pipe

176

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Pulling Temporary Casing

Casing must be clean to pull.

177

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Pulling Temporary Casing

- Before breaking the casing loose, the head pressure inside the casing must be a minimum 1.25 times the head pressure outside the casing, but in no case shall the concrete be less than 5 feet from bottom of casing. (4.2.3/Class Problem Handout)
- It is possible for casing to jump 3 to 4 ft. when casing is broken lose.

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Pulling Temporary Casing

- Why is 1.25 head pressure specified?
  - Head pressure prevents breach of casing and inflow of drilling fluid. The drilling fluid will most likely be mixed with soils.
  - Head pressure will help fill surface voids in wall.
  - Head pressure will compact loose soil material to ensure tight fit for friction purposes.

179

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Pulling Temporary Casing

- Measure depth of concrete before and after the casing is broke loose.
  - If concrete has risen, this is an indication that soil or drilling fluid has been sucked into the shaft. This could result in necking of the shaft or complete loss of concrete section in a section of shaft.
  - Concrete will drop because of voids behind the casing.

180

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Pulling Temporary Casing

- Remember 6" slump is needed. This will prevent the following problems.
  - Contractor unable to remove casing.
  - Concrete could arch or lift when the casing is raised, and thus cause a "neck" to form below the casing or possible lift and twist the rebar cage.
    - Place target on rebar cage and monitor movement with a level when the casing is broken loose.

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Pulling Temporary Casing

- Once final concrete level is achieved, casing can be removed if head pressure is 1.25.
- To pull casing, downward pressure is used to cause movement.
- Hammering or vibrating may also facilitate extraction.

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Pulling Temporary Casing - Excavator

Starter Casing

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Pulling Temporary Casing - Vibrating Equipment

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Monitoring Concrete Pour

- Slump retention testing recommended.
- Monitor the concrete level in the shaft and the volume placed.
  - Complete BBS 135 – Drilled Shaft Concrete Placement Log/Drilled Shaft Concrete Curve.
- Explain calculations for drilled shaft concrete curve. (4.2.2/Class Problem Handout)

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Monitoring Concrete Pour

Concrete Volume Check

- Calculating the shaft volume is an important quality control step.
- Check concrete level after discharge of each truck.
- Compare the theoretical shaft volume to the volume of placed concrete.

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Monitoring Concrete Pour

Concrete Volume Check

- If the volume placed is larger than the calculated volume there could be void or cavity in the side wall of the shaft.

187

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Monitoring Concrete Pour

Concrete Volume Check

- If the volume placed is smaller than the calculated volume there could be a problem as follows:
  - Void in shaft from pulling casing.
  - Shaft squeeze or necking because of soft soils.
  - Side wall caving or sloughing of the excavation.
  - Concrete didn't flow through rebar cage due to slump.
- All these could lower shaft capacity.

188

Missing concrete, leached concrete, washed-out gravel lower 10 ft of shaft

189

Date Sampled: **11/20/07**
Date Received: **11/26/07**
Date Tested: **11/27/07**
Date Cast: **11/6/07**

Test Condition: As Received
Mix Design Strength: 10,000p.s.i @ 56 days

Summary of Test Results

Core No.	Ht. (in.)	Cap Ht. (in.)	Dia. (in.)	Area $(in)^2$	H/D Ratio	Corr. Factor	Load (lb)	Strength (psi)	Weight (gm.)	Unit Wt. (pcf) *	Location
1	4.74	4.91	2.49	4.85	1.97	0.9976	12340	2,540	712.4	118.0	38'
2	4.59	4.74	2.49	4.85	1.91	0.9928	8700	1,780	754.8	129.3	41.5'
3	4.69	4.89	2.49	4.87	1.96	0.9968	11590	2,370	818.4	136.5	43.5'
4	4.59	4.77	2.49	4.86	1.92	0.9936	9680	1,980	848.5	144.8	62.5'
5	4.67	4.90	2.48	4.83	1.98	0.9984	10440	2,160	892.9	150.9	72'
6	4.72	4.87	2.49	4.88	1.95	0.9960	20560	4,200	919.9	152.0	92'

Compressive strength tests of concrete cores at 21 days average only 2000 psi for 10,000 psi mix design concrete

This shaft was drilled out and replaced by contractor at great expense

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Over Pour of Concrete

- Over pour concrete to fill void left by removal of casing.
- Over pour to eliminate contaminated concrete at the surface.
  - Placement continues until 18 inches of good quality uncontaminated concrete is expelled.
  - Strength sample is encouraged.
- Ensure continuous supply of concrete.

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Over Pour of Concrete

- If tremie or pump pipe discharge end seal was broken, Contractor may have to over pour several feet to flush out contaminated concrete.
- Contaminated concrete must be disposed of in a proper manner, similar to concrete washout facility.

192

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Concrete Washout Facility

193

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Over Pour of Concrete

Overflow containment needed.

194

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Over Pour of Concrete

Overflow containment needed and plastic pipe prohibited.

195

Module 5
Inspector's Checklist and Documentation

196

Checklist

- Bureau of Construction
  - Construction Inspector's Checklist for Drilled Shafts

197

Documentation

- Complete each day the required Bureau of Bridges and Structures forms for field documentation.
  - BBS 134 Drilled Shaft Excavation and Inspection Record
  - BBS 135 Drilled Shaft Concrete Placement Log/Drilled Shaft Concrete Curve
- Use the field book for inspection of construction tolerances, and to record any additional information.
- Maintain accurate records.

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Module 6
Non-Destructive Testing and Load Testing

199

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Non-Destructive Testing Methods

- Non-Destructive Testing is necessary to check the concrete integrity when shafts are constructed by the wet method.
  - The most common type of NDT testing likely to be specified on IDOT jobs is cross-hole sonic logging (CSL).
  - Thermal integrity profile (TIP) is being evaluated.

200

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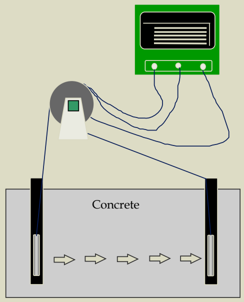
Non-Destructive Testing Methods

- For CSL and TIP, a Consultant that specializes in this area will evaluate the test results.
- The drilled shaft concrete placement log (Form BBS 135) should be provided to the Consultant to aid in their evaluation.

201

Cross-hole Sonic Logging Method

- Performed in tubes tied to the rebar cage cast directly into the concrete for the full depth of the shaft
- A transmitter and receiver are lowered in tube pairs to discrete depths to measure the Ultrasonic Pulse Velocity of the concrete between the tubes
- UPV is recorded every 1 to 2 ft in depth for every tube pair
- Tubes should be diametrically opposed and spaced about every 3 to 4 ft on the perimeter
- A minimum of four tubes is recommended



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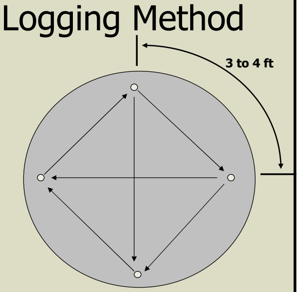
Cross-hole Sonic Logging Method

Inspector Issues:

- Review test procedures in ASTM D 6760
- Tubes should be 2-inch I.D. steel with water-tight connections without rubber gaskets or tape
- Tubes must be capped at bottom, be filled with water, and be capped at top before pouring concrete
- Ensure all required profiles are recorded at the specified depth interval
- After testing the tubes are grouted



Four tubes = six profiles

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Cross-hole Sonic Logging Method

- Key Inspection Points
  - Steel tubes provide best bond and installed on inside of cage.
  - Steel tubes must be filled with water to prevent debonding from heat of hydration.
  - Important to install tubes at proper spacing for accurate results
  - Important to install tubes in straight alignment for accurate results. Proper lifting of rebar cage is important.

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Cross-hole Sonic Logging Method

- Key Inspection Points
  - Improper lifting can compromise the threaded connections of the various pipe segments. If threaded connections are compromised, they should be resealed using caulk or duct tape to prevent concrete from flowing into the access ducts and preventing the lowering of the transmitter and receiver during CSL testing.

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Drilled Shaft Defect - Repair

- Can a drilled shaft be repaired?
  - Yes, in some cases a void can be repaired.
  - Concrete is cored down to the location of the void and grout is pumped in.
  - Cross-hole sonic logging testing is repeated after the repair.

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Drilled Shaft Defect - Repair

Removal of cored concrete to allow pumping of grout.

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Drilled Shaft Defect - Repair

Shale mixed in with concrete.

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Thermal Integrity Profile Method

- A recently developed non-destructive test that is based on measuring temperature during heat of hydration.
- If a relatively uniform and symmetrical temperature profile develops during hydration, it can be assumed there are no defects in the shaft.

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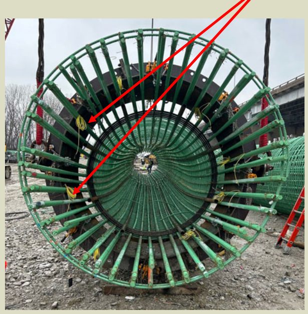
Thermal Integrity Profile Method



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Drilled Shaft Load Testing

- Load tests may be specified to prove the design capacity of a drilled shaft. The load test checks not only the soil/shaft capacity but checks the contractor's procedures. A failed shaft may not be the result of poor design assumptions or changed ground conditions, but may result from poor construction procedures.

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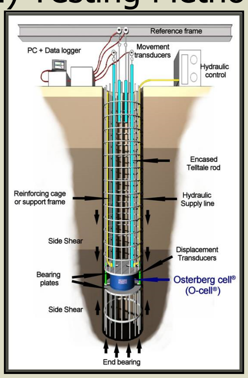
Bi-Directional (O-cell) Testing Method

- Hydraulic jack is attached to rebar cage and is embedded in the drilled shaft concrete
- Jack is pressurized which splits the shaft and simultaneously loads the two parts of the shaft in opposite directions
- No reaction system, weights or anchors are needed
- Very high test loads can be achieved (greater than 30,000 tons) with multiple jacks
- Measures shaft friction, end bearing and displacement separately using instrumentation



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O-cell bi-directional load testing

Two O-cells at the mid-level of shaft measuring shaft friction to a total load of 7400 tons

O-cell at base of small shaft to measure end bearing on rock

Strain gauges and displacement transducers measure load and movement in the shaft at multiple points

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THE END

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