

ILLINOIS DEPARTMENT OF TRANSPORTATION

SPECIFIC TASK TRAINING PROGRAM

**DRILLED SHAFT
FOUNDATION
CONSTRUCTION INSPECTION**

S 32

CLASS REFERENCE GUIDE

**Prepared and Published
by
Bureau of Construction**

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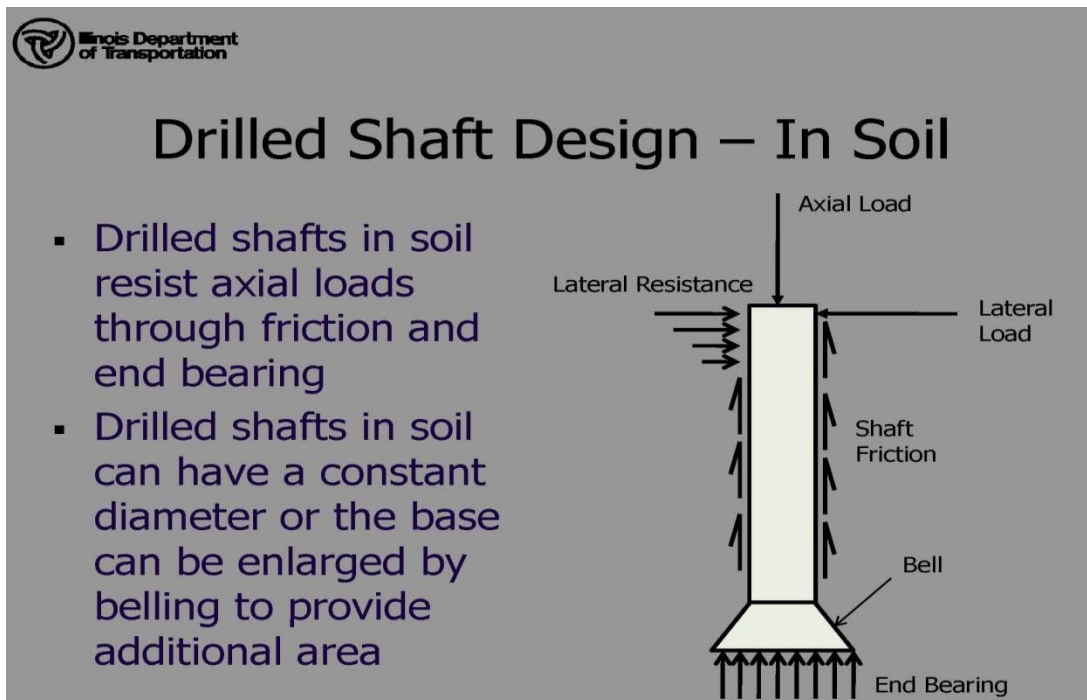
1 INTRODUCTION TO DRILLED SHAFT INSPECTION

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, you 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. You have the responsibility to report any deviations from the plans and specifications or deviations from the contractor's approved work plan to the engineer in charge. The drilled shaft inspector should realize they have the authority and responsibility to observe every aspect of the foundation construction process. By reporting to the engineer in charge, the inspector has the authority to stop work if construction is not being performed in accordance with the design, plans or specifications.

1.2 – Introduction to Drilled Shafts

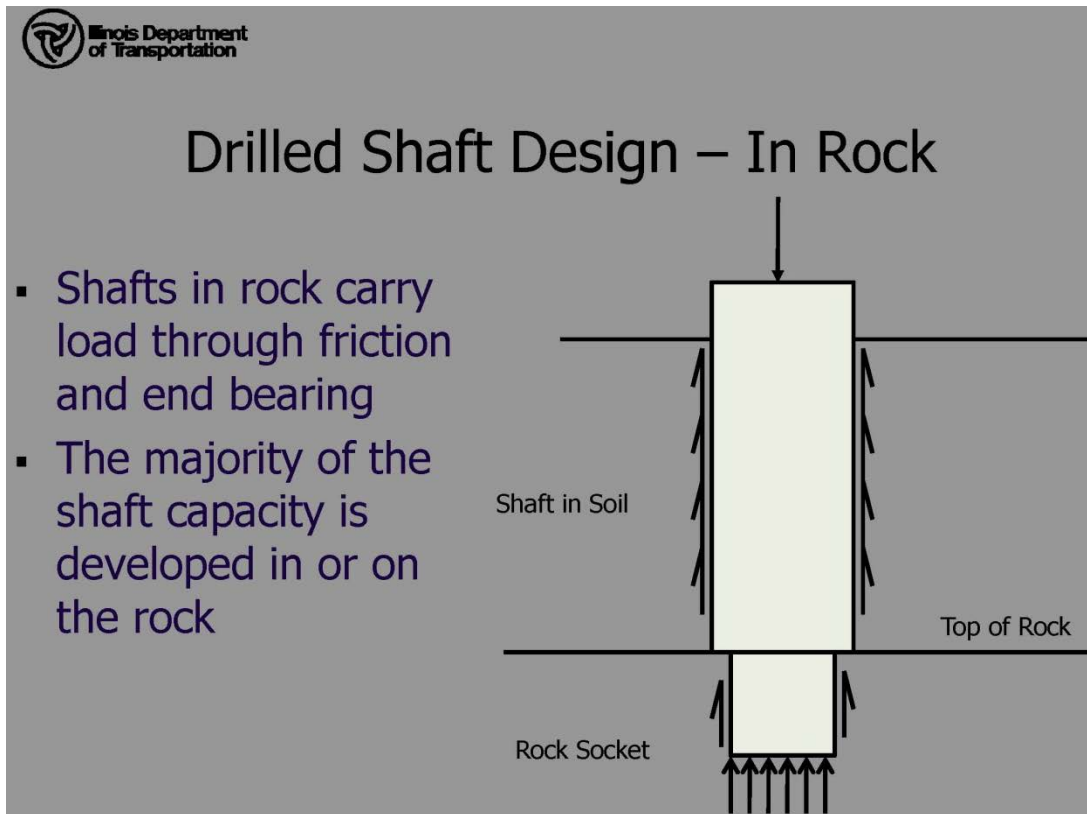
A drilled shaft is a foundation element composed of cast-in-place reinforced concrete that is placed into an open drilled excavation. In general, drilled shafts will have a higher resistance against axial and lateral loads than driven piles. The additional capacity is a result of the size of the drilled 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 to the use of the drilled shafts is the relatively low vibration levels which are induced during construction compared to driven pile installation.



- 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

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.



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

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 – Plans, Specifications and Reports

The construction of drilled shafts is controlled by design drawings and plans and the IDOT Standard Specifications for Road and Bridge Construction. The geotechnical aspects of the drilled shaft design are controlled by the Structure Geotechnical Report.

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

The IDOT Standard Specifications for Road and Bridge Construction provide details regarding the drilled shaft construction process. Before arriving on site, the inspector should be familiar with Sections 508, 516, 1006, and 1020. Refer to 1.5 – Additional References for more information.

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 design drawings package. 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
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SOIL BORING LOG

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Date 7/18/07

ROUTE FAU 6378 (Airport Rd) DESCRIPTION Airport Rd over Kankakee Cr. Trib. & IPRR LOGGED BY JBR

SECTION 0-VBR LOCATION SEC. 18, TWP. 36S, R. 10E

COUNTY Peoria DRILLING METHOD ISA HAMMER TYPE Automatic

STRUCT. NO. 072-000(road) D B U M Surface Water Elev. _____ ft D B U M
 Station 45+42 E L C O Shallow Bed Elev. _____ ft C L C O
 BORING NO. 5 (LAB#1) T W S Groundwater Elev. 43.5 ft T W S
 Station 47+50 H S Du T First Encounter 43.5 ft H S Du T
 Offset 4.062(1.1) Upon Completion None ft
 Ground Surface Elev. 506.47 (ft) (ff) (1/4") (1/8") (1/4") (1/8") (1/4") (1/8") (1/4") (1/8")

DEPTH (ft)	SOIL TYPE	REMARKS	DEPTH (ft)	SOIL TYPE	REMARKS
0	DC Brown SILTY CLAY LOAM	Surface Water Elev. _____ ft	0	DC Brown SILTY CLAY LOAM	Surface Water Elev. _____ ft
1	DC Brown SILTY CLAY LOAM	Shallow Bed Elev. _____ ft	1	DC Brown SILTY CLAY LOAM	Shallow Bed Elev. _____ ft
1.50	DC Brown SILTY CLAY LOAM	Groundwater Elev. <u>43.5</u> ft	1.50	DC Brown SILTY CLAY LOAM	Groundwater Elev. <u>43.5</u> ft
1.75	DC Brown SILTY CLAY LOAM	First Encounter <u>43.5</u> ft	1.75	DC Brown SILTY CLAY LOAM	First Encounter <u>43.5</u> ft
509.47	Brown SILTY CLAY LOAM	Upon Completion <u>None</u> ft	509.47	Brown SILTY CLAY LOAM	Upon Completion <u>None</u> ft
1	Brown SILTY CLAY LOAM		1	Brown SILTY CLAY LOAM	
1.5	Brown SILTY CLAY LOAM		1.5	Brown SILTY CLAY LOAM	
2	Brown SILTY CLAY LOAM		2	Brown SILTY CLAY LOAM	
499.92	Brown & Gray CLAY LOAM		499.92	Brown & Gray CLAY LOAM	
2	Brown & Gray CLAY LOAM		2	Brown & Gray CLAY LOAM	
3	Brown & Gray CLAY LOAM		3	Brown & Gray CLAY LOAM	
2	Brown & Gray CLAY LOAM		2	Brown & Gray CLAY LOAM	
2.8	Brown & Gray CLAY LOAM		2.8	Brown & Gray CLAY LOAM	
3	Brown & Gray CLAY LOAM		3	Brown & Gray CLAY LOAM	
414.92	Brown & Gray LOAM		414.92	Brown & Gray LOAM	
2	Brown & Gray LOAM		2	Brown & Gray LOAM	
2.5	Brown & Gray LOAM		2.5	Brown & Gray LOAM	
1	Brown & Gray LOAM		1	Brown & Gray LOAM	
6	Brown & Gray LOAM		6	Brown & Gray LOAM	
4	Brown & Gray LOAM		4	Brown & Gray LOAM	
2	Brown & Gray LOAM		2	Brown & Gray LOAM	
2.2	Brown & Gray LOAM		2.2	Brown & Gray LOAM	
4	Brown & Gray LOAM		4	Brown & Gray LOAM	
1	Brown & Gray LOAM		1	Brown & Gray LOAM	
4	Brown & Gray LOAM		4	Brown & Gray LOAM	
3.0	Brown & Gray LOAM		3.0	Brown & Gray LOAM	
3	Brown & Gray LOAM		3	Brown & Gray LOAM	
1.0	Brown & Gray LOAM		1.0	Brown & Gray LOAM	
22	Brown & Gray LOAM		22	Brown & Gray LOAM	

The Unconfined Compressive Strength (UCS) Failure Mode is Indicated by (B)Bulk, (S)Shear, (P)Penetrometer
 The SPT (N value) is the sum of the last two blow values in each sounding zone (ASTM D 1586)
 BBS, form 137 (Rev. 8-99)

Illinois Department of Transportation
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ROCK CORE LOG

Page 1 of 3
Date 7/18/07

ROUTE FAU 6378 (Airport Rd) DESCRIPTION Airport Rd over Kankakee Cr. Trib. & IPRR LOGGED BY JBR

SECTION 0-VBR LOCATION SEC. 18, TWP. 36S, R. 10E

COUNTY Peoria CORING METHOD _____

STRUCT. NO. 072-000(road) CORING BARREL TYPE & SIZE NMD4 x 5' Dual Tube R E R S
 Station 45+42 Core Diameter 3.1 in E C O D T E
 BORING NO. 6 (LAB#1) Top of Rock Elev. 414.00 ft P R E D E C
 Station 43+50 Begin Core Elev. 412.00 ft H T E Y -
 Offset 13.00(4.1) Ground Surface Elev. 515.00 ft (ff) (ft) (ft) (ft) (ft) (ft) (ft) (ft)

DEPTH (ft)	DEPTH (m)	REMARKS	DEPTH (ft)	DEPTH (m)	REMARKS
0	0.00	Gray SHALE (continued)	0	0.00	Gray SHALE (continued)
6.75	2.02	Geomechanics Class of Rock Mass(GRM) 25, Poor Rock	6.75	2.02	Geomechanics Class of Rock Mass(GRM) 25, Poor Rock
6.80	2.07		6.80	2.07	
6.85	2.10		6.85	2.10	
6.90	2.13		6.90	2.13	
6.95	2.16		6.95	2.16	
7.00	2.13	GRM#45, Fair Rock	7.00	2.13	GRM#45, Fair Rock
7.05	2.16		7.05	2.16	
7.10	2.19		7.10	2.19	
7.15	2.22		7.15	2.22	
7.20	2.25		7.20	2.25	
7.25	2.28		7.25	2.28	
7.30	2.31		7.30	2.31	
7.35	2.34		7.35	2.34	
7.40	2.37		7.40	2.37	
7.45	2.40		7.45	2.40	
7.50	2.43		7.50	2.43	
7.55	2.46		7.55	2.46	
7.60	2.49		7.60	2.49	
7.65	2.52		7.65	2.52	
7.70	2.55		7.70	2.55	
7.75	2.58		7.75	2.58	
7.80	2.61		7.80	2.61	
7.85	2.64		7.85	2.64	
7.90	2.67		7.90	2.67	
7.95	2.70		7.95	2.70	
8.00	2.73		8.00	2.73	
8.05	2.76		8.05	2.76	
8.10	2.79		8.10	2.79	
8.15	2.82		8.15	2.82	
8.20	2.85		8.20	2.85	
8.25	2.88		8.25	2.88	
8.30	2.91		8.30	2.91	
8.35	2.94		8.35	2.94	
8.40	2.97		8.40	2.97	
8.45	3.00		8.45	3.00	
8.50	3.03		8.50	3.03	
8.55	3.06		8.55	3.06	
8.60	3.09		8.60	3.09	
8.65	3.12		8.65	3.12	
8.70	3.15		8.70	3.15	
8.75	3.18		8.75	3.18	
8.80	3.21		8.80	3.21	
8.85	3.24		8.85	3.24	
8.90	3.27		8.90	3.27	
8.95	3.30		8.95	3.30	
9.00	3.33		9.00	3.33	
9.05	3.36		9.05	3.36	
9.10	3.39		9.10	3.39	
9.15	3.42		9.15	3.42	
9.20	3.45		9.20	3.45	
9.25	3.48		9.25	3.48	
9.30	3.51		9.30	3.51	
9.35	3.54		9.35	3.54	
9.40	3.57		9.40	3.57	
9.45	3.60		9.45	3.60	
9.50	3.63		9.50	3.63	
9.55	3.66		9.55	3.66	
9.60	3.69		9.60	3.69	
9.65	3.72		9.65	3.72	
9.70	3.75		9.70	3.75	
9.75	3.78		9.75	3.78	
9.80	3.81		9.80	3.81	
9.85	3.84		9.85	3.84	
9.90	3.87		9.90	3.87	
9.95	3.90		9.95	3.90	
10.00	3.93		10.00	3.93	

Color pictures of the cores _____
 Cores will be stored for examination until _____
 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 drawing package 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 (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 drilling equipment. Limestone tends to be a much harder rock; excavation in limestone will be a slower process. It is also important to note the RQD on the rock core log. The RQD is a measure of the quality of rock that was encountered. RQD is presented as a percentage. It is the percent of the rock core that was collected that consists of solid pieces greater than 4 inches in length. 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 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, steel toed boots, hard hat, safety glasses, high visibility vest, 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, testing for oxygen content, flammable gases and vapors, and potential 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.

Another hazard to consider is the open hole when unattended. Holes need to be covered with a protective covering, or a fence may need to be erected around the hole.

With some types of soils, there is the danger of the soil collapsing near the surface as the driller advances the hole. Usually a safety (a.k.a. starter) casing will be placed around the hole to protect workers. 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 fix object. Thus, the contractor shall take into consideration the inspection activities of the inspector when constructing the drilled shaft. The contractor is also responsible for providing safety measures to protect the general public from open holes when unattended.

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 boring 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. Without these tools you will not be able to document the construction completed at the site. To aid in the documentation process a camera may be useful. 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 or a heavy bolt taped to the end of the tape is generally sufficient. The contractor will usually have available a weighted tape in addition to an explosion proof light to lower to the bottom of the shaft for inspection.

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 is recommended to check the unconfined compressive strength of clayey soil. The inspector should have a calculator to aid in computing the unconfined strength as well as for volume calculations.

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 steel cable. The rock probe will be heavier than the weighted tape so that the rock surface can be probed and sounded.

In some instances the bottom of the drilled shaft can be inspected using an explosion-proof down-hole camera. For deep holes which are free from water and for belled shafts it is difficult to visually observe the base of the excavation from the top of the excavation. A camera can be lowered to the base of the shaft to evaluate the bottom condition and cleanliness.

1.5 – Applicable Specifications and Forms


The intent of this manual and course is to provide an introduction to the construction and inspection of drilled shafts. 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 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.

 Illinois Department of Transportation

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



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.



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.



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 table. 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.

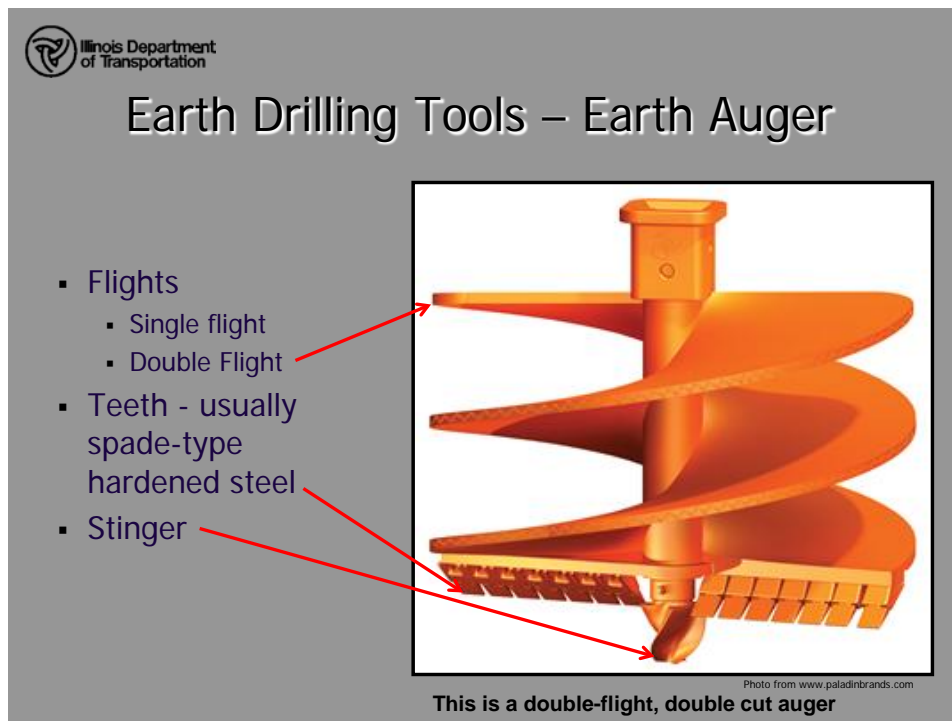
2.2 – Drilling Tools

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 used more frequently for hard drilling and large diameter shafts. The auger shown in the above 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 bellling bucket or under-reamer is required. The bellling 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.

 Illinois Department of Transportation

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



Because, the quality of clean up is limited with a belling tool, bells are often over-sized 1 foot to provide additional bearing area. The spoil at the bottom can sometimes be back-bladed to the bell periphery.

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. 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 a 5,000 to 15,000 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 3.1 – Obstructions and Differing Site Conditions for more information on equipment to remove boulders.

2.2.3 – Clean Up Tools

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 on the bottom capturing the material and water inside. Clean out buckets can also be used to clean the base of excavations which are full of water.



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



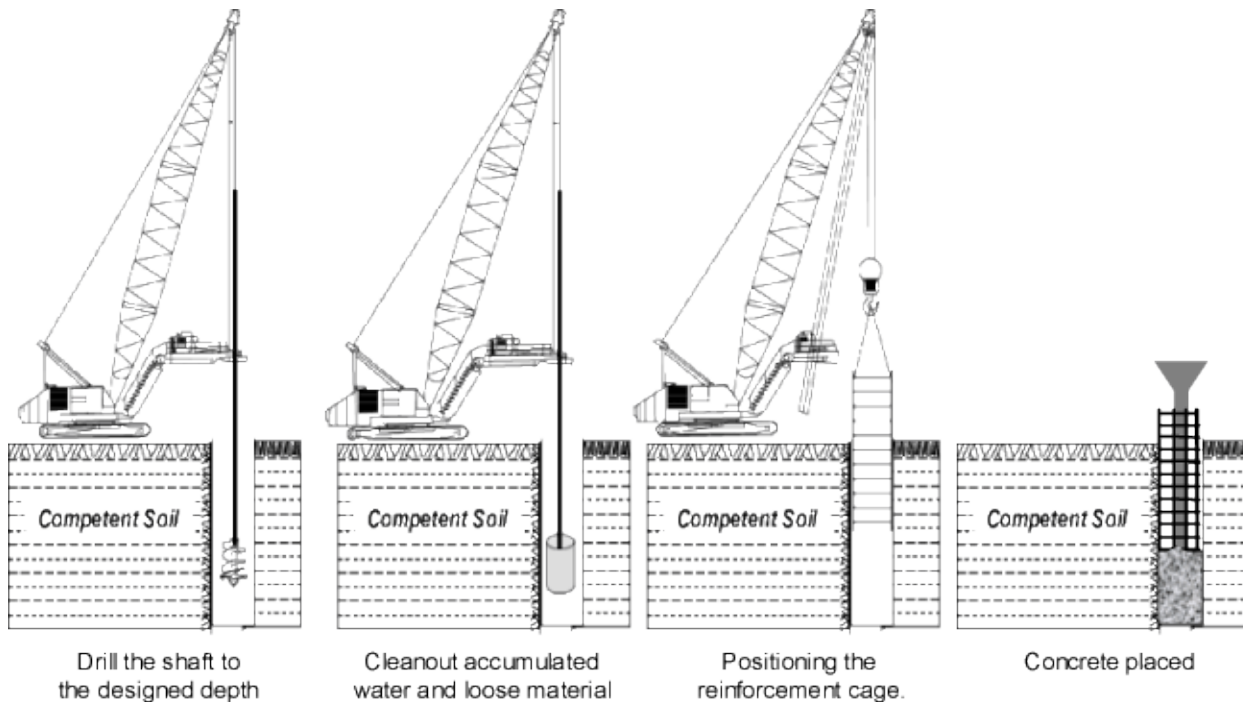
Emptying bucket into loader

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.

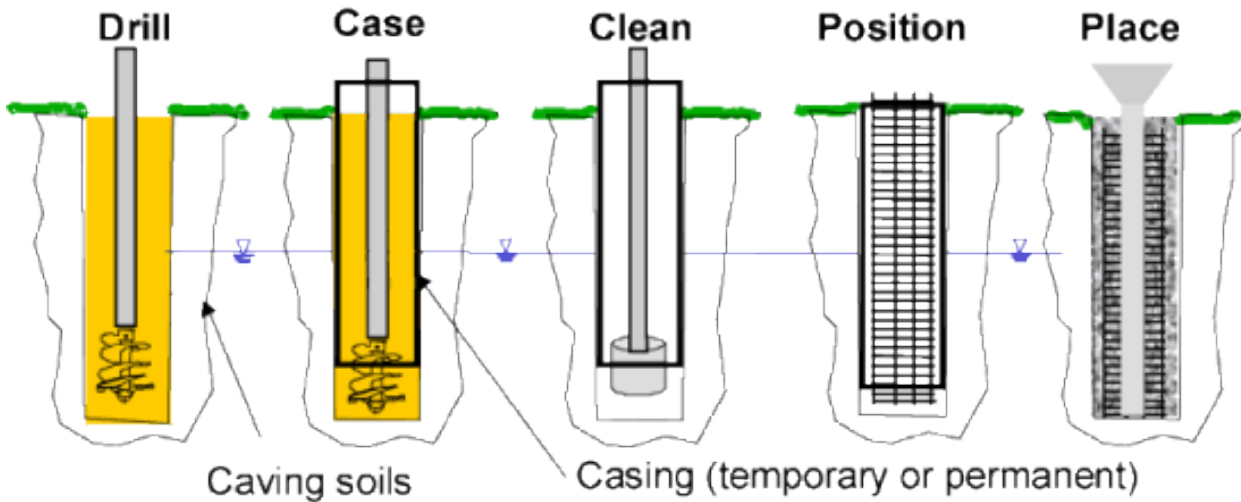
2.3 – Shaft Excavation Methods

The excavation method for drilled shaft construction is dependent on a combination of two factors: cased or open, and wet or dry. The following sections and figures from the FHWA Drilled Shaft Tutorial illustrate the most common combinations.

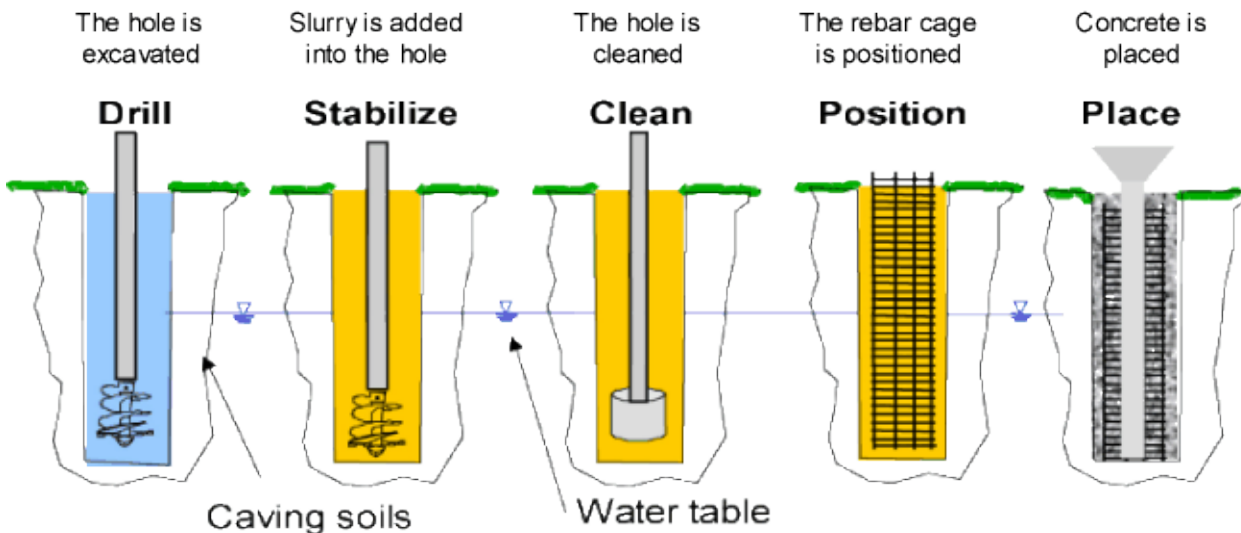


Open dry excavations (Dry Method) are the simplest option for drilled shaft construction. Only a small surface (a.k.a. starter) casing is utilized if any casing at all. Surface casings protect workers and provide additional benefits. Refer to 1.4 – Equipment and Safety for more information on surface 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 open dry excavations is by freefall methods.

Cased excavation methods can be used for wet or dry construction. Casing is used to prevent caving in unstable soils and can also be used as a groundwater cutoff for intermediate water bearing granular layers. Casing can be temporary or permanent. Temporary casing is installed to stabilize the excavation, and is typically 6 inches larger than the specified drilled shaft diameter to allow passage of the drilling tool. The temporary casing is removed while placing 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. Permanent casing reduces the risks of ground movement due to 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.



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 construction (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 or an open hole method. The shaft is then flooded with water or drilling slurry. The level of the water or

drilling slurry in the excavation must be 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 water or drilling slurry 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 drilling slurry. The two most common additives are bentonite clay and polymer. 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 drilling slurry 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 unconfined compressive strength of the concrete. Over the course of a few 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 drilling slurry. 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 12 inches of the base of the excavation just before the concrete is placed. Specially designed slurry samplers are available for bottom sampling.

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. An example of a drilled shaft pre-drill meeting agenda is provided in the Appendix.

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. 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 BBS134) 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 and that the base of the shaft is sufficiently clean.

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.

The inspector should also be aware that water may degrade shale, and this information should be recorded if there are any concerns.

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 is one of the more common since a small diameter boring could easily miss it. A boulder may be removed by a downhole hammer as discussed in 2.2.2 – Rock Drilling Tools but 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 hammer grab 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. 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 material 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 normally 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.

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 related to 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 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 level. If caving is occurring, materials from the upper parts of the shaft will fall onto the auger, drilling bucket or bell bucket as

they enter and leave the excavation. Also, after the tool is out of the hole, you 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 or drilling slurry will be needed. If squeezing soils are not supported by casing, 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 – Rock Sockets

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 can ask the contractor to use a core barrel to extend a shaft a few feet deeper into bedrock when unusual conditions are encountered or when doubt exists.

If rock is not encountered at the planned elevation, the inspector is required to notify the design engineer to determine the need for additional drilling.

3.7 – Shaft Acceptance

3.7.1 – Friction Shafts

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 you cannot determine this based on the Structure Geotechnical Report or the Design Drawings you 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 you are 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 and 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.

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 3.4 – Rock Sockets. If the variation is greater than 10 percent of the length of the drilled shaft above the rock, contact the design engineer.
- 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, except any sediment or debris located in the depression from the stinger is not a concern. Refer to 3.5.4 – Bottom Cleanliness for additional information.

3.5.4 – Bottom Flatness and Cleanliness

Bottom flatness is not specified is not specified, but should be relatively flat. 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 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 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, err on the side of over cleaning 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 cleanout bucket should be sufficient. For shafts bearing on rock, an airlift pump or down-hole pump will be required to get the shaft sufficiently clean. Refer to 2.2 – Clean Up Tools for more information on airlift and down-hole pumps. For belled shafts on soil, clean the bottom with a bell bucket as best as possible. The remaining spoils can be back-bladed to the bell periphery.

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 design drawings. The vertical spacing for the spiral bar is sometimes referred to as pitch.
- Check the cage diameter matches the design drawings 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 normally located at 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 you have confirmed the rebar cage meets the design requirements, additional considerations related to the installation are required. It is important that 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.

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.

Rebar spacing must be designed to work with the concrete mix design. It is recommended the nominal maximum aggregate size does not exceed two-thirds the clear distance between parallel reinforcement bars, or between the reinforcement bar and the form. Nominal maximum aggregate size is defined as the largest sieve which retains any of the aggregate sample particles. IDOT mix designs typically use a maximum aggregate size of ½ inch or less than.

When non-destructive testing tubes are added to a cage as explained in Section 6 of 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 maintain a cage with appropriate rebar spacing for placement of concrete.

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 related to the maximum aggregate size used relative to 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. This will ensure the concrete flows out and fills the gap behind the casing as it is removed. Another requirement is when concrete displaces drilling fluid. The slump of all concrete placed shall be a minimum of 6 inches at the end of concrete placement. 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 and may be stopped when the slump 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. Concrete placement shall 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 movement 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. If a small amount of standing water is present in the base of the excavation free fall placement can continue. The 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.

Another important consideration during free fall placement is that the concrete needs to be directed 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, concrete must be placed by tremie or using a 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 all types of pours, 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 $((\pi r^2) \times (\text{shaft length})) \div 27$.
- Example:
 Shaft Diameter = 4.0 feet
 Shaft Radius = 4.0 feet \div 2 = 2.0 feet
 Shaft Length = 60.0 feet
 $\pi = 3.14$
 $((3.14 \times 2.0^2) \times (60.0)) \div 27 = 27.9$ 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.

When comparing the theoretical concrete volume to be placed with the actual concrete volume placed, 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 from pulling the casing, shaft squeeze or necking, side wall cave-in during concrete placement, or the concrete did not flow through the rebar cage.

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.

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. If the plug is excessively long, this will require the discharge end to be lifted a considerable distance off the bottom in order for the plug to exit the discharge end, thus allowing the concrete to mix with the drilling fluid. Finally, 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 which will wash cement and cementitious materials out of the previously placed concrete.

During the first few feet of concrete placement with a tremie or pump, the discharge end shall be kept within a few inches of the bottom until a minimum of 10 feet of concrete head is obtained. 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. An example of concrete head and drilling fluid head 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 is calculated as drilling fluid unit weight times the depth of drilling fluid in feet within the shaft. Assume the unit weight of water is 62.4 pounds per cubic feet. Assume the unit weight of slurry or water mixed with excavated soils is 67 pounds per cubic feet.
- Example:
Assume the depth of concrete is 10 feet.
Concrete Head Pressure = $145 \times 10 = 1450$ pounds per square feet
Assume the depth of slurry is 20 feet.
Slurry Head Pressure = $67 \times 20 = 1,340$ pounds per square feet
The 10 feet of concrete embedment with the tremie or pump is adequate.

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. The inspector is also reminded that contaminated concrete must be expelled and disposed of in a proper manner.

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 fill surface voids in the wall, and to 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 concrete head and drilling fluid head follows when casing is removed.

- 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 is calculated as drilling fluid unit weight times the depth of drilling fluid in feet within the shaft. Assume the unit weight of water is 62.4 pounds per cubic feet. Assume the unit weight of slurry or water mixed with excavated soils is 67 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 = $145 \times 5 = 725$ pounds per square feet

Assume the depth of slurry above the concrete is 5 feet.

Slurry Head Pressure = $67 \times 5 = 335$ pounds per square feet

Total Head Pressure Inside the Casing = $725 + 325 = 1,050$ pounds per square feet

Assume the depth of groundwater measured from the bottom of the casing to the groundwater elevation is 15 feet.

Total Head Pressure Outside the Casing = $62.4 \times 15 = 936$ pounds per square feet

Minimum Head Pressure Required Inside the Casing = $1.25 \times 936 = 1,170$ pounds per square feet

The actual head pressure inside the casing is inadequate per specifications.

When casing is used, it is important the interior of the casing is free from concrete to facilitate removal. When the casing is pulled, the concrete will drop immediately because there is normally a void behind the casing. Therefore, 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. It is also essential to have the slump of the concrete at least 6 inches. This will enable the concrete 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 during removal of the casing. It is also possible that the Contractor will not be able to remove the casing if too much slump is lost. Thus, 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.

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 distance from the ground surface to the top of concrete should be measured. Prior to pulling the casing, the concrete level in the casing must be at least 5 feet above the natural ground water level, 5 feet above the level of water or slurry outside the casing, or 5 feet above the level of any artesian pressure level that existed while drilling. The casing can then be completely removed. After casing removal the concrete level should again be checked. The concrete level should drop slightly as the space created by the casing is filled. If the concrete level rises, it would be an indication that soil or water outside the casing has collapsed into the concrete forming a defect. In this situation, the casing should be re-inserted. The contractor will likely need to muck out all of the concrete and start the pour over since the location of the defect would not be known.

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. All forms for the project must be filled out completely.

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 NDT 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 most common, and should be required, 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. IDOT has also begun to evaluate thermal integrity profiling on a limited basis the job.

6.1.1 – Impulse Echo or Impulse Response

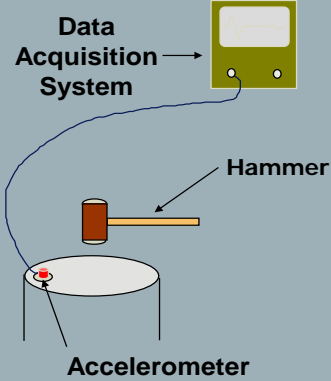
Impulse echo and impulse response are two tests for evaluating the length and condition of a drilled shaft. For both testing types, a hammer is used to strike the top of the drilled shaft. An instrument is attached to the top of the drilled shaft which measures the behavior of a wave, induced by the 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.

 Illinois Department of Transportation

Impulse Echo or Impulse Response Method

- Hammer is used to strike the head of the drilled shaft
- Accelerometer measures the wave reflection from the shaft
- The shaft toe, changes in geometry or significant defects cause reflections which can be detected
- Penetration depth is limited to 10 to 30 D, depending on soil stiffness

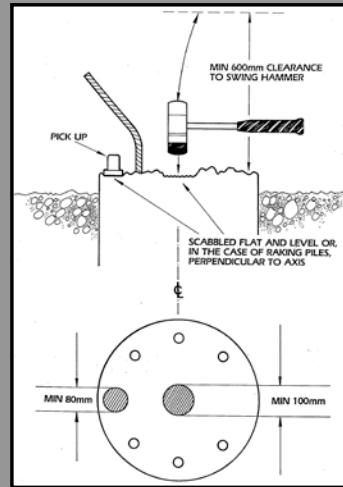


While the inspector does not generally perform the actual testing, there are a few items to be aware of if impulse echo or impulse response will be used on the project.



Impulse Echo or Impulse Response Method

- Inspector Issues:
 - Review test procedures in ASTM D 5882-07
 - Shaft head must be prepared as shown
 - Large jack hammers should not be used because they can cause micro-cracking of the concrete which may prevent penetration of the signal



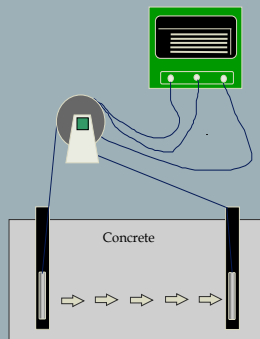
The results of impulse echo and impulse response testing are highly dependent on the size of the shaft and the soil conditions. These testing methods also only provide an estimate of the depth to a defect if one exists, but no information is provided on the type or size of the defect in the shaft. Other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

6.1.2 – Cross-Hole Sonic Logging

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 methods is provided on the following slides. It shall be noted that IDOT specifications require steel tubes even though the slide mentions tubes that are not steel..

Cross-hole Sonic Logging Method

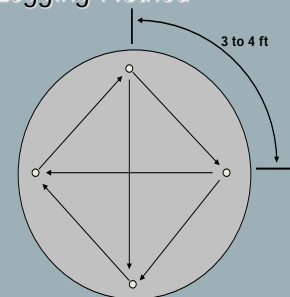
- Performed in tubes tied to the rebar cage cast directly into the concrete for the full depth of the shaft
- A transmitter and receiver are lowered in tube pairs to measure the Ultrasonic Pulse Velocity of the concrete between the tubes
- UPV is recorded every 2 to 3 inches in depth for every tube pair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



Cross-hole Sonic Logging Method

Inspector Issues:

- Review test procedures in ASTM D 6760-07
- Tubes should be 2-inch I.D. steel with water-tight connections without rubber gaskets or tape
- If tubes are not steel, record the elevations of the tube connectors
- 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 and RE approval, tubes should be grouted



Four tubes = six profiles

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:

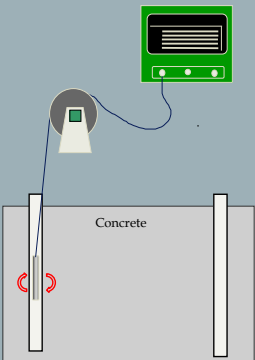
- Steel tubes are required because they provide the best bond to the concrete, and shall be installed on the outside of the rebar cage.
- The CSL tubes must be filled with water to ensure the tubes remain at the same temperature as the concrete. Concrete will hydrate and generate heat which will debond 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. The following slides provide additional information on the testing method and the issues the field inspector should watch for if gamma-gamma testing is to be performed on their project.

Gamma-gamma Logging Method

- Performed in PVC tubes tied to the rebar cage cast directly into the concrete for the full depth of the shaft
- A probe with a radioactive source and a receiver is lowered in a tube to discrete depths to measure the back-scatter radiation (concrete density) within 4 inches of the tube
- Testing is performed every 1 to 2 ft in depth for every tube
- This method allows concrete quality outside the rebar cage to be evaluated
- A minimum of two to four tubes is typical

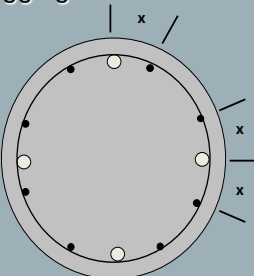




Gamma-gamma Logging Method

Inspector Issues:

- Review test procedures
- Tubes should be 2-inch I.D. PVC positioned as shown
- Tubes, however, should not block concrete flow in a tight cage
- Steel tubes cannot be used because the gamma radiation will not penetrate the steel
- Tubes must be capped at bottom, be filled with water, and be capped at top before pouring concrete
- Ensure all tubes are tested at the specified depth interval
- After testing and RE approval, tubes should be grouted



Tubes away from longitudinal rebar
Use constant spacing "x" from rebar

6.1.4 – Thermal Integrity Profile

Thermal integrity profile 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 anomalies in the shaft.

TIP uses a thermal probe containing four infrared temperature sensors. The probe is lowered in tubes, such as those specified for CSL. The internal shaft temperature is measured and the depth of the probe is recorded. This testing is performed within one to two days after concrete placement. The test results are compared to a model of the temperature profile for the shaft. The model predicts shaft temperatures as a function of time, and is based on the concrete mix design and soil profile. The soil profile provides an insulation factor to the model

The advantage of TIP is the ability to detect anomalies 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 an anomaly 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.

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 is utilized, it is critical that the inspector be present for the construction of that shaft to observe the construction methods and procedures. A test shaft must be constructed using the same procedures as the final production shafts.

6.2.1 – Static Load Test

The simplest load test method is the static load test. In 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.

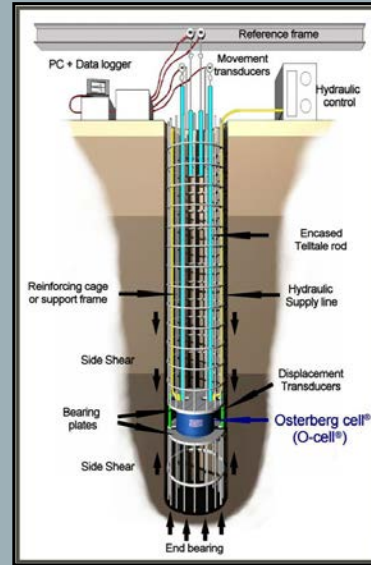
6.2.3 – Bi-Directional Load Test

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 slide provides a schematic of a bi-directional load test.



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



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 which were utilized during test shaft construction. Other items for an inspector to be aware of are presented in the following slide.





Load Testing

Inspector Issues:

- Review ASTM test procedures if available
- Review with R.E. specifications, loading schedule and contractor's procedures
- Check that shaft is constructed the same as a production shaft
- Confirm that all required instrumentation is installed
- Reference beams should be supported at least 8 ft from the test shaft
- Reaction shafts should be at least 5 D away from the test shaft but not less than 7 ft clear
- Independent monitoring of reference beam (survey) should be done
- Separately 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 recommended steps to address these issues.

Problem 1:
Top of rock elevation varies from design drawings

Solution:


- At beginning of job, discuss with design engineer and R.E. the likely rock elevation variation to be expected based on the geotechnical information and project geology
- Review the geotechnical report for nearest boring log for rock elevations
- Is the rock elevation within the variation found within all borings for the project site?
 - If yes then no issue. Complete the shaft
 - If rock is deeper, then extend shaft deeper (see Trouble Shoot Problem 2)
- If rock is shallower than expected, you may need to verify that you are on bedrock and not a boulder or shelf rock. Possible remedies:
 - For friction design, confirm entire socket length is in rock
 - For an end-bearing design, confirm that refusal occurred with a rock auger
 - Sound bottom at multiple places with Kelly bar or weighted probe.
 - Have contractor take a smaller diameter core several feet deep
 - If all indicates rock, call RE for approval

Problem 2:
Bearing soil does not meet requirements at specified depth

Solution:

- Discuss with design engineer and R.E. and have a contingency plan which is discussed with contractor at the pre-construction meeting
- Review the geotechnical report for recommendations and nearest boring log for soil conditions
- Is going deeper an option or is there a depth restriction due to encountering possible water bearing soils, weaker soils or caving soils?
 - If no depth restriction, extend shaft 5 ft to 10 ft deeper to find suitable bearing material
 - If still no bearing, call RE. Shaft may need to be abandoned and backfilled
- If shaft cannot extend deeper because of soil conditions – call RE
 - Possible remedies:
 - New procedures: use casing or slurry to extend deeper
 - New design: larger shaft or larger bell





Problem 3:
Base of shaft is not clean

Solution:

- Standard IDOT Specifications require that at least 50% of the shaft base have less than ½ inch of sediment. In addition, no point of the shaft shall have more than 1.5 inches of sediment
- A clean base is more critical for end-bearing shafts than friction shafts
- Check that the clean-out bucket has a flat bottom, that the base of the shaft was level within 6.25% and the cleanout tool is not riding up and down on a boulder or uneven rock
- Perform extra passes of the muck bucket until the shaft is clean
- An air lift may be needed in rock sockets to achieve IDOT requirements
- For belled shafts in soil it will not be possible to achieve IDOT requirements with the bell bucket. Belled shafts should be over-sized one foot and the remaining spoil can be back-bladed to the bell periphery



Problem 4:
Water at base of shaft with free-fall concrete

Solution:

- Check water depth after cage is installed and just before pouring concrete
- If water depth is less than 3 inches – pour the concrete
- If water depth exceeds 3 inches, contractor may elect to ...
 1. ... use smaller diameter muck bucket within the cage to remove water
 2. ... insert air-lift (if available) through cage to dewater
 3. ... pull cage to dewater with muck bucket
 4. ... in a rock socket, lower a dewatering pump through the cage
- If water cannot be controlled, switch to a tremie or pumped procedure (wet method)



Problem 6:
Sand content is too high in slurry before concrete pour

Solution:

- Sample slurry 1 ft above bottom of shaft after cage is installed and just before pouring concrete
- For bentonite:
 - If sand content > 4%, contractor should circulate slurry by pumping from bottom, de-sand slurry and fill with fresh slurry from top
 - Re-sample slurry and repeat until sand content is within spec
- For polymer:
 - If sand content > 1%, allow sand and sediment to settle out of slurry up to two hours
 - Contractor should clean bottom thoroughly and re-sample the slurry



Problem 7:
Concrete placement is interrupted during a tremie pour under water or slurry

Solution:

- Any blockage when pumping or tremie pouring concrete under water or slurry can cause shaft failure
- Measure top of concrete and confirm that tremie is not pulled out of placed concrete
- If pour can be resumed within 15 minutes – recheck concrete elevation to confirm no change. Resume pour
- If tremie is pulled out of concrete only two methods are acceptable to complete pour:
 - Pull and clean tremie of blockage, water and slurry
 - Attach a sacrificial steel bottom plate to clean tremie pipe, reinsert 5 to 10 ft into fresh concrete (within 15 minutes), and restart concrete pour
 - Over pour concrete at least 5 ft or as needed to flush contaminated concrete above cut-off
- If less than 5 ft of concrete in shaft, concrete in shaft has set >15 mins, or no bottom plate available, pull cage, muck out wet concrete and start over



Problem 8:
Concrete rises when pulling casing

Solution:

- Concrete mix design must be appropriate for pulling casing. Slump should be 7 to 9 inches, casing should be clean and concrete should not set in the casing more than about 30 minutes. It is very important to tape the top of concrete before and after pulling the casing
- The concrete surface should **lower** while pulling casing as the concrete flows outward to fill the annular space outside the casing
- If the concrete has risen, it is a definite indicator that water/slurry or soil 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
- Casing must be reinserted and concrete should be mucked out and be re-poured

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 LFRD Design Methods (FHWA – May 2010)
www.fhwa.dot.gov/engineering/geotech/foundations/nhi10016/index.cfm
Comment: Refer to Table 19-2 for common problems encountered during drilled shaft construction and the potential cause of the problem.
- 336.1-01 Specification for the Construction Drilled Piers (American Concrete Institute (ACI))
Available on IDOT's intranet as follows:
Click "Library"
See Reference Collection and Click "View All"
Click "ACI Manual of Concrete Practice"
Select "336.1-01 Specification for the Construction Drilled Piers"
- Drilled Shaft Inspector's Manual (ADCS: The International Association of Foundation Drilling, and DFI: Deep Foundations Institute)
www.adsc-iafd.com/

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
- 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 (consistency, pH, sand content, etc.)
- 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) Article 516.04
 - 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

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 center to offset
 - (2) No more than 1 in. above and 3 in. below plan elevation
- f. Method of cage installation
- 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 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 5 ft. above the bottom of the top 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 the plan elevation
- (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. INTEGRITY 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 5000 psi grout
 - 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 5000 psi grout

8.3 – Drilled Shaft Straight and Belled Concrete Volume Calculation Tables



Shaft Volume

- For straight shaft the calculation is pretty simple, shaft area times 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

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

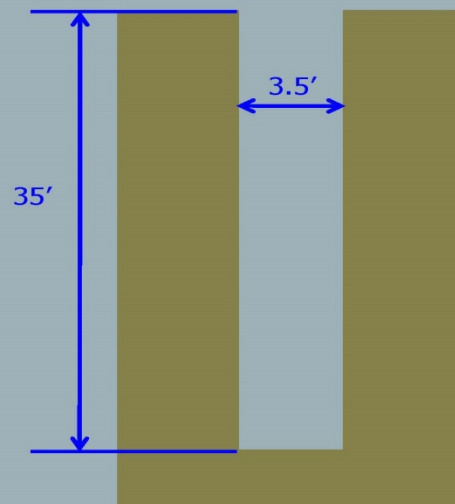
$$Volume = Area \times \text{Length}$$

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



Shaft Volume Calculation

- How about an example?
 - Diameter = 3.5'
 - Length = 35'
 - $\frac{3.14}{4} \times 3.5^2$
 - Area = 9.6 square feet
 - 9.6×35
 - Volume = 336.6 cubic feet
 - $\frac{336.6}{27}$
 - Volume = 12.5 cubic yards



STRAIGHT SHAFT VOLUME IN CUBIC YARDS																			
	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																		
		12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120
Shaft Length in Feet	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

Specific Task Training Program Drilled Shaft Foundation Construction Inspection S-32 Class Reference Guide

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
24	54	2.00	2.56		84	2.00	7.93		102	2.00	12.63
	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		
30	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		
	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	25.55		
	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		
42	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	
	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	
48	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					

Specific Task Training Program Drilled Shaft Foundation Construction Inspection S-32 Class Reference Guide

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)	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	0.93	0.39	48	54	0.93	2.26	66	72	0.93	4.12
	30	1.37	0.74		60	1.37	3.60		78	1.37	6.35
	36	1.80	1.23		66	1.80	5.20		84	1.80	8.93
	42	2.23	1.89		72	2.23	7.10		90	2.23	11.88
	48	2.67	2.74		78	2.67	9.32		96	2.67	15.22
	54	3.10	3.81		84	3.10	11.89		102	3.10	18.98
24	30	0.93	0.64	54	90	3.53	14.82	72	108	3.53	23.19
	36	1.37	1.14		96	3.96	18.15		114	3.96	27.87
	42	1.80	1.80		102	4.40	21.90		120	4.40	33.05
	48	2.23	2.66		108	4.83	26.09		126	4.83	38.74
	54	2.67	3.73		114	5.26	30.76		132	5.26	44.98
	60	3.10	5.05		120	5.70	35.92		138	5.70	51.80
	66	3.53	6.64		126	6.13	41.60		144	6.13	59.21
	72	3.96	8.52		132	6.56	47.83		150	6.56	67.24
30	36	0.93	0.95	54	138	7.00	54.63	72	156	7.00	75.91
	42	1.80	2.08		144	7.43	62.02		162	7.43	85.26
	48	2.23	3.02		60	0.93	2.82		168	7.86	95.31
	54	2.67	4.20		66	1.37	4.43		174	8.29	106.08
	60	3.10	5.62		72	1.80	6.33		180	8.73	117.60
	66	3.53	7.32		78	2.23	8.56		186	9.16	129.89
	72	3.96	9.33		84	2.67	11.13		192	9.59	142.97
	78	4.40	11.66		90	3.10	14.07		198	10.03	156.88
	84	4.83	14.34		96	3.53	17.40		78	0.93	4.86
	90	5.26	17.40		102	3.96	21.15		84	1.37	7.44
36	42	0.93	1.33	54	108	4.40	25.35	72	90	1.80	10.39
	48	1.37	2.19		114	4.83	30.02		96	2.23	13.74
	54	1.80	3.28		120	5.26	35.19		102	2.67	17.51
	60	2.23	4.61		126	5.70	40.87		108	3.10	21.73
	66	2.67	6.20		132	6.13	47.11		114	3.53	26.41
	72	3.10	8.09		138	6.56	53.91		120	3.96	31.59
	78	3.53	10.30		144	7.00	61.31		126	4.40	37.29
	84	3.96	12.86		150	7.43	69.33		132	4.83	43.54
	90	4.40	15.78		156	7.86	78.00		138	5.26	50.35
	96	4.83	19.10		162	8.29	87.34		144	5.70	57.77
	102	5.26	22.84		60	0.93	3.43		150	6.13	65.80
	108	5.70	27.03		72	1.80	6.87		156	6.56	74.49
42	48	0.93	1.76	60	78	2.23	9.25	72	162	7.00	83.84
	54	1.80	3.66		84	2.67	11.98		168	7.43	93.89
	60	2.23	5.10		90	3.10	15.09		174	7.86	104.67
	66	2.67	6.82		96	3.53	18.60		180	8.29	116.19
	72	3.10	8.84		102	3.96	22.54		186	8.73	128.48
	78	3.53	11.15		108	4.40	26.93		192	9.16	141.57
	84	3.96	13.90		114	4.83	31.80		198	9.59	155.49
	90	4.40	16.98		120	5.26	37.18		204	10.03	170.25
	96	4.83	20.46		126	5.70	43.08		210	10.46	185.89
	102	5.26	24.37		132	6.13	49.54		216	10.89	202.42
	108	5.70	28.74		138	6.56	56.58				
	114	6.13	33.58		144	7.00	64.22				
	120	6.56	38.93		150	7.43	72.50				
	126	7.00	44.81		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						

Specific Task Training Program Drilled Shaft Foundation Construction Inspection S-32 Class Reference Guide

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)
78	84	0.93	5.66	90	96	0.93	7.45	96	102	0.93	8.44
	90	1.37	8.62		102	1.37	11.24		108	1.80	16.32
	96	1.80	11.57		108	1.80	15.46		114	2.23	21.25
	102	2.23	15.75		114	2.23	20.16		120	2.67	26.68
	108	2.67	19.96		120	2.67	25.36		126	3.10	32.63
	114	3.10	24.85		126	3.10	31.07		132	3.53	39.15
	120	3.53	29.84		132	3.53	37.33		138	3.96	46.24
	126	3.96	35.54		138	3.96	44.17		144	4.40	53.94
	132	4.40	41.79		144	4.40	51.59		150	4.83	62.27
	138	4.83	48.62		150	4.83	59.64		156	5.26	71.25
	144	5.26	56.04		156	5.26	68.34		162	5.70	80.91
	150	5.70	64.08		162	5.70	77.71		168	6.13	91.28
	156	6.13	72.76		168	6.13	87.78		174	6.56	102.38
	162	6.56	82.12		174	6.56	98.56		180	7.00	114.24
	168	7.00	92.18		180	7.00	110.10		186	7.43	126.87
	174	7.43	102.96		186	7.43	122.41		192	7.86	140.32
	180	7.86	114.48		192	7.86	135.52		198	8.29	154.59
	186	8.29	126.78		198	8.29	149.45		204	8.73	169.72
	192	8.73	139.88		204	8.73	164.22		210	9.16	185.74
	198	9.16	153.80		210	9.16	179.87		216	9.59	202.66
	204	9.59	168.57		216	9.59	196.42		222	10.03	220.51
	210	10.03	184.21		222	10.03	213.90		228	10.46	239.32
	216	10.46	200.75		228	10.46	232.32		234	10.89	259.11
	222	10.89	218.21		234	10.89	251.72		240	11.33	279.91
228	11.33	236.63	240	11.33	272.12	246	11.76	301.75			
234	11.76	256.01	246	11.76	293.54	252	12.19	324.64			
84	90	0.93	6.53	252	12.19	316.01	258	12.62	348.61		
	96	1.37	9.88	258	12.62	339.55	264	13.06	373.70		
	102	1.80	13.66	264	13.06	364.20	270	13.49	399.91		
	108	2.23	17.89	270	13.49	389.97	276	13.92	427.29		
	114	2.67	22.58				282	14.36	455.85		
	120	3.10	27.77				288	14.79	485.62		
	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									