

Drilled Shaft Inspection

HQ Construction Office
HQ Geotechnical Division

Drilled Shafts:

- What are Drilled Shafts
- Drilled Shaft Construction
- Challenges of Drilled Shaft Construction
- The WSDOT SHAFT Special Provision

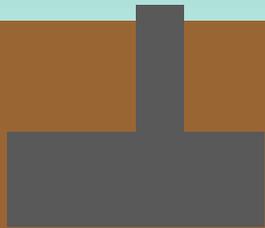
Typical Foundations for WSDOT Structures

Spread footings are still the least expensive type of foundation.

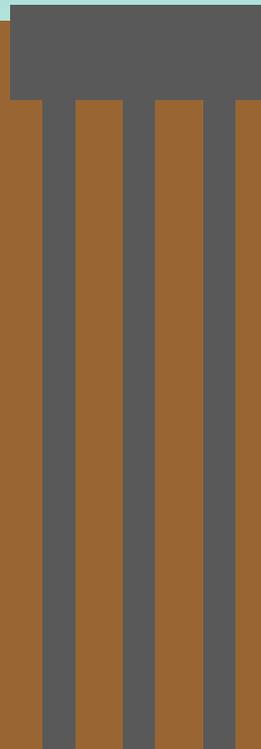
For most projects, drilled shaft foundations have become the preferred deep foundation. Reasons for this include:

1. Noise concerns with pile driving in urban environments.
2. Environmental issues and added cost associated with constructing large reinforced concrete pile caps
3. Challenges with constructing pile caps adjacent to existing structures (i.e. bridge widenings).

Spread Footings



Driven Piles



Drilled Shafts

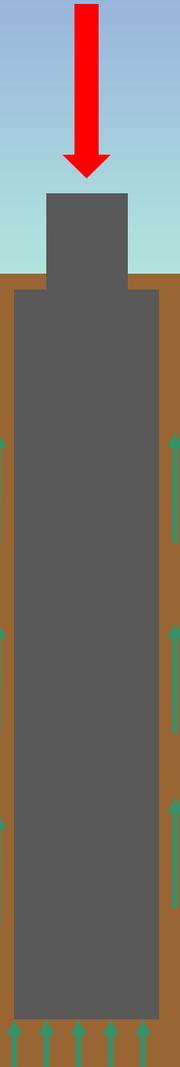


Drilled Shafts

- Loads:
- Axial
 - Lateral
 - Torsional

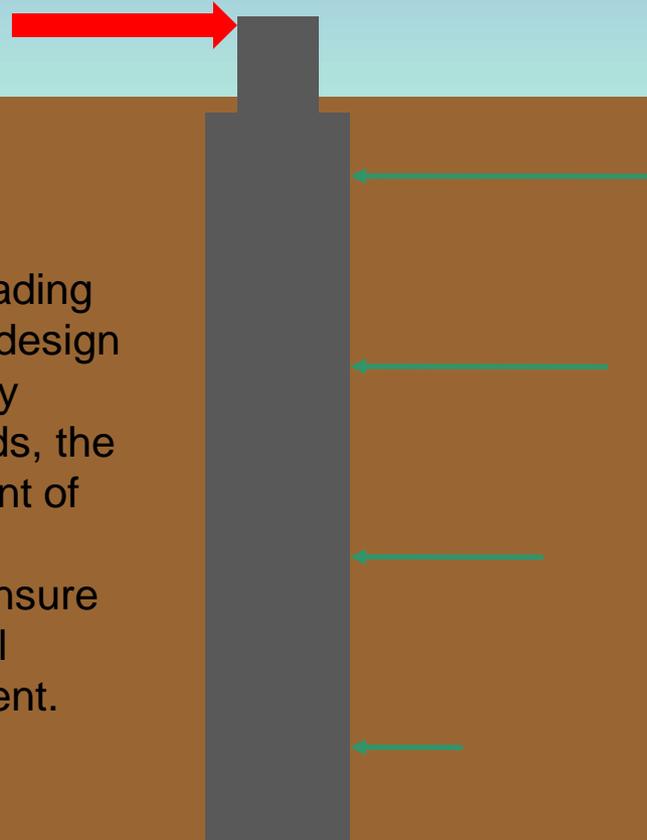
Axial loads are resisted by a combination of skin friction and end bearing.

In non-seismic zones (Eastern Washington) shaft designs are normally controlled by axial capacity.



Drilled Shafts

- Loads:
- Axial
 - Lateral
 - Torsional

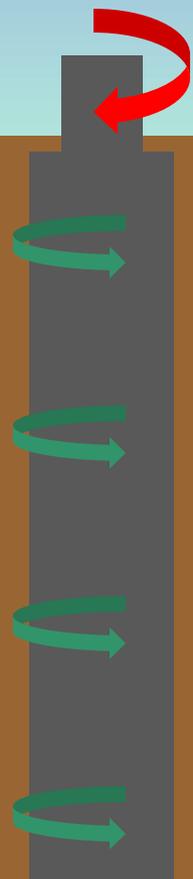


In areas with high seismic loading (Western Washington) shaft design is almost always controlled by seismic forces. In other words, the shafts have an excess amount of axial capacity, and have a tip elevation that is selected to insure the shaft has sufficient lateral capacity during a seismic event.

Lateral loads are resisted by passive resistance of the soil.

Drilled Shafts

- Loads:
- Axial
 - Lateral
 - Torsional



Shafts provide torsional resistance, but this is not typically a design check.

Torsional loads are resisted by skin friction.

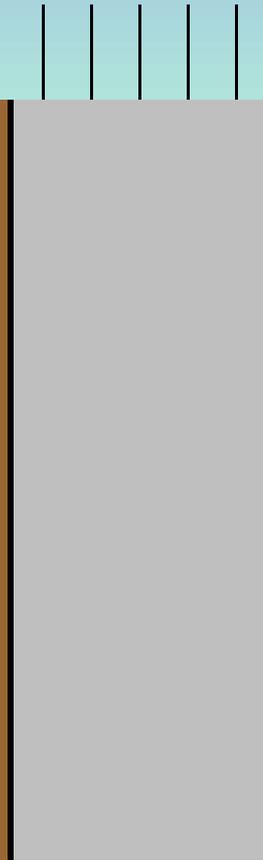
Drilled Shafts: Open Excavation

This is the simplest way to construct a shaft. However, most of our shafts are drilled below the groundwater table or “in the wet”. Drilling in the wet usually requires casing and/or a slurry to be used to provide stability of the shaft sidewalls.



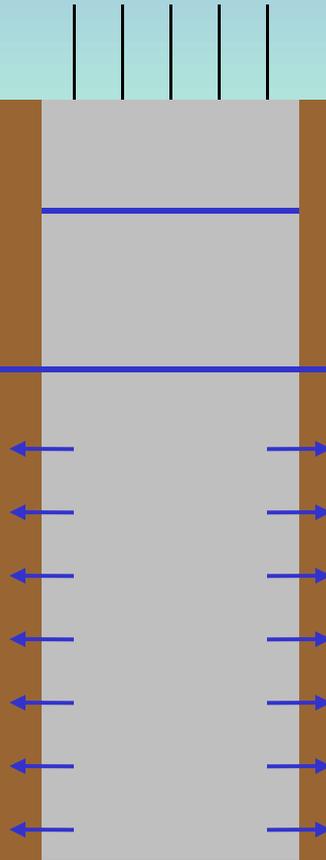
Drilled Shafts: Cased Excavation

Oscillator drilling is done as a cased excavation. If water is present then a water slurry is used, sometimes with a flocculent to drop out suspended material.



Drilled Shafts: Slurry Excavation

This shows a drilled shaft being constructed below the groundwater table. It's also a common practice to use some amount of casing at the top of the shaft to provide stability of the surface soils during drilling.



Construction of Drilled Shafts:

- Excavation - methods and equipment
- Casing - methods and equipment
- Slurry
- Reinforcing
- Concrete placement

Excavation: Rotary Drill Rigs (Conventional)



Excavation: Rotary Drill Rigs



Excavation: Rotary Drill Rigs - Tooling



Rock Auger



Clean-out Bucket / Digging bucket



Rock Auger



Core Barrel

Excavation: Rotary Drill Rigs - Tooling



The auger is “screwed” into the soil, then is pulled vertically out of the hole. Spoils from the shaft are collected on the flights of the auger. The auger is then “back-spun” which drops the spoils into the collection area.

Casings: Methods and Equipment – Vibratory Hammer

A vibratory hammer is a common way to install casing for conventional shaft construction.



Casings: Methods and Equipment – Casing Twister

Conventional drilling can also install casing by twisting it into the ground. Conventional drilling equipment has only a limited amount of torque that can be put into the casing. The torque capacity of conventional equipment is much smaller than oscillator/rotator equipment.



Oscillator: How it Works

Position casing oscillator at shaft location.

Install additional base frame as needed.



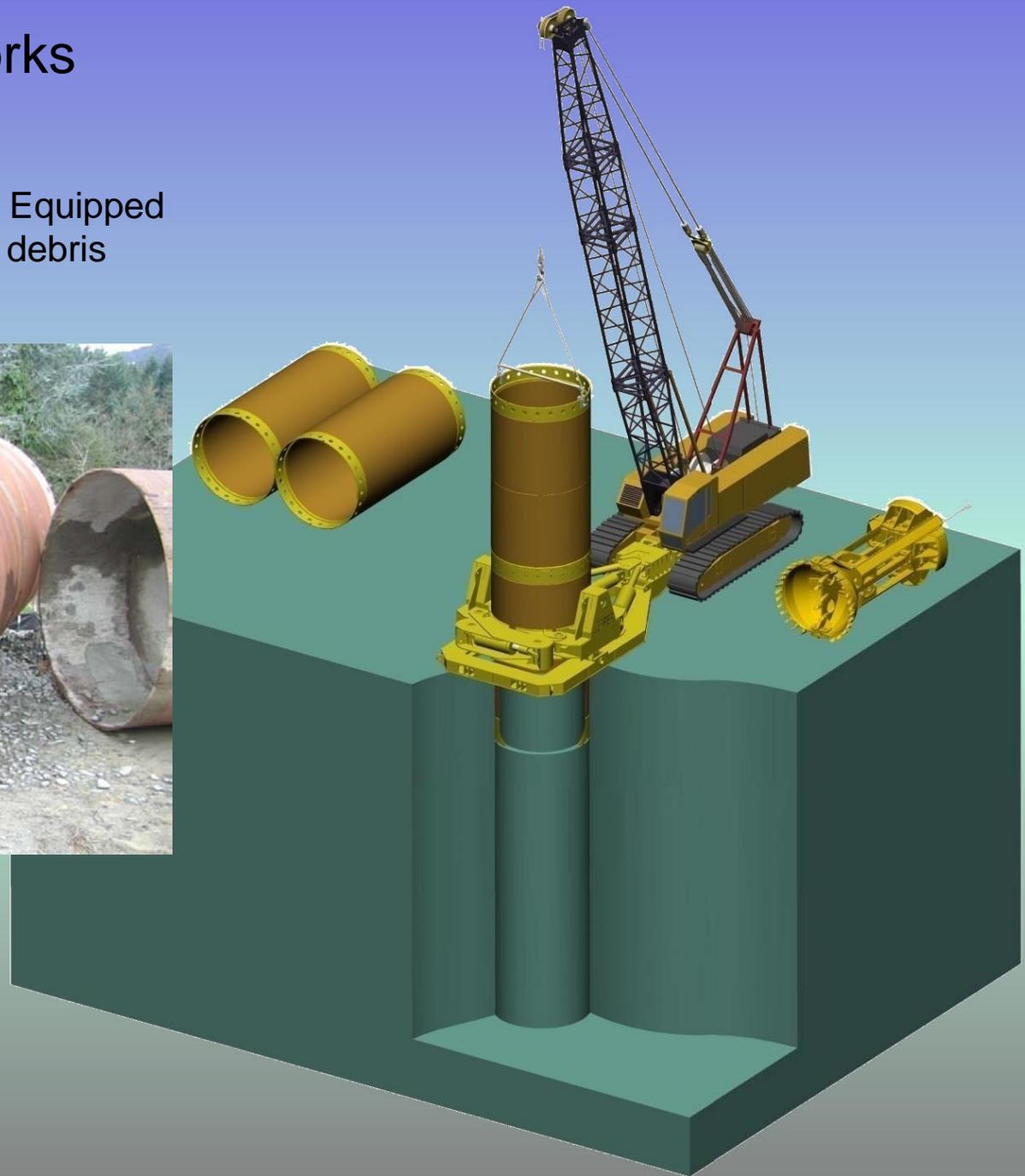
Casings: Methods and Equipment - Rotator

Oscillator casing is only rotated in a single direction (clockwise or counter-clockwise).
Rotator casing is rotated back and forth (alternating clockwise and counter-clockwise).



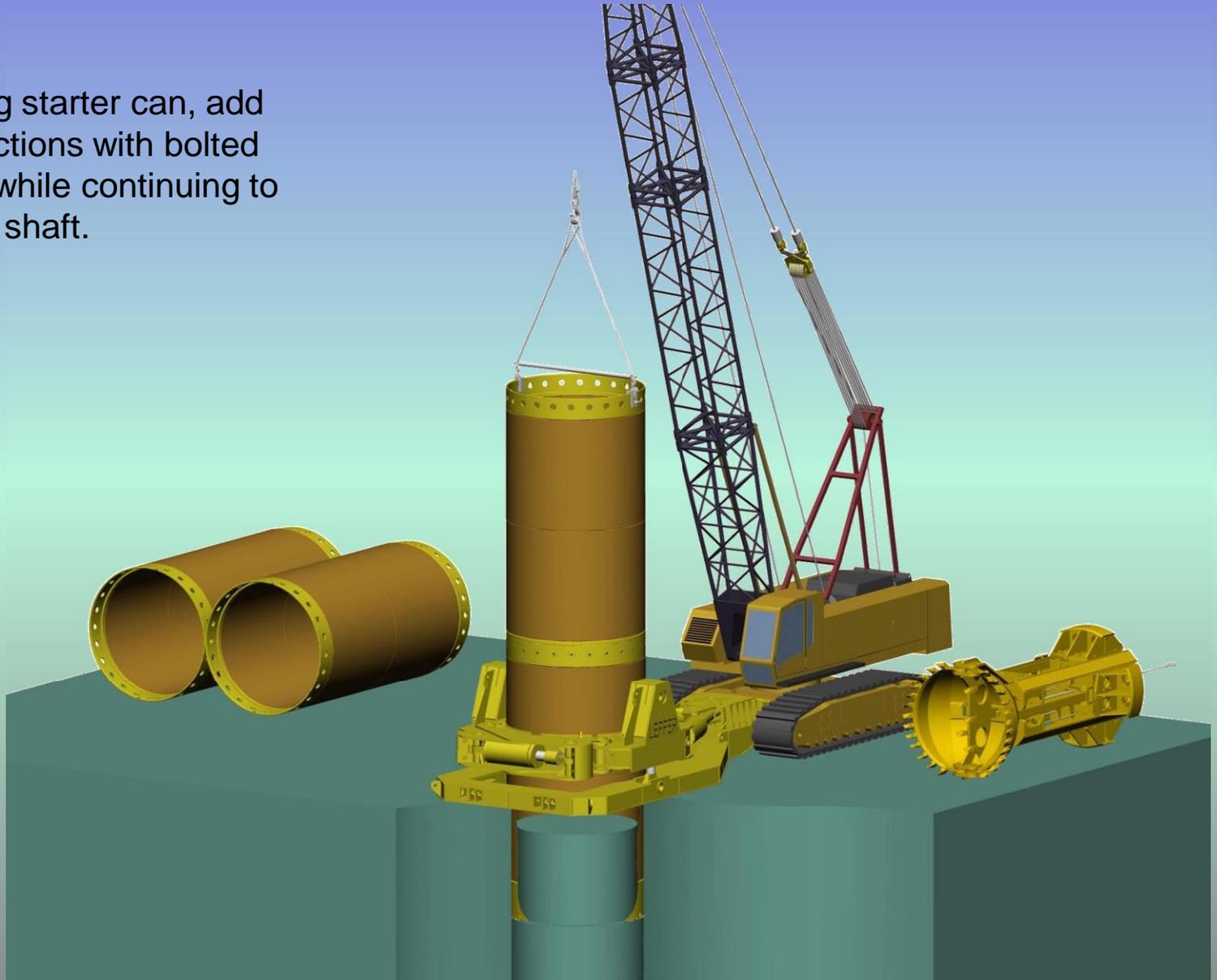
Oscillator: How it Works

Install bottom or starter casing. Equipped with cutting teeth to cut through debris and cut clearance.



Oscillator: How it Works

After inserting starter can, add additional sections with bolted connections while continuing to excavate the shaft.



Oscillator: How it Works

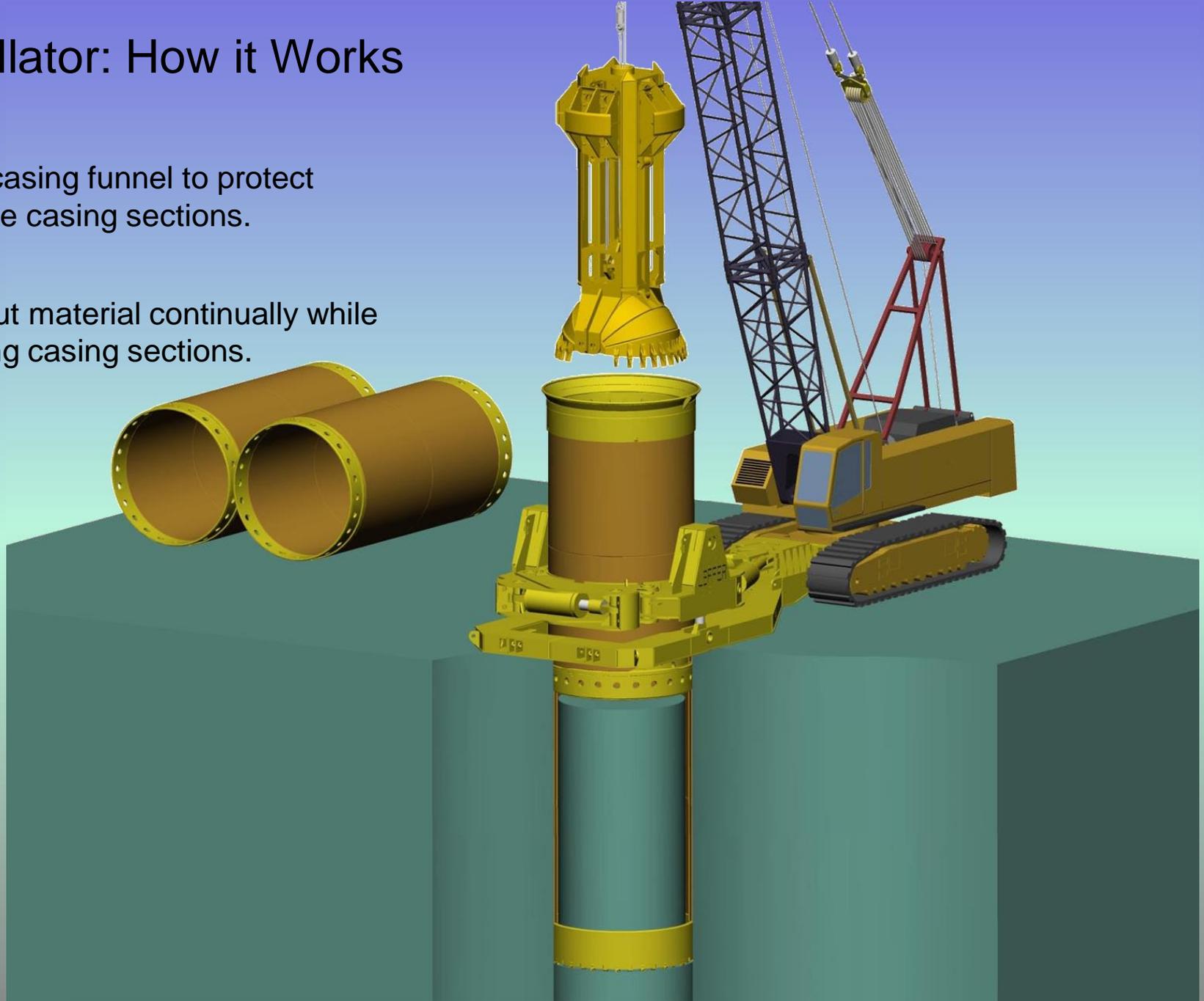
Casing is installed in 10 - 20 foot sections. It is installed by oscillating the casing while simultaneously pushing the casing down vertically.



Oscillator: How it Works

Install casing funnel to protect reusable casing sections.

Grab out material continually while installing casing sections.



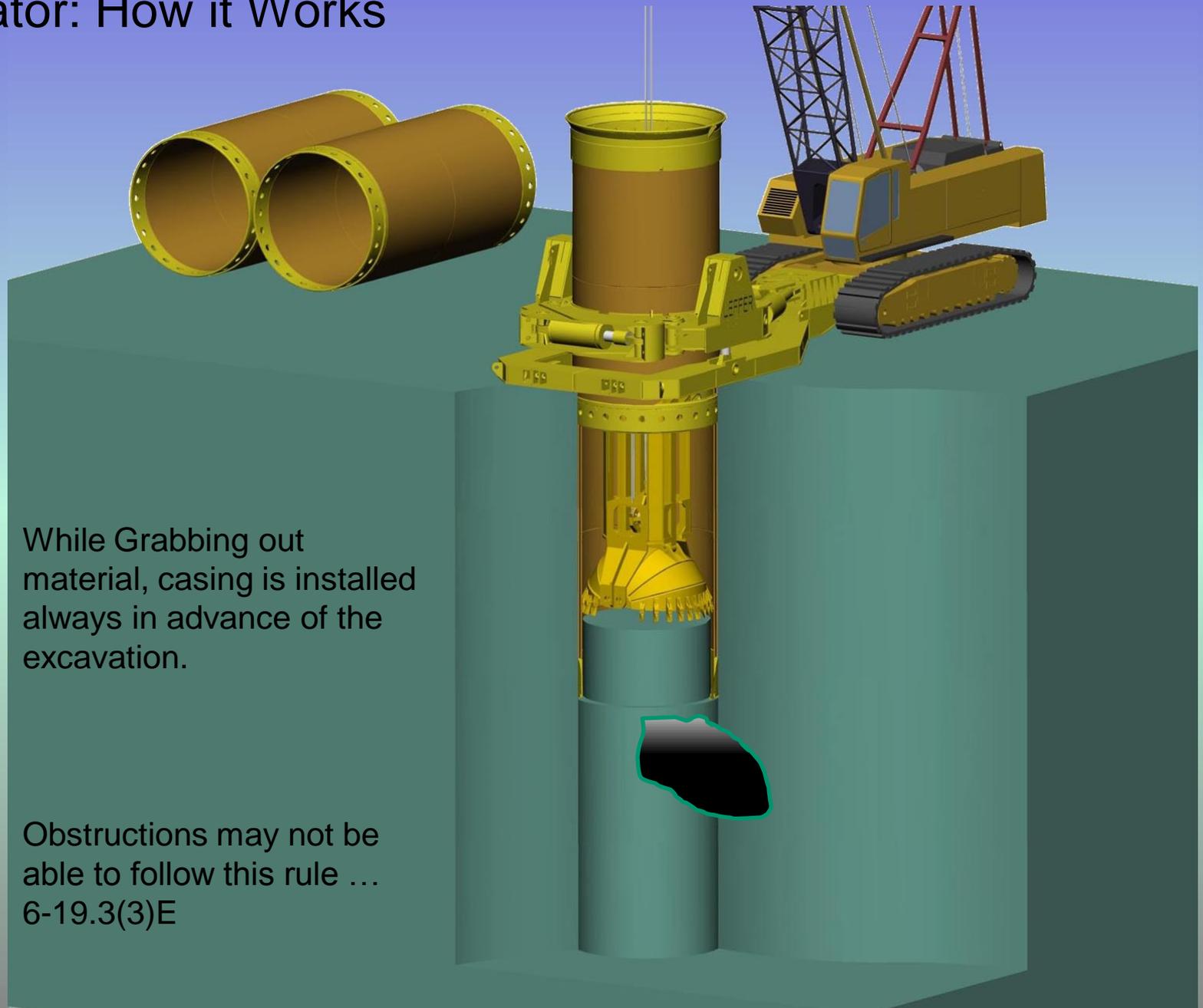
Oscillator: How it Works ~ Hammer Grab



Hammer grabs are generally only used with oscillator/rotator construction methods.



Oscillator: How it Works



Oscillator: How it Works ~ Chisel

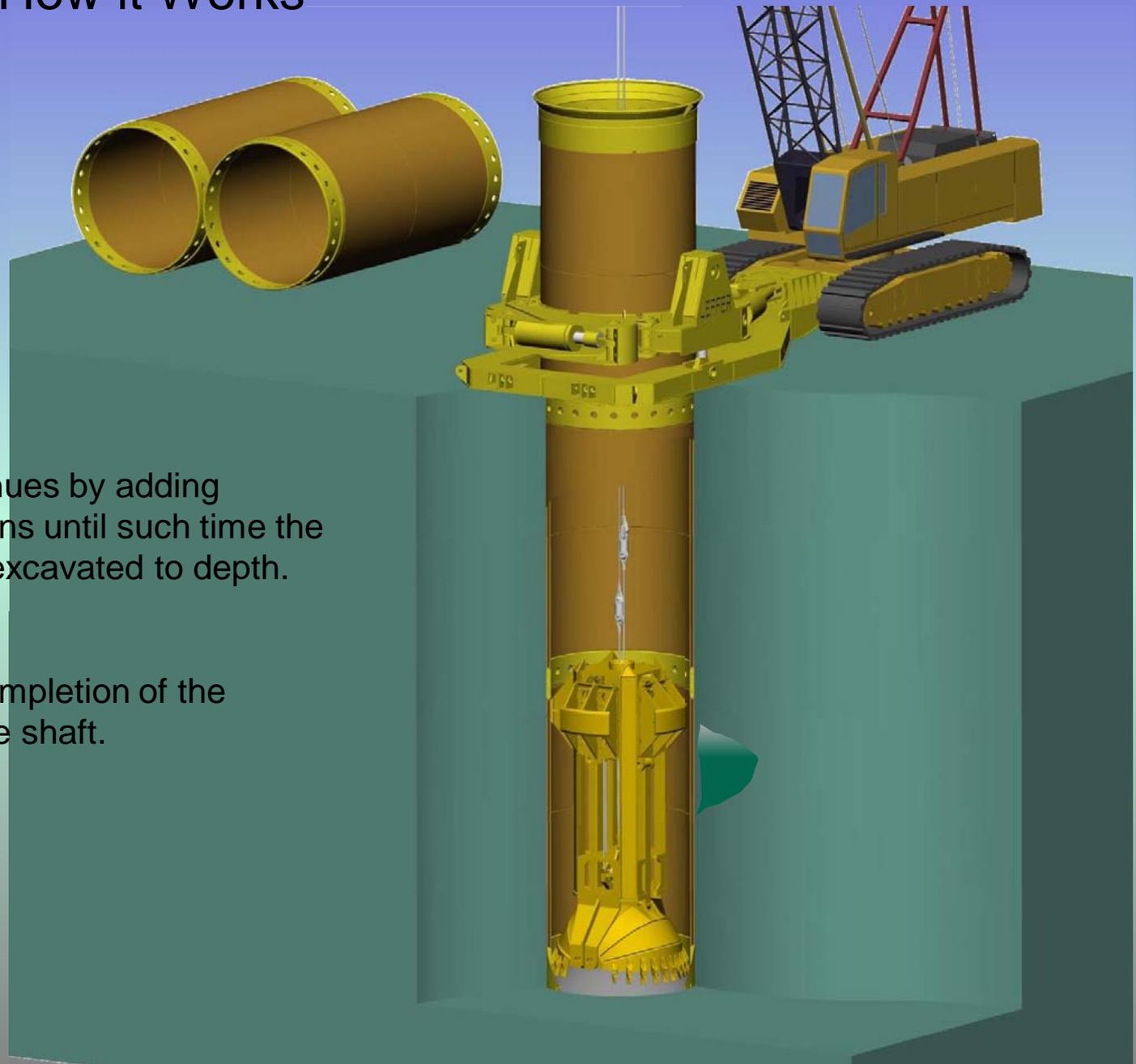


The “conventional drilling tools” can’t be used with oscillator/rotator construction methods because there is no “Kelly Bar” to attach the tools to.

Oscillator/rotator construction often uses various types of chisels to get through obstructions. These chisels are gravity dropped into the excavation, breaking up anything that is impeding shaft construction.



Oscillator: How it Works



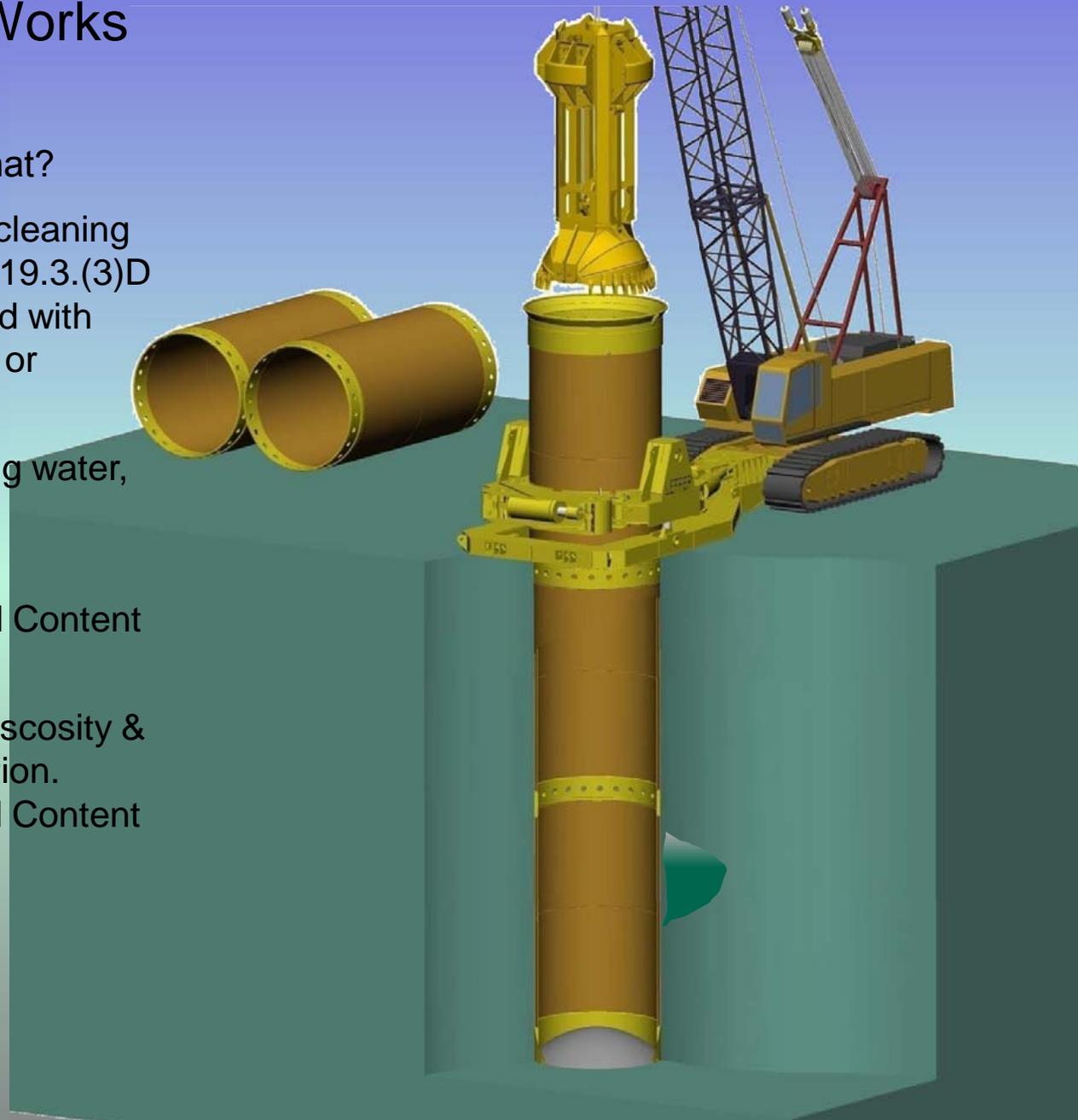
Operation continues by adding additional sections until such time the shaft has been excavated to depth.

Grab nearing completion of the excavation of the shaft.

Oscillator: How it Works

Shaft at final depth ... now what?

- 1) Contractor has a plan for cleaning out the bottom of shaft. 6-19.3.(3)D requires this to be checked with airlift pipe, weighted tape, or approved method.
- 2) If a slurry is used, including water, then there are tests to be performed 6-19.3(2)B...
 - a) Water ~ Density & Sand Content tests after final clean out.
 - b) Mineral or Synthetic ~ Viscosity & PH tests throughout construction.
Viscosity, PH, Density & Sand Content tests after final clean out.



Reinforcing Cage

Drilled shaft cages can be fabricated on-site, or they may be fabricated off-site and trucked/barged to the project.



Reinforcing Cage

Make sure cages are tied per the WSDOT Standard Specifications. Generally, every other bar intersection should be tied.

Verify the Cross-Hole Sonic Log (CSL) tubes are installed correctly, and are uniformly spaced within the cage. Note that it is acceptable to install the CSL tubes inside the shaft bracing hoops.



Reinforcing Cage ~ Centralizers

Centralizers are used to insure the reinforcing cage is centered within the shaft excavation and there is sufficient concrete cover outside of the cage. Because they are in contact with the soils, centralizers are required to be made out of epoxy-coated steel.

Oscillator sizes vary from conventional casing and a slip casing is often employed as the permanent casing. This may create different centralizer sizes over the length of the shaft.

Verify centralizers are positively connected to the outside of all reinforcement.



Reinforcing Cage ~ Picking

Shaft cage picking can be a challenging operation. Inspectors should insure that bracing and picking is being done in accordance with this approved plan.

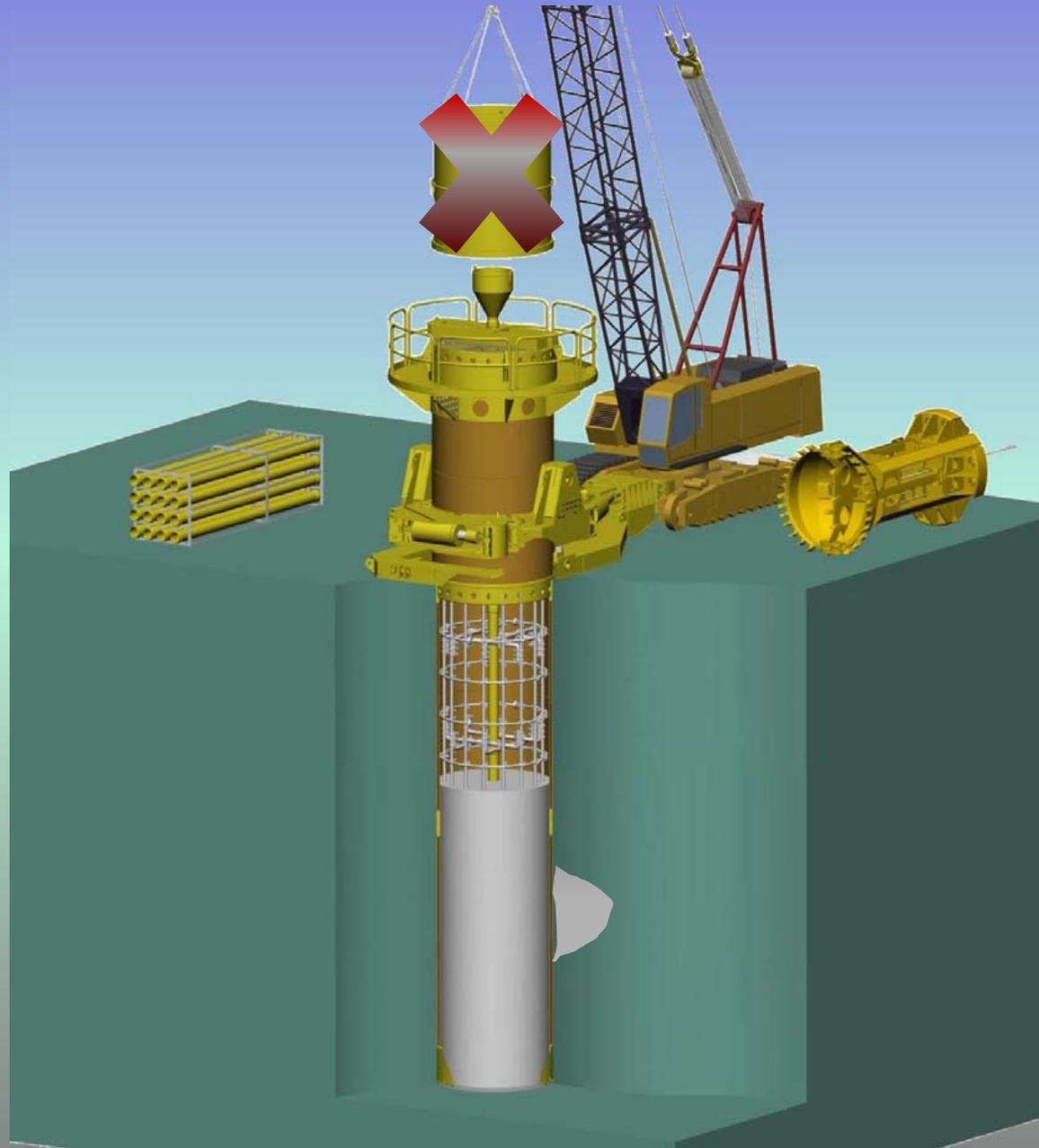


Oscillator: How it Works

Concrete placement shall begin **immediately** after completion of excavation ... *get cage set and concrete pumping.* At some point call HQ, the cage may need to be pulled and everything retested before concrete can be poured.

Pressurized Concrete Tremie to maintain 5' -10' of head at all times until completion of Shaft.

Tremie lengths are sized to break apart at the same time as the casing sections.



Concrete Placement: Tremie Method

Tremie placement is required anytime there is slurry in the shaft excavation.

The tremie is usually 4" to 8" in diameter and the tip of the tremie is at the bottom of the drilled shaft.

WSDOT requires the tremie to be connected directly into the line from the pump truck.



Concrete Placement: Tremie Method

The reinforcing cage should be supported at all times during concrete placement.

As concrete is placed in the shaft through the tremie, it will displace the slurry in the shaft. As the slurry level rises, the contractor will pump it off into storage tanks.

Note: Near the top of the shaft this can become a problem in soft soils.



Concrete Placement: Free Fall Method

Free fall method is allowed for shafts that use no slurry (i.e., constructed “in the dry”).

Note: for reinforced shafts, the concrete needs to be directed down the center of the reinforcing cage.



Slurry ~ Water, Synthetic, & Mineral / Polymer

Regardless of the drilling method (conventional or oscillator/rotator), slurry is required once the drilling operations encounter groundwater, to maintain sidewall stability and help excavation.

Note: A plain water slurry is allowed when the shaft is cased full-depth. Most oscillator/rotator projects use a water slurry.



Slurry ~ Synthetic & Mineral / Polymer

Once the slurry has been introduced, the drilling operation becomes a little messier. Note the gooey slurry dripping of the shaft spoils.

Ensure permits are not being violated.



Slurry ~ Synthetic & Mineral / Polymer

Synthetic or mineral slurry is usually made up ahead of time and kept in storage tanks (also called Baker tanks) when it is not being used to drill a shaft.

A synthetic or mineral slurry is required when part of all of the shaft is uncased.



Challenges of Drilled Shaft Construction

- Digging the hole
- Lifting and placing the reinforcing
- Placing concrete

Challenges of Drilled Shaft Construction: Caving Soils

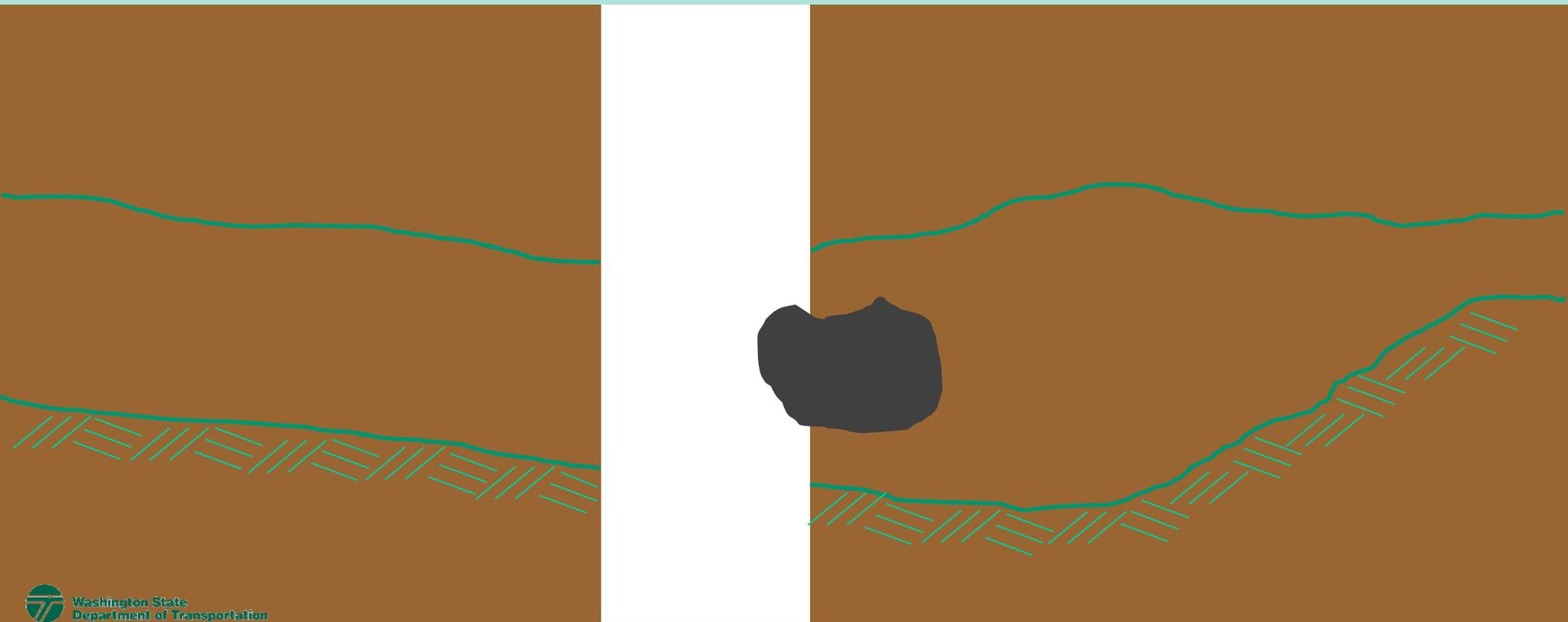
Shaft stability is the responsibility of the contractor.



Challenges of Drilled Shaft Construction: Obstructions

WSDOT pays force account for removal of obstructions. Track before obstruction happens:

- Soil properties as described in the contract vs. what is coming out of the hole...
(Differing Site Condition Claims)
- Rate of production in each independent soil layer...
- Equipment on site (each day, as changes)...
 - tools as described in plan for dealing with obstructions...
 - equipment involved in work...



Challenges of Drilled Shaft Construction: Obstructions

These are all examples of obstructions. We only make force account payment for removal when the obstruction slows down the shaft construction. Sometimes, these types of cobbles/boulders are just removed as part of the shaft excavation work.



Challenges of Drilled Shaft Construction: Obstructions

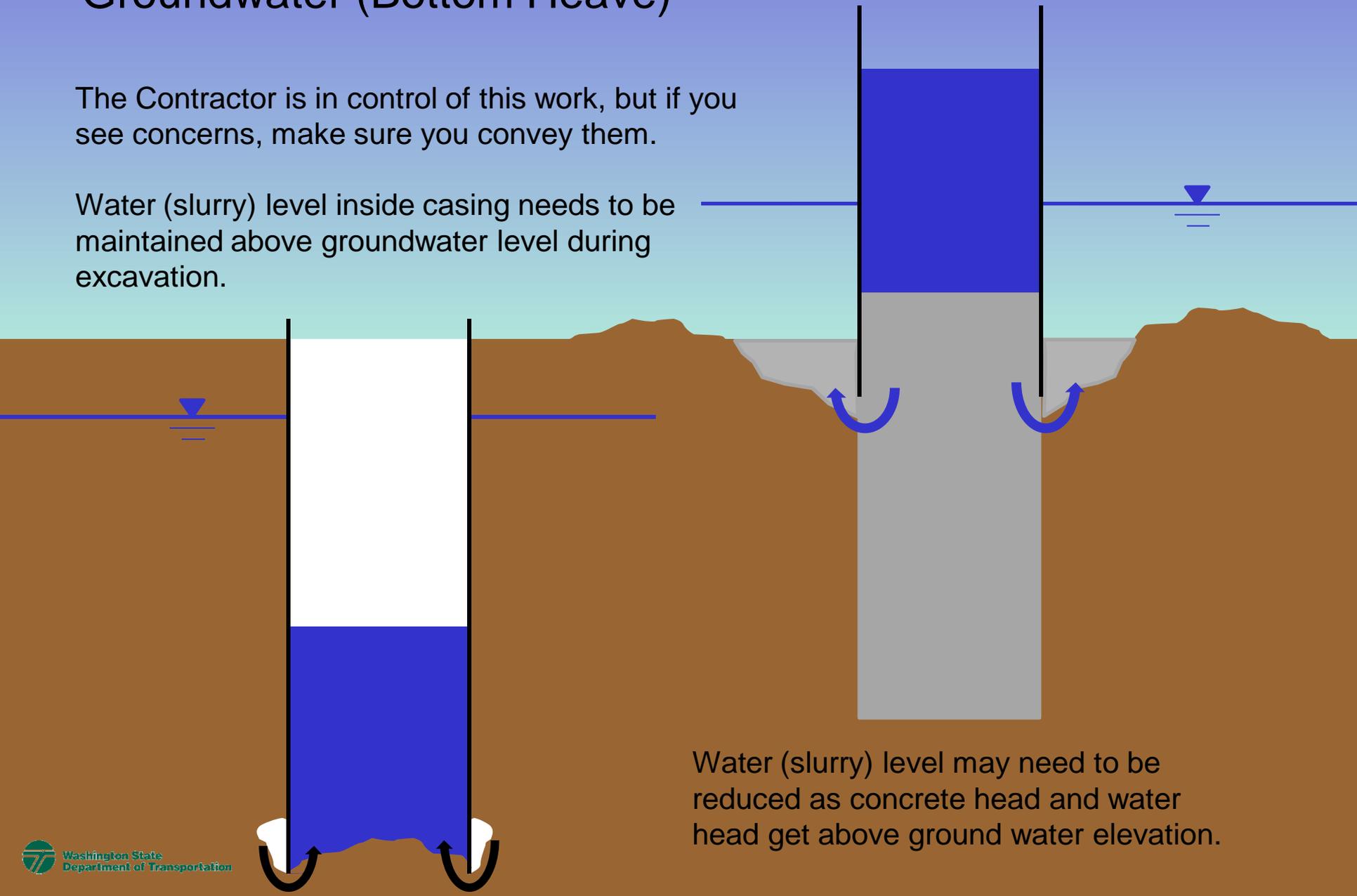
Obstructions can damage casing, cutting teeth, Kelly bars, tractors, and other equipment. Based on the WSDOT/ADSC agreement, these items are not covered due to an obstruction.



Challenges of Drilled Shaft Construction: Groundwater (Bottom Heave)

The Contractor is in control of this work, but if you see concerns, make sure you convey them.

Water (slurry) level inside casing needs to be maintained above groundwater level during excavation.



Water (slurry) level may need to be reduced as concrete head and water head get above ground water elevation.

Challenges of Drilled Shaft Construction: Lifting the cage.

Inspect the following, per the approved plan:

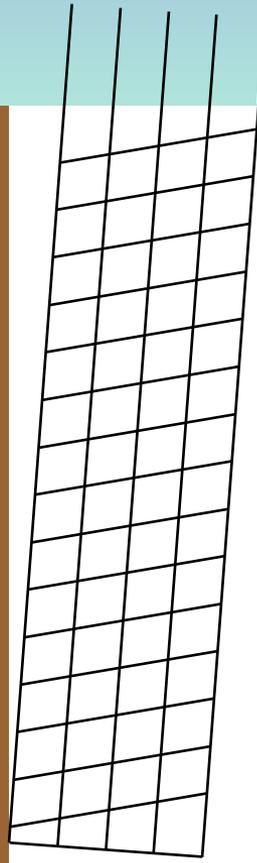
- Longitudinal Lifting bars ~ 100% tied using figure 8 and the proper gauge
- Other locations tied 50%
- Wagon Wheel TS&L
- Cranes and pick locations
- CSL tubes tied off adequately



Challenges of Drilled Shaft Construction: Keeping the reinforcing cage centered

We have seen many different types of centralizers used over the years. Non of these are approved types...

The detail shown in the plans is often modified, but this requires a change order.



Challenges of Drilled Shaft Construction: Concrete Placement



Shaft details used to use reinforcing bars that were very tightly spaced. This shaft has spiral reinforcing that was at a 3-4 inch pitch. With a tight reinforcing spacing, we have several cases where the concrete wouldn't flow through the cage. Current practice is for the cage detailing to have "windows" between the reinforcing steel that are 5" by 5" minimum.

Challenges of Drilled Shaft Construction: Concrete Set-up Time



The tremie wasn't removed immediately after concrete placement. When the contractor went to remove the tremie, they found the concrete has already started to set up. The tremie couldn't be extracted, and became a permanent part of this drilled shaft.

Challenges of Drilled Shaft Construction: Concrete Set-up Time



Contractor finished concrete placement before lunch, but elected not to complete the process and extract the oscillator casing. After lunch, contractor attempted to remove the oscillator casing but found out the concrete had already set up and was unable to remove casing. This shaft had to be abandoned. It was cut off at mud line using an underwater wire saw, and a new shaft was constructed alongside this one with an extended crossbeam. (Riverside 2002)

Challenges of Drilled Shaft Construction: Concrete Set-up Time



NE 6th, early setting of concrete. The first truck on concrete “flash set” immediately after it was placed. Contractor realized there was a problem, and attempted to remove the rebar cage after 10’ of concrete was placed. Concrete was already set, and the cage couldn’t be removed. Sent divers into the hole to torch off the damaged reinforcing steel, used a 6’-0” core barrel to remove the concrete, then installed a new cage and re-poured the shaft.

The WSDOT Shaft Standard Specifications

(Incorporated in the 2012 book)

6-19.2 Materials

6-19.3 Construction requirements

- (1) – Quality Assurance
- (2) – Submittals
- (3) – Shaft Excavation
- (4) – Slurry Installation Requirements
- (5) – Assembly and Placement of Reinforcing Steel
- (6) – Access Tubes for CSL Testing
- (7) – Placing Concrete
- (8) – Casing Removal
- (9) – Nondestructive Testing of Shafts (CSL Testing)

6-19.4 Measurement

6-19.5 Payment

6-19.3(1) – Quality Assurance

A – Tolerances

B – Nondestructive Testing

C – Shaft Preconstruction conference

(Submittals should be reviewed and any revisions made prior to pre-con)

6-19.3(2) – Submittals

A – Construction Experience Submittal

B – Shaft Installation Narrative Submittal

(Amendment coming August 2013; otherwise a Change Order is required. Engineering of Shafts not enforceable, but requirements are Contractor's responsibility to collaborate between sub-contractors)

C – Shaft Slurry Technical Assistance Submittal

6-19.3(3) – Shaft Excavation

A – Conduct of Shaft Excavation Operations

B – Temporary and Permanent Shaft Casing

C – Conduct of Shaft Casing Installation and Removal

D – Bottom of Shaft Excavation

E – Shaft Obstructions

F – Voids Between permanent Casing and Shaft Excavation

G – Operating Shaft Excavation Equipment From an
Existing Bridge

H – Seals For Shaft Excavation in Water

I – Required Use of Slurry in the Excavation

6-19.3(4) – Slurry Installation Requirements

A – Slurry technical Assistant

(If slurry is used to maintain sidewall stability, a site specific slurry design/plan is required. Generic brochures from the slurry manufacturer are not adequate)

B – Minimum Level of Slurry in Excavation

C – Slurry Sampling and Testing

D – Maintenance of Required Slurry Properties

(Slurry use requires proper storage, handling, and disposal)

E – Maintenance of a Stable Shaft Excavation

F – Slurry Disposal (Amendment)

6-19.3(5) – Assembly & Placement of Reinforcing Steel

A – Steel Reinforcement Bar Cage Assembly

B – Steel Reinforcement Bar Cage Centralizers

C – Concrete Cover Over Steel Reinforcement Bars

D – Steel Reinforcement Bar Cage Support at Base of Shaft Excavation

6-19.3(6) – Access Tubes for CSL Testing

A – Shafts Requiring CSL Access Tubes

B – Orientation and Assembly of the CSL Access Tubes

C – Care for CSL Access Tubes From Erection Through
CSL Testing

(It is **critical** the tubes are filled with water before or immediately after concrete placement. PVC end caps are required in case they need to be drilled out as part of a shaft repair procedure)

6-19.3(7) – Placing Concrete

A – Concrete Class for Shaft Concrete

B – Concrete Placement Requirements

C – Concrete Vibration Requirements

D – Requirements for Placing Concrete Underwater

E – Testing & Repair of Shaft Concrete Placed Underwater

F – Cleaning & Removal of Previously Placed Shaft Concrete

G – Protection of Fresh and Curing Concrete From Vibration

H – Uniform Yield Plot

I – Requirements for Placing Concrete Above the Top of Shaft

6-19.3(8) – Casing Removal

A – Concrete Head Requirements During Temporary Casing Removal

B – Removing Portions of Permanent Casing Above the Top of Shaft

C – Requirements for Leaving temporary Casing in Place

6-19.3(9) – Nondestructive Testing of Shafts (CSL Testing)

A – Schedule of CSL Testing

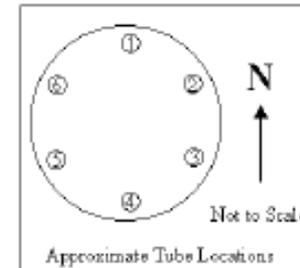
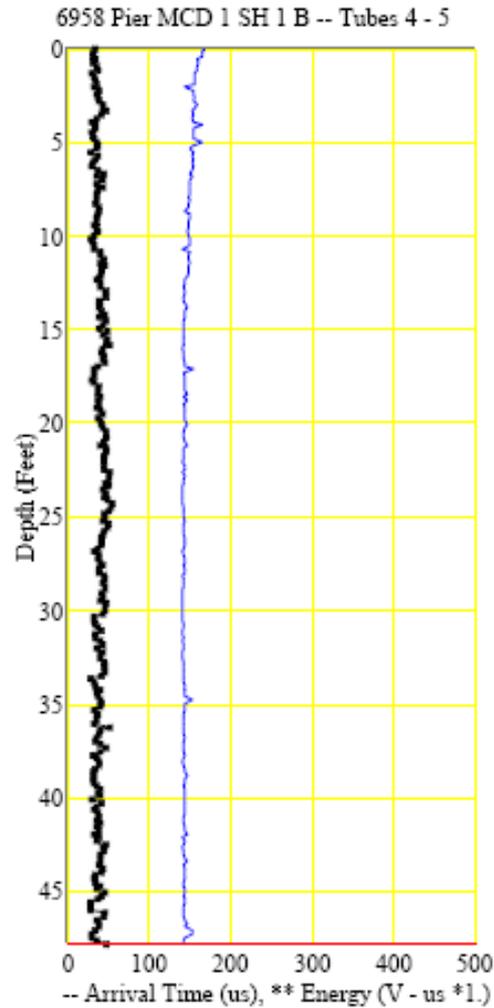
B – Inspection of CSL Access Tubes

C – Engineer's Final Acceptance of Shaft

Nondestructive Testing of Shafts (CSL Testing)

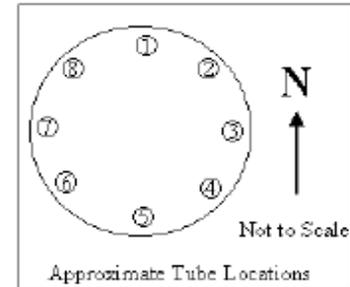
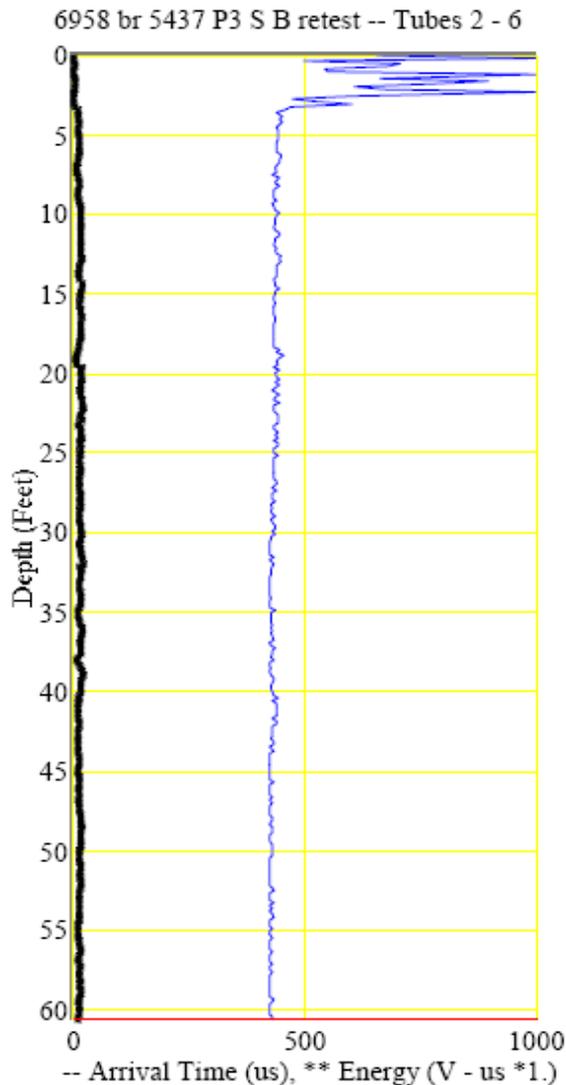


Nondestructive Testing of Shafts (CSL Testing)



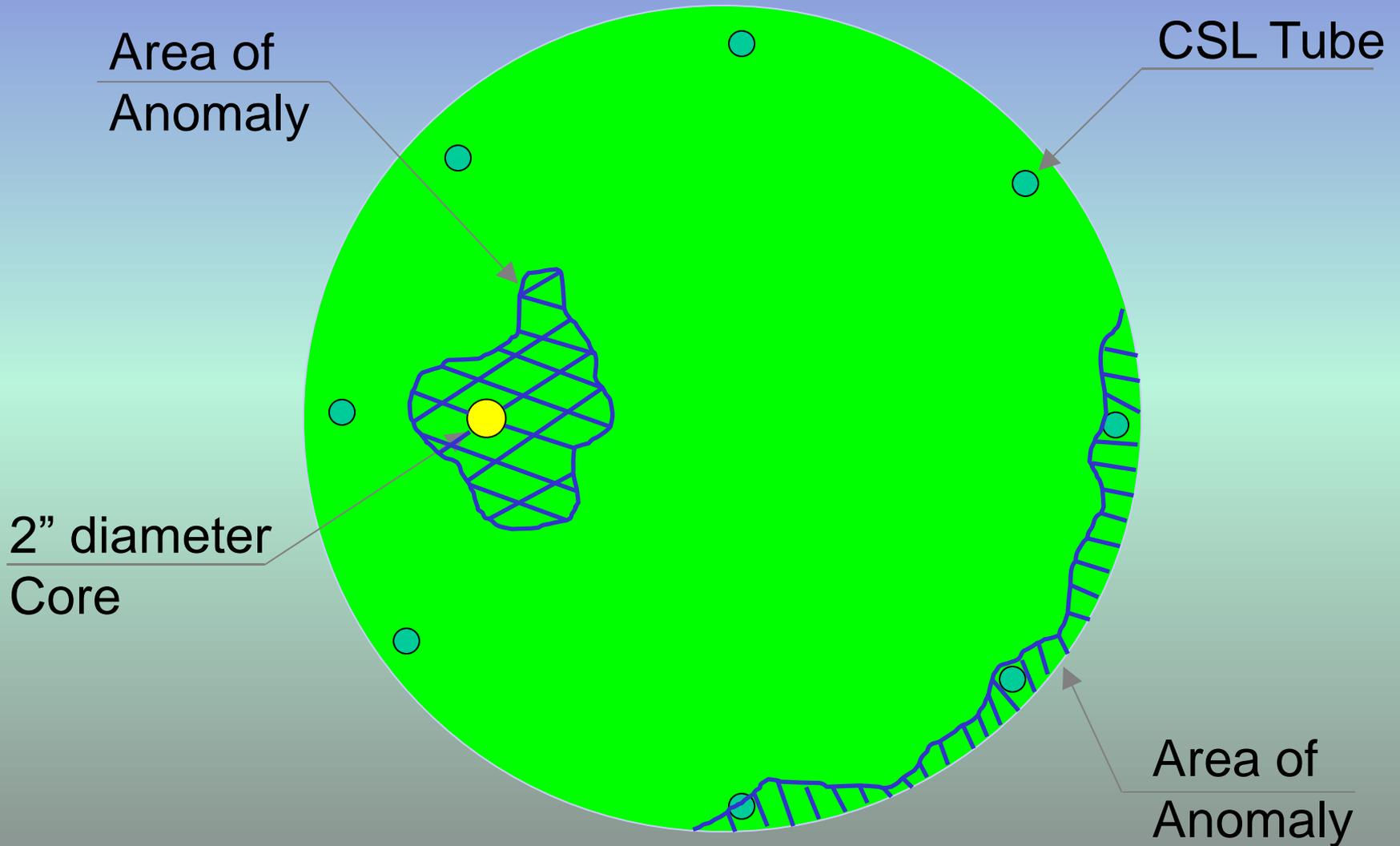
Tube Spacing :	25.50 inches
Signal Gain :	80
Threshold :	1.50
Cursor Depth	47.81 ft
Velocity	14700 ft/sec
First Arrival Time	144 us
Signal Energy	31.42 V-us

Nondestructive Testing of Shafts (CSL Testing)



Tube Spacing :	76.00 inches
Signal Gain :	200
Threshold :	1.50
Cursor Depth	60.61 ft
Velocity	10400 ft/sec
First Arrival Time	604 us
Signal Energy	1.22 V-us

Nondestructive Testing of Shafts (CSL Testing) Example of a Shaft Anomaly



Investigation of Anomalies



Investigation of Anomalies



Documents:

- Standard Specifications
 - Amendments
 - Contract Plans
 - Special Provisions
 - Addendums
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- Summary of Geotechnical Conditions
 - Boring Logs
 - Geotechnical Reports

Questions:

Contact HQ Construction

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 - Marco Foster – 360-705-7824
 - Bob Dyer – 360-705-6980
 - Mike Fleming – 360-705-7830
 - Derek Case – 360-705-7826
 - Dave Jones – 360-705-7832
-
- For geotechnical questions, Mark Frye – 360-709-5469
 - For CSL Testing, Kyle Cauffman – 360-798-4260