Texas Department of Transportation

Construction & Materials Tips

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Underwater Drilled Shaft Construction

Because they can be installed in virtually any soil type, can support large axial and lateral loads on a single member, and provide the most economical foundation type for most situations, drilled shafts are the most commonly used bridge foundation by TxDOT.

On many projects, excavation of drilled shafts encounters no soft soils or groundwater. In these shafts, concrete is placed "in the dry"—that is without the need to displace water or drilling slurry. Placing concrete in this type of shaft is similar to placing concrete in a column form, and it does not require specialized methods or equipment.

However, a considerable number of drilled shafts placed in the state each year either require drilling slurry to stabilize the excavation or encounter enough groundwater that the shaft excavation cannot be dewatered. For these shafts, the concrete is placed using "slurry displacement" or "underwater placement." These shafts require specific methods and equipment.

Slurry. Drilling slurry stabilizes the drilled shaft excavation in soft soils or when groundwater is present. The most common drilling slurry is mineral slurry consisting of commercial bentonite clay mixed with water. Mineral slurry offers a combination of higher-than-water specific gravity to offset hydrostatic pressure, and it deposits clay particles on the excavation walls ("filter cake") to help stabilize them. During excavation, the main function of the slurry is to maintain hole stability. During placement of the concrete, however, the slurry must displace cleanly from the hole and not leave the reinforcing steel or sides of the hole coated. This is the reason for the slurry testing requirements in Item 416, "Drilled Shaft Foundations." Before placement of the concrete, slurry should be sampled from the bottom of the hole with a device known as a "thief." Then the slurry is tested for specific gravity, viscosity, and sand content in accordance with Test Method Tex-130-E. These three tests show the amount of suspended soil particles in the slurry and how easily the slurry will be displaced during the concrete pour. Determining the amount of suspended solids is important as these materials will thicken the slurry and may actually settle out of it before and during the concrete pour. Excessive amounts of particles, especially sand, can leave deposits against the sides and bottom of the shaft and along the reinforcing steel.

If slurry sampled from the bottom of the hole does not meet specification requirements, the contractor should pump slurry from the bottom of the hole, replacing it with fresh slurry introduced at the top, until the slurry meets the requirements. Although Item 416 currently gives the engineer discretion to accept slurry with specific gravity or sand content limits exceeding specified limits, this discretion should be exercised with caution. The 2004 standard specification will not contain this clause and will reduce the allowable sand content to 6%.

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Information on obtaining slurry samplers and test equipment may be obtained from the Bridge Division Geotechnical Branch.

Polymer Slurry. Use of polymer slurry has increased in recent years. Although it offers advantages over mineral slurry in specific situations, it does not offer the same stabilizing properties in many others. For instance, polymer slurry has a slightly lower specific gravity than water and, therefore, does not have the same ability to offset hydrostatic pressure as mineral slurry. After allowing polymer slurry for several years, TxDOT has seen settlement of several bridge structures founded on drilled shafts that used polymer slurry. On these projects, polymer slurry was used in conditions incompatible with the slurry, leading to severe soil disturbance and defects within the shafts. TxDOT now has a moratorium on the use of polymer slurry in drilled shaft construction—reference Special Provision 416-008 (1993) and 416-004 (1995)—and is setting up a task force with industry representatives to re-evaluate polymer slurry requirements and usage.

Concrete Placement. Three issues are critical to the placement of concrete under water or slurry:

- A delivery method must be used that keeps the concrete separated from the water or slurry and prevents intermixing.
- The concrete must maintain a high slump to completely fill the shaft and flow easily around the reinforcing steel.
- The top of the shaft must be thoroughly flushed at completion of the pour.

Delivery. Concrete placed underwater or slurry must be placed through a closed, sealed tremie or with a pump. A tremie is a smooth steel pipe, usually 10 to 12 inches in diameter, with a hopper on top into which concrete is deposited. Concrete is discharged out the bottom of the tremie pipe. At the start of the pour, some means must be provided to separate the concrete from the water or slurry. Most commonly, the open tremie is inserted to the bottom of the excavation and allowed to fill with water or slurry. A foam rubber plug, usually referred to as a “pig,” is placed in the top of the tremie pipe before the hopper is filled with concrete. As concrete enters the tremie pipe, the pig slides down, separating the concrete from the water or slurry. Once the tremie pipe and hopper are full of concrete, lifting the tremie slightly allows the pig to be expelled, and concrete begins flowing into the shaft. Concrete with the correct slump will often flow up the sides of the tremie a considerable distance (10 to 20 feet) while the hopper is recharged with concrete as needed. Once flow slows or stops, the tremie is lifted to restart the flow. It is critically important that the tremie remain well embedded in the concrete. Five feet of embedment should be maintained as a minimum at all times. The inspector should check this using a weighted tape to determine the level of concrete within the shaft and then calculating tremie embedment based on the measured length of the tremie. Failure to maintain tremie embedment will trap the soil cuttings, sediment, and washed-out concrete in the shaft. In a correct pour, these materials remain on top of the concrete and are flushed off at the top of the shaft at the end of the pour.

Pumped concrete is placed in a similar manner. The concrete and water must be prevented from mixing at the start of the pour, and a foam rubber plug is often used in the pump line as a separator. Additionally, embedment of the pump line into the concrete is critical throughout the pour.

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Concrete Slump. Using a high-slump concrete and maintaining slump during the pour are keys to a quality drilled shaft. Item 421, "Portland Cement Concrete," currently calls for all drilled shaft concrete to have a desired slump of 6 inches with a maximum slump of 7 inches. For underwater placement of drilled shafts, the slump should be too high rather than too low: low slump concrete will not flow out through the tremie and around reinforcing steel in the manner necessary to achieve a quality shaft. Many exposed shafts poured with low slump concrete have honeycombing outside the reinforcing steel cage, or in some cases they have no concrete at all. The Drilled Shaft specification in the 2004 *Standard Specifications* will present separate requirements for shafts placed under water or slurry. The desired slump will be 8 inches, with a maximum of 9 inches.

Retention of slump throughout the concrete pour is also important. Adequate retarder must be included in the concrete to retain workable slump throughout the duration of the pour. Inadequate retardation will cause the upper portion of the concrete to stiffen as it begins to set during the pour. If this occurs, the tremie must be raised very near the surface (or out) of the concrete to restore flow. When this happens, the concrete actually flows up alongside the tremie and over the top of the stiffened concrete, including cuttings, sediment, and diluted concrete. This may happen several times during a lengthy pour if slump is not maintained. The Construction Division's Materials and Pavements Section is developing a Slump Loss Test (Tex-430-A) that will be used to generate a slump vs. time curve for drilled shaft concrete mix designs. Concrete used for underwater pours will be required to maintain a 4-inch slump for the duration of concrete placement, including extraction of casing if used. Testing for concrete slump loss will be required in the 2004 Drilled Shaft specification.

Completing the Pour. During an underwater pour, cuttings, sediments, and diluted concrete are carried on top of the concrete column as it is being placed. As the pour is completed, all loose material and contaminated concrete must be flushed off the top of the shaft. In some cases a cubic yard or more of concrete will be wasted to assure that all contaminated material is removed. The top of the shaft should be strongly flushed while concrete is being placed through the tremie or pump at the same rate as the rest of the pour. Attempting to dip or shovel this material off the shaft often leaves behind inclusions and low quality concrete. ****

Selection and Use of Proprietary Repair Materials for Structural Concrete

Selection of Materials

Consider several material properties when selecting or reviewing a particular repair product. These include strength, permeability, adhesion (bond), corrosion resistance, and application method. Base selection of a repair material on its intended purpose. Repairs that will carry loads, such as bearing repairs, need a higher strength. Repairs for protection of reinforcing steel, such as restoring concrete cover, don't necessarily need high strength, but they should have adequate bond and lower permeability. The key to selecting an appropriate repair material is to understand its purpose in the repair.

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Many products are capable of obtaining very high strengths, some at a very early age. Strength is often the best selling point for various products. In general, the higher the early strength gain, the lower the service life of the repair. This is because the ingredients used to obtain high early strength (lots of Type III cement, accelerators, water-reducing agents, etc.) can result in repair concrete with a higher potential for shrinkage cracking and more brittle than the concrete it is repairing. Use a material with strength appropriate for the type of repair.

Some products produce very dense, low permeability patches suitable for repairs in marine environments or where exposure to salt is high. Other products contain corrosion inhibiting admixtures that can reduce corrosion of steel in the new concrete. Without additional mitigation measures, these products often accelerate corrosion in the surrounding original concrete (referred to as "patch-accelerated corrosion" or "halo effect"). Adhesion is also an important property to ensure that the repair material will adhere to the original concrete. Keep in mind that adhesion is most affected by the quality of the original concrete. No repair product, no matter how well made, will adhere to an unsound substrate.

Application method is another key factor to consider. Repair products can be applied by several methods: forming and pouring, pressure grouting, troweling, or pneumatic methods (shotcrete).

The 2004 specification for Concrete Structure Repair (Item 429) refers to a new "DMS-4655, Rapid-Hardening Cementing Materials for Concrete Repair." This document, which will be online, will list pre-reviewed repair products by application: vertical or overhead, horizontal applications such as decks, and pneumatic methods. The list will not be comprehensive but can be used as a guide to review products not on the list.

Material Application

Most if not all proprietary repair products have specific mixing and placing requirements. These are usually printed on the bag but can come as a separate sheet of instructions. Follow these instructions exactly as stated. Even slight deviations can result in poor performance of the repair. The instructions will also identify limitations on the use of the product. TxDOT encourages major suppliers of repair products to provide their instructions in English and Spanish.

Surface preparation is the most important step in the repair process. Failure to remove all unsound concrete will result in a repair that will not perform as desired. The American Concrete Institute (ACI) and the International Concrete Repair Institute (ICRI) both have excellent references for evaluating the quality of the prepared substrate. The ICRI also has surface profile cards for evaluating surface roughness.

Need More Information?

Contact the Bridge Division's Construction and Maintenance Branch at 512-416-2232 (or check the soon-to-be online *Bridge Maintenance Manual*) for information on repair products and their application. Engineers in this branch are experienced in concrete repairs and familiar with most of the repair products on the market. They have a copy of the ACI/ICRI Concrete Repair Manual, the ICRI Surface Profile Cards and many other references.****