Drilled Shaft Construction

MDT Project Case Studies

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Introduction

This document provides some examples of problems that have occurred with drilled shafts on MDT projects and discusses general construction methods that may help avoid recurrence of the problems. It will be updated periodically.

The material presented in this document is for informational purposes only. No warranty, expressed or implied, is included or intended. The Contractor must develop job specific construction methods and is solely responsible for selecting methods that are suitable for the work.

Case Study 1: Concrete Placement Startup and Control of Tremie/Pump Line

Construction Observations:

On this project, a shaft had been excavated to 73' deep and temporary casing was sealed full depth, into decomposed granite formation. Before concrete placement started, the water level within the temporary casing was observed to be about 30 feet deep. Drilled shaft concrete was placed using an 80 foot long rigid pipe attached to a pump hose. It was observed that when concrete pumping began, the water inside the casing churned violently for a short time and then became calm as concrete placement continued.

Concrete was placed until the concrete level was brought to a point 38 feet below ground level.

At that point, the pump hose was disconnected from the rigid pipe to allow the temporary casing to be partially withdrawn. When the pipe was disconnected, concrete fell from the pump hose, creating air pockets within the hose.

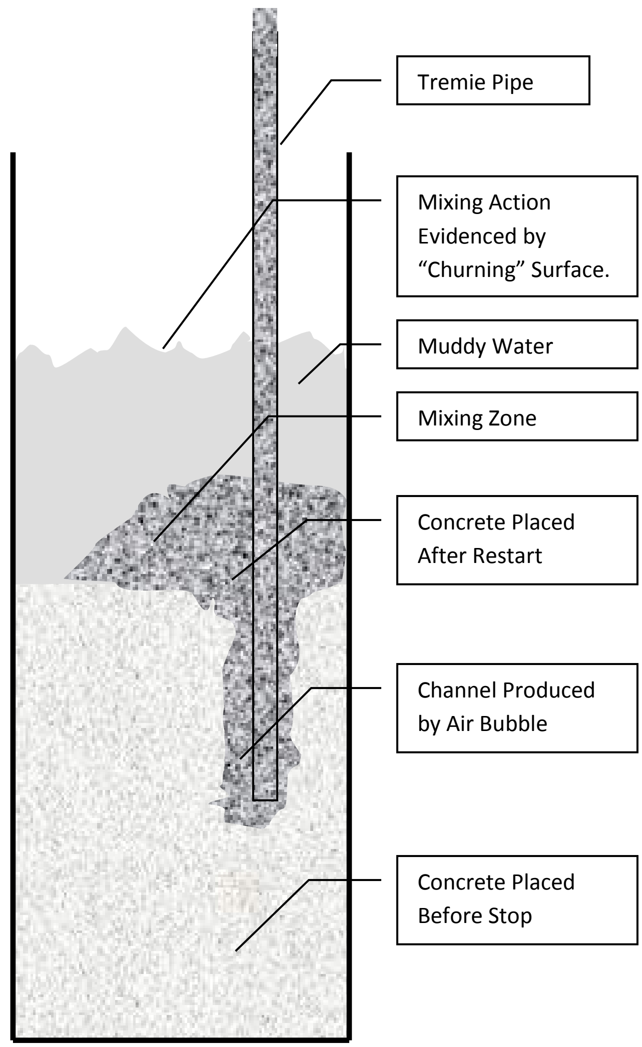
A single clamp vibratory hammer and two cranes were used to withdraw the casing about 10 feet.

The pump line was reconnected to the rigid line and concrete placement resumed. It was observed that again the water churned for some time as air was pushed through the hose and upward through the concrete in the shaft. It appeared that the churning continued for a period much longer than what would have been expected to vent out the air.

Discussion:

It is thought that the expelled air created a path for the newer concrete to travel through, allowing the concrete to bypass the zone of laitance and leave it deposited within the shaft.

This illustration to the right shows what may have happened when the column of air was allowed into the tremie pipe. Crosshole sonic logging did not indicate any problems in this area of the shaft however.



Possible condition shortly after restarting concrete placement

Figure 1. Concrete bypassing laitance.

Crosshole sonic logging did indicate a potential anomalous zone at the shaft bottom. Since the shaft was cased full depth, the most likely source of the anomalous readings was thought to be concrete aggregate. Air in the line and high initial pumping velocity apparently created a churning action that may have washed out concrete aggregate and deposited it at the shaft toe. Since the bottom of the shaft was confined in a granite rock socket, this anomaly was determined to not present a risk to the shaft capacity or durability so coring was not required.

There are several potential lessons learned from this case. They are included below as well as other related recommendations.

- At start of concrete placement, minimize the potential for washout by limiting pumping energy.
- Use a “Concrete Brake”, shown in Figure 1, which assists in the buildup of a head of concrete in the pump boom and reduces the pumping of air into the shaft when using a pump line. A “Concrete Brake” consists of a bladder valve or French horn.
- A cover plate or plug (“pig”), shown in Figures 1 – 3, should be used to minimize contamination of the concrete during the initial placement of concrete underwater. A plug that is too long requires the tremie to be raised too far off the bottom for the plug to clear the tremie. A plug that is too compressible will fail and not perform correctly as a separator. Commercially available foam “pigs” are recommended.
- Maintain a continuous delivery of concrete until a sufficient head of concrete is achieved above the tip of the tremie/pump line during the initial placement of concrete to keep water from flowing into the tremie causing contamination of the concrete.
- Removal of the tremie/pump line before completion of the pour can result in trapped debris or laitance.
- If it is necessary to disconnect the pump hose from the rigid pipe and then reconnect it, install a pig in the top of the rigid line, connect the pump line and bleed any air from within the pump line. A bleeder valve in the top of the rigid line will facilitate this.

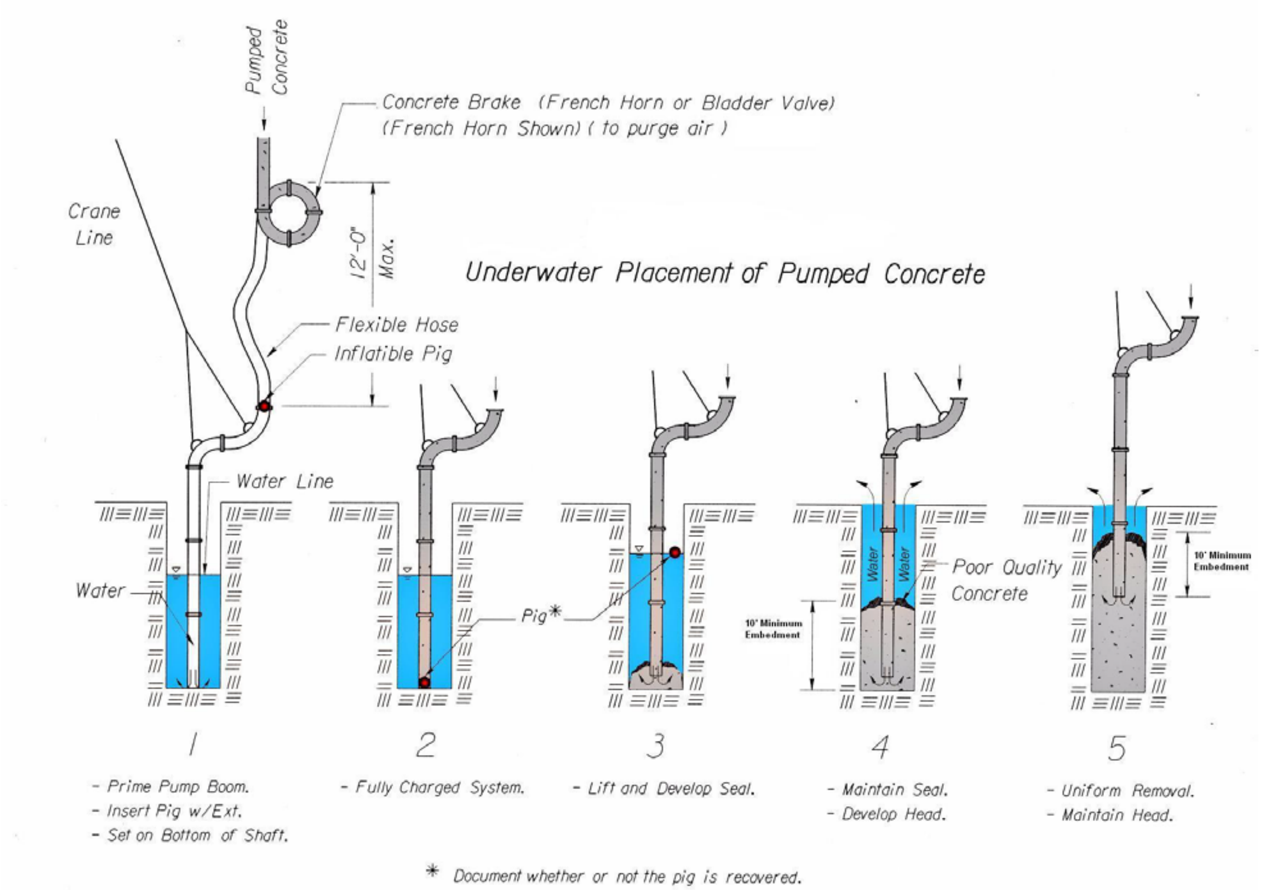


Figure 2. Underwater Placement of Pumped Concrete (KDOT 2008)

Case Study 2: Loss of Slump/Workability During Concrete Placement

Construction Observations:

On this project, concrete placement of the shaft initially began about 12:00 PM. Less than 2 hours into the drilled shaft pour and after placement of 50 cu. yd. of concrete the Contractor attempted to pull the temporary casing. While the casing was being extracted the rebar cage was coming out with the temporary casing. The Contractor used an "oscillator" for extraction of the temporary casing rather than the more conventional "vibratory hammer". The oscillator is capable of pulling one million pounds with a torque of 6,000 ft-lbs to dislodge jammed casings. The Contractor cycled the temporary casing up and down about 3 feet several times to try to free the rebar cage from the casing. The Contractor tried several more times to free the cage including additional weight from the drill rig on the rebar cage and attaching a vibratory hammer to the casing and vibrating 2-3 times for 10 second bursts. Three hours into the pour The Contractor gave up on the pour, cancelled the rest of the concrete and sent the pump truck home. The tremie was removed and the casing (along with the rebar cage) was extracted. The shaft was later excavated again and the foundation was re-constructed.

Discussion:

Loss of workability during the placement can be the result of an improper concrete mix or excessively long placement times. The shaft shown in Figure 3 had to be removed due to loss of workability resulting from of an improper concrete mix.

Figure 3. Excavated Shaft - MDT Photo.

Other problems can also result from loss of workability in the drilled shaft concrete:

- Loss of workability can increase shear resistance between temporary casing and the concrete. The increased shear resistance can cause necking or voids as the temporary casing is removed.
- Loss of workability can create a concrete “vent” during placement allowing laitance to become entrapped. See Figure 1.
- Loss of workability will limit the concretes ability to flow through the reinforcement cage. An illustration of this can be seen in Figure 10. Laitance or soil can become entrapped along the shaft perimeter as the high level of concrete within the cage spills over or through the rebar cage above rebar splice zones and falls down into the space outside the cage.

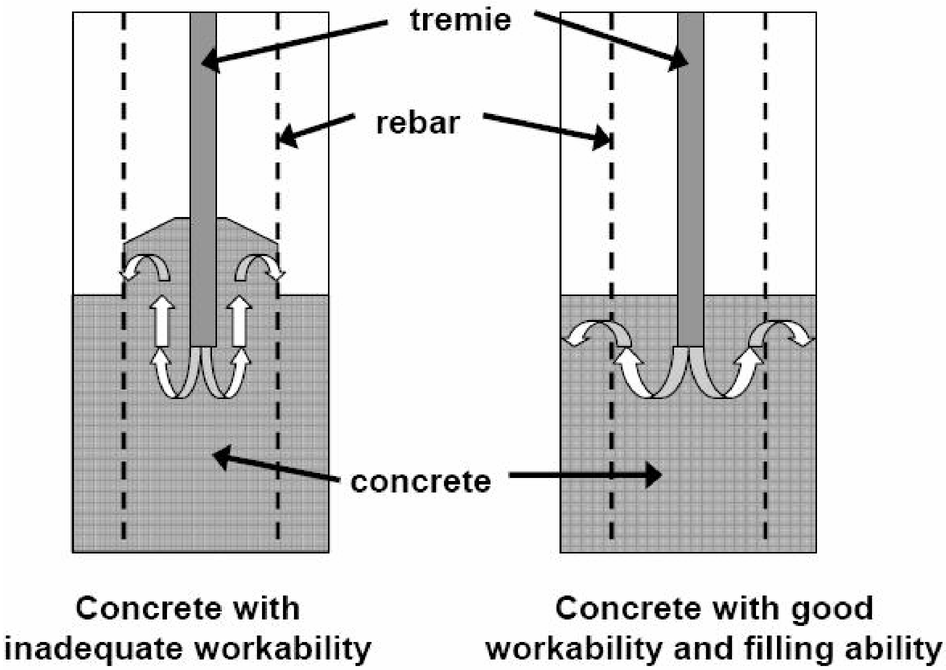


Figure 4. Concrete flow under tremie pipe placement (Brown and Schindler 2007)

Case Study 3: Segregated Concrete

Construction Observations:

On this project, shafts were wet and were specified to be cased with temporary casing to the bottom of the shaft. The temporary casing was “telescoped” using three sections of casing. The respective diameters of the bottom, middle, and top sections of temporary casing were 8 feet, 8.5 feet, and 10 feet. The placement sequence was: Concrete was placed directly into the shaft using a concrete pump with a flexible hose attached to an extension pipe. The pour was periodically stopped to remove sections of the temporary casing. A set retarder dosage was used to allow the concrete to remain workable for 12 hours, the amount of time the Contractor estimated for concrete placement duration. Actual concrete placement time took 17 hours. Concrete was being produced just off site so the haul distance was very short.

Discussion:

Figure 5 shows three dimensional imagery of the drilled shaft with anomalies that were detected by Crosshole Sonic Log testing (CSL). The anomalies were confirmed to be defects when the shaft was later cored, (Figures 6 and 7) and were found to be areas of segregated concrete.

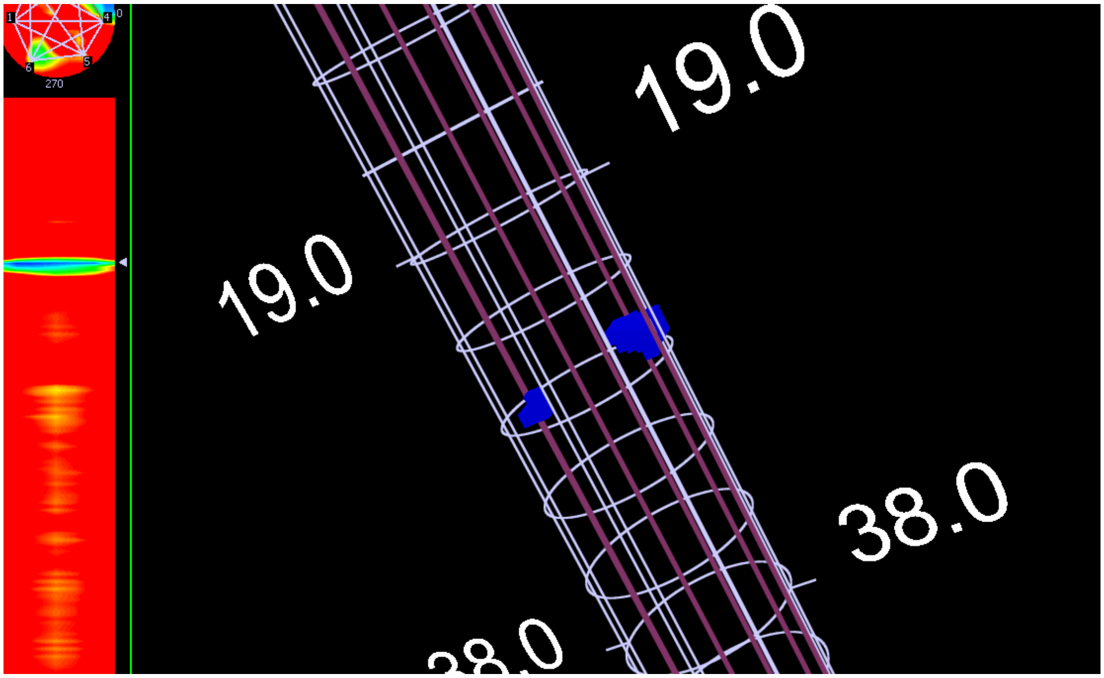


Figure 5. Tomosonic Image of drilled shaft showing anomalies. MDT Image.

Figure 6. Core showing cemented sand without aggregate. MDT photo.

Figure 7. Image from within core shows cemented sand above weakly cemented aggregate. MDT photo.

The defective area of the shaft was cleaned out using high pressure water jetting then repaired by grouting.

Case Study 4: Failure to Prevent Intrusion of Unstable Soils

Construction Observations:

Shafts were wet and were specified to be cased with temporary casing to at least 2 feet into siltstone. The Contractor had difficulty sealing the temporary casing into the siltstone which became apparent as depth measurements were made intermittently during excavation. Rather than drive the casing further into the rock, the Contractor elected to add water to the shaft in an effort to increase the positive hydrostatic head within. The typical placement sequence was reported to be: Concrete was placed using a tremie, filling the entire shaft. Then, the casings were withdrawn to within a few feet of the surface. An additional 6 feet or so of concrete was then placed by tremie into the shaft. The casing was then removed.

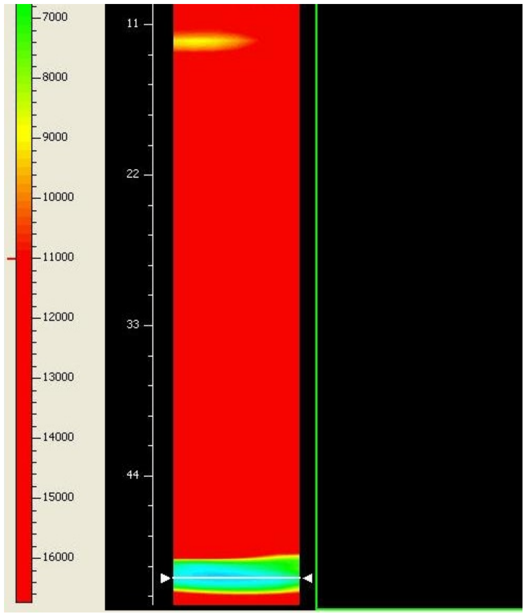


Figure 8. Tomosonic Image of Anomaly at Shaft Bottom. Coring confirmed sand filled toe ranging from 1-2 feet thick.

Discussion:

It is not unusual for a Contractor to perform a “final cleanout”, immediately sound the bottom of the shaft with a weighted tape to verify the hole is sufficiently clean and then proceed to place the rebar cage and start concrete placement. It is possible that flowing sand or other material may be slowly intruding into an excavation and could build up during the time it takes to place the rebar cage, cut away excess rebar, add cage spacers, connect tremie, etc. It is recommended that the hole be inspected multiple times after cleanout to verify that the hole has remained clean between the time cleanout was performed and concrete placement is started.

Other than the cleanout buckets, other non-rotary tools may be very useful for removing cuttings and debris from the base of the shaft. Most common is some type of pump to lift cuttings for removal such as an air lift or a hydraulic lift. Hydraulic pumps are more controllable than the airlift system in that the volume and velocity of pumping can be regulated more easily. Airlifts tend to remove larger particles than pumps. Note that while pumping systems are probably the most effective means of removing loose cuttings or debris from the base of a wet hole, the aggressive use of these tools in cohesionless soils can advance the shaft excavation. The effectiveness of shaft base cleanout tools and techniques in wet holes can best be evaluated using a down-hole camera. It may be necessary to circulate clean water into the hole to improve visibility.[1]

Case Study 5: Failure to Prevent Intrusion of Unstable Soils II

Construction Observations:

Temporary casing was specified to be socketed into the sandstone formation and was withdrawn during concrete placement. The Contractor submitted a drilled shaft construction plan which was approved by MDT. However, the contractor deviated from the plan and/or specifications in several ways:

- Telescoping casings were used instead of a single temporary casing as originally planned.

[1] Adapted from NHI Drilled Shafts: Construction Procedures and LRFD Design Methods, Publication No. FHWA-NHI-10-016.

- The Contractor partially dewatered the shaft just before placing concrete.
- The tremie pipe in the shaft was removed and later reinserted in order to top off the concrete.

CSL testing indicated anomalous areas at the toe of several shafts on this project. Coring confirmed the presence of silt in the lower 1 foot (approx.) of the shafts. Shafts were repaired using a core, flush and grout procedure.

Discussion:

Note the level of water between the two casings in the photo below is higher than the water level inside the inner casing. Before starting the concrete placement, the Contractor pumped water from within the inner temporary casing. Dewatering in this manner created a differential pressure head with positive pressure outside the casing. This probably led to intrusion of silt under the casing. Rather than dewater the inner casing, the Contractor could have added water to maintain a positive pressure head within.

Figure 9. Dewatering inside casing creates adverse pressure head.

When this was observed by MDT, the Contractor was made aware of the concern. The Contractor chose to move the pump intake to the space between the casings and continued placing concrete.

While pulling the casing, a positive head of concrete was not maintained within the casing which created another opportunity for soil or water intrusion into the shaft. In addition, there was an inadequate volume of concrete within the casing to displace any laitance and the surface water:

The Contractor pumped off the excess water, reinserted the tremie pipe and placed the remainder of the concrete.

Recommendations:

- Clean out tools and drilling tools should allow fluid to pass through or around the tool during extraction, and the tool must be extracted slowly to prevent the development of suction pressure beneath the tool.
- Adding water to wet shafts to maintain a higher fluid head within the shaft can assist in preventing soil or water intrusion.
- Ensure there is an adequate level of concrete within a temporary casing when it is being removed so that it will displace contaminated concrete and surface water.
- Provide an overflow trench or basin to allow the excess concrete and water to drain away from the shaft location.

Case Study 6: Lifting of Reinforcement Cage

Construction Observations:

This reinforcing cage collapsed under its own weight when being picked by a crane.

Figure 10. Reinforcing cage collapse. MDT photo.

The method for bracing and lifting the reinforcement cage must be carefully planned in order to prevent collapse or permanent distortion of the cage.

Case Study 7: Failure of Tremie Pipe Coupling

In the photo below, workers are assembling the concrete placement tube which consisted of several 3.1 meter long segments of 150mm diameter steel pipe, coupled together with quick release couplers.

Figure 11 Assembling Concrete Placement Tube

Concrete placement started about 1:30 PM. At 3:30 PM, while concrete was still being placed, it became apparent that one of the couplings in the placement tube had failed which had allowed some volume of concrete to be dropped through the standing water within the shaft. The contractor stopped placement and dewatered the shaft in an attempt to retrieve the disconnected section of pipe. This was unsuccessful and the contractor finally decided to abort the placement and attempt to remove the reinforcing cage. Even though the concrete had not taken set, the contractor was unable to hoist the cage.

Figure 12 Attempting to Dewater and Retrieve Pipe

Over the course of several days, the contractor excavated the concrete and removed the reinforcing cage. The cage was destroyed during removal so a new cage was ordered with an additional 1.2 m of length in case additional excavation (depth) would be required by MDT.

Figure 13 Destroyed Reinforcing Cage

Figure 14 Twisted Rebar, CSL pipe, and Tremie Tube

After discussions between the project design consultant and the geotechnical sub-consultant, it was determined that the shaft depth would have to be increased by 650mm and the diameter would have to be over-reamed by at least 100mm. The over-reaming was required because of concern that the shaft sides, the claystone layer in particular, may have softened due to long term exposure to water. The contractor fabricated a folding reaming tooth and added it to the drill tool. This allowed the reamer to fit through the upper cased portion of the shaft and then expand to widen the excavation through the claystone layer.

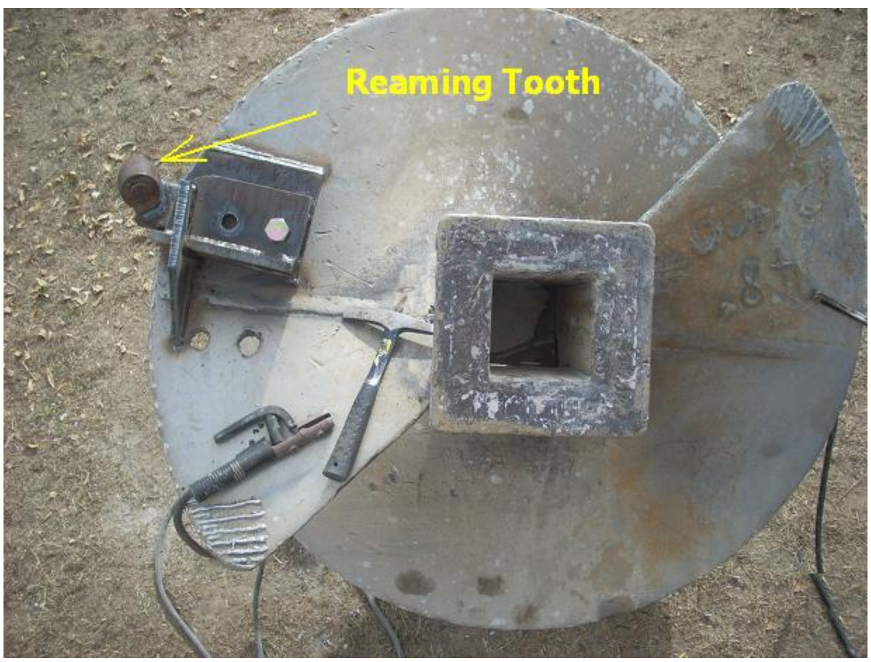


Figure 15 Drilling Tool Modification

Recommendation:

Use bolted couplers or welded connections for joining sections of tremie pipe.

Case Study 8: Failure to Prevent Intrusion of Unstable Soils III

Crosshole Sonic Logging (CSL) testing was performed on each bent. Anomalies were indicated in the test results for Bents 1, 4 and 5. Each of these drilled shafts was cored to determine if defects were present. In December, 2012, two full depth cores were taken at Bent 1. Approximately 6 inches of sand was found at the bottom of one core but this was determined by MDT to not be significant enough to reduce the capacity of the foundation so the Bent 1 shaft was accepted.

Four cores were taken to full depth at Bent 4. Substantial defects, consisting of sand pockets were located at depths of approximately 42’, 52’ and 58’.

The contractor also cored Bent 5. The first two core holes did not find any significant defects. The contractor was then required to remove the fluid from the CSL tubes and drill holes in the steel caps that seal the tube bottoms. The contractor was reluctant to drill beyond the bottom of the caps. Based on before and after measurements, it was not certain whether or not each tube bottom had been penetrated. A continuity tester was made by connecting 100’ of wire (an extension cord) to a 12 inch steel spike. The sides and head of the spike were insulated with tape so that only the tip of the spike was exposed to contact when inserted into the CSL pipe. By dropping the probe to the bottom of the CSL tube and checking electrical continuity between the probe and the tube at ground level, it was possible to determine which tubes had not been drilled out. Two tubes required additional drilling.

Continuity Probe and Multimeter

Measurements taken after drilling found that sand had entered several of the tubes. Two of the tubes had as much as 10 feet of sand. In addition water was applied at low pressure to each of the tubes, in turn, to see what the effects would be. Tubes 5 and 7 produced water when water was applied to tube 6 indicating connectivity there. By comparing the static water level outside the permanent casing and the water level in the tubes after some time, it was thought that there was likely connectivity between the void and the groundwater. All of this information was taken to indicate that a defect was likely present around the perimeter of the base of the shaft so two more cores were drilled. Sand pockets were found at a depth of approximately 52’ and at the shaft bottom. Dave Cunningham of MDT Geotech was on site for several days assisting the project staff with logging the cores.

Core and Recovered Sand from the Bent 5 Shaft

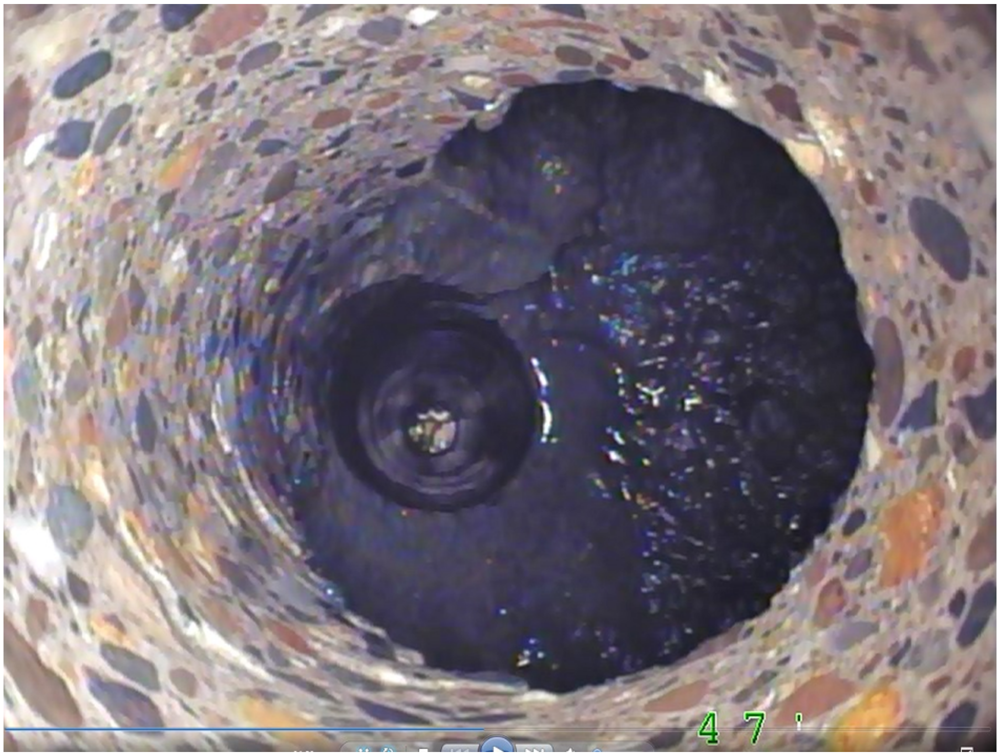
The contractor elected to repair the bent 5 shaft first. They submitted a flush and grout repair procedure that was used on a previous project along with a grout mix design. After some MDT comment and information requests, a revised plan was ultimately accepted by MDT.

The contractor was able to effectively flush the sand from the shaft using compressed air. An air line was inserted down into the hole and when air was applied, groundwater along with sand was blown out. Connectivity was observed between the core holes and the CSL tubes, indicating that the void system was interconnected and relatively extensive.

Flushing Sand from the Bent 5 Shaft

Flushing Sand from the Bent 5 Shaft

The Contractor hired a plumber with a sewer camera to inspect the core holes. The photo below is taken from a video clip of the inspection of one core hole and shows a substantial void in the shaft concrete at a depth below 47 feet. Note that the diameter of the core hole is approximately 3.5 inches.



It was not possible to view the defect at the shaft bottom due to the presence of water there.

The Bent 5 shaft was repaired on 4/2/2013. The general procedure was as follows: (condensed)

1. Flush sand from holes while adding water to maintain a positive or neutral head of water within the voids/holes.

2. Insert tube into lowest part of the void system and pump grout in, displacing water upward.

3. When any tube or core hole starts producing grout, cap that hole to force the grout to fill the other areas.

4. After all tubes/holes are filled, cap them and pressurize the system for 10 minutes.

Based on grout flow measurements it was estimated that approximately 1.9 cubic yards of grout was used in total. The estimated volume needed to fill the tubes and core holes was calculated to be .55 cubic yards. Based on this approximately 1.36 cubic yards went to fill void spaces with some potentially lost to the surrounding soil.

Grout Repair of Bent 5 Shaft

4/10/2013: A similar procedure was used for repair of the Bent 4 shaft. However, using compressed air to clean the voids was not effective for this shaft due to inflow of new sand. Flushing the voids with water while maintaining a full head of water within the void system appeared to be effective at removing much of the sand. The Bent 4 shaft required approximately 6 cubic yards of grout and the grouting process took approximately 6 hours to complete.

Flushing Sand from Voids with Water

The photo below shows CSL tubes capped with plumbing fittings and core holes having short threaded steel pipes grouted in place to facilitate capping and pressurizing.

Top of the Bent 4 Drilled Shaft

Mixing Grout on Site with Portable Mixing Plant

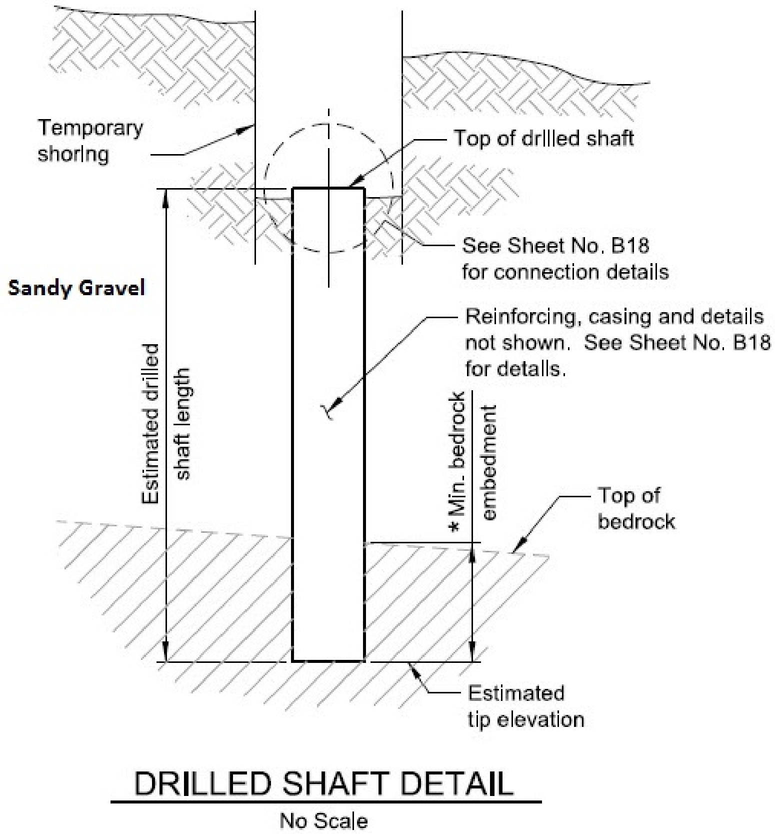
Grout was mixed on site. The mixture used consisted of cement, water, set retarder and a shrink reducing admixture.

Recommendations:

- **Be certain that unstable soils are prevented from entering the excavation.**
- **For defects occurring at the shaft bottom, consider drilling out CSL tubes bottoms to use as cleaning and grouting ports. This was very effective on this project.**
- **When grouting defects, the pneumatic packers were found to be unreliable. It is recommended that threaded steel nipples be grouted into each core hole that will be used in the repair process.**

Case Study 8: Failure to Prevent Intrusion of Unstable Soils IV

This bridge had four drilled shafts that were fully cased with permanent casing.



Shafts were wet, although cleanout resulted in substantial lowering of the water level within the shaft. The contractor had no means of adding water to the shafts to maintain a positive hydrostatic head within the shafts.

MDT inspectors checked cleanout on all shafts using a split spoon sampler, tied to a rope and dropped at 4 locations around the shaft bottoms. The spoon did not recover any material when dropped.

Shaft 4 was sounded a second time, after the reinforcing cage was placed, and it was determined that the bottom was no longer clean. The contractor removed the cage and performed additional cleanout. The presence of sand was observed on the bottom hoop of the cage, indicating sand was present in the excavation to a depth of at least 8 inches.

Figure 16 Bottom of Cleanout Bucket.

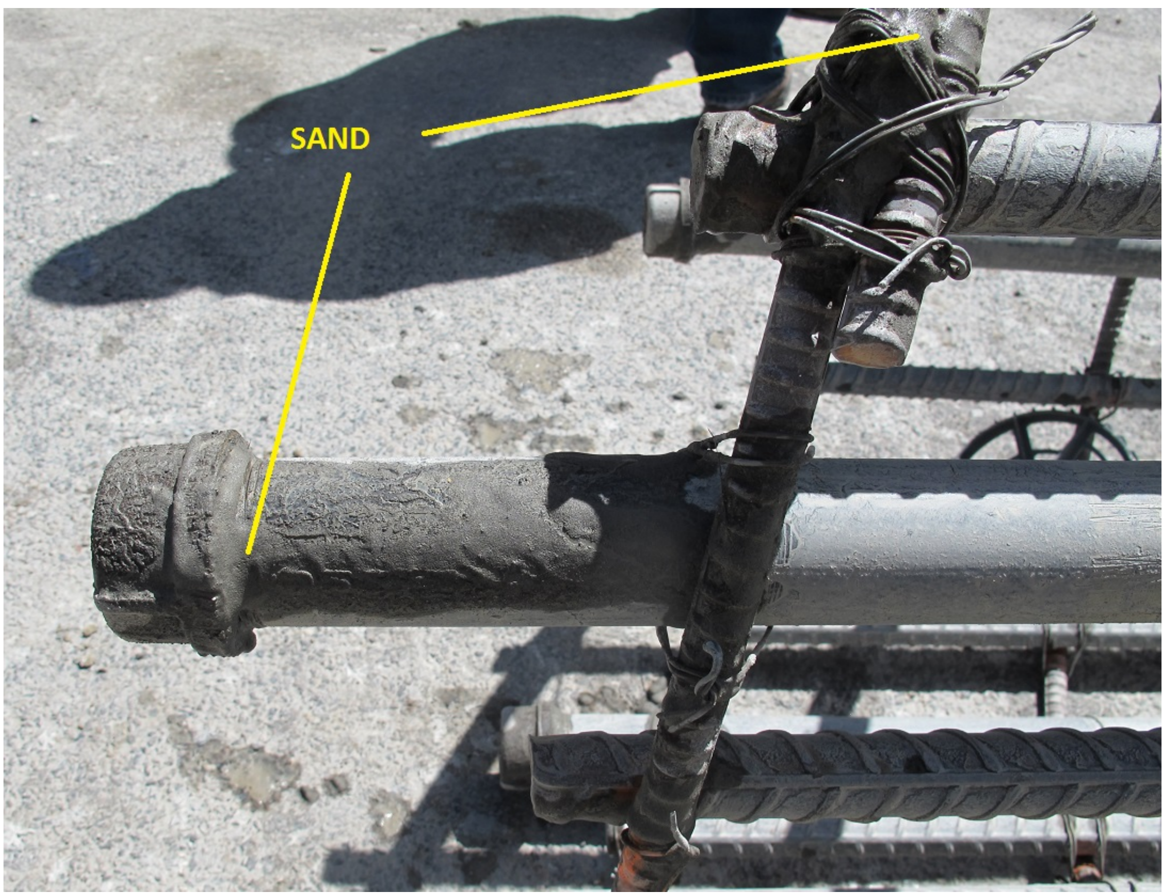


Figure 17 Shaft 4 Reinforcing Cage / CSL Tube

After additional cleanout the excavation was sounded again and thought to be clean. The cage was replaced and concrete was cast.

CSL testing of the cured concrete indicated a soft toe for two of the shafts. The approved investigation plan involved puncturing the bottoms of the CSL tubes and air lifting/pumping water to check for the presence of soil materials and to determine if there was communication between tubes (water flowing in one tube and coming out of another.)

The contractor tried drilling and then puncturing the CSL tube caps. It was found that puncturing the caps with a spear type device was by far more effective than drilling.

Figure 18 Spear Tool with Rod Extensions

After the presence of sand/gravel was confirmed, the contractor used air lifting to flush the void clean. The illustration below shows a typical system. Note that this system has been used on several repairs and is has proven to be a very durable and effective system for removing loose material from within a drilled shaft. Plumbing fittings are arranged to allow the operator to alternately inject water and compressed air into the shaft at the toe. The PEX pipe is easily inserted to the shaft bottom in a core hole or a punctured CSL pipe. To operate, the tube is initially filled with water (water valve open, air valve closed). Next, the water valve is closed and the air valve is opened. A burst of compressed air lifts out loose material that is small enough to exit the annular space between the CSL pipe and PEX pipe. The process is repeated many times in each hole until the void is sufficiently clean. Note that the PEX line must be secured to the CSL tube or rebar cage prior to pressurizing with air. An effective method for doing this involves taping the end of a rope to the PEX pipe at approximately 2 feet above the top of the CSL tube, adding several half hitches, and tying the rope to a fixed object. If the distance between the last half hitch and the top of the CSL pipe is more than about 6 inches, the PEX pipe can be ejected from the hole when it is pressurized creating a hazard for workers or traffic.

In some cases, ground water will naturally refill the pipe which eliminates the need for the operator to refill.

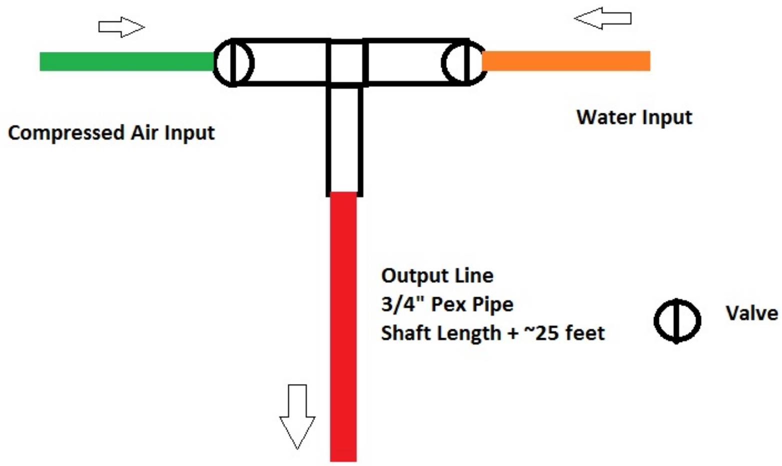


Figure 19 PEX Pipe Tied in Place with Rope (photo from a different project)

Figure 20 Air Lifting to Clean Out Shaft Toe

Injecting water into one location, while airlifting from another, was also found to be an effective technique for cleaning the defective areas. Eventually, it was possible to pump water into one tube and observe water free flowing from the other tubes.

After cleanout, the shafts were repaired using a replacement grouting process.

Recommendation:

- Many times contractors have attempted to use rigid steel pipe for flushing out shaft defects. These require lifting with a crane they often break. PEX pipe has proven to be much more durable and can be inserted and removed from a hole easily by one person.

References/Resources:

Kansas Department of Transportation, 2008. Bridge Construction Manual. 5.4-Drilled Shafts, http://www.ksdot.org/burdesign/bridge/constructionmanual/drilledshafts.pdf

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