

CHAPTER

9 Slurry Displacement Piles

9.1 Introduction

A slurry displacement pile is a Cast-In-Drilled-Hole (CIDH) pile where a drilling fluid is introduced into the excavation concurrently with the drilling operation. The drilling fluid, also referred to as slurry or drilling slurry, is used to prevent caving of unstable ground formations and intrusion of groundwater into the drilled hole. The drilling slurry remains in the drilled hole until it is displaced by concrete, which is placed under the drilling slurry through a rigid delivery tube.

Because the slurry displacement method, also referred to as the wet method, is a specific construction method for the construction of CIDH piles, the reader is advised to review Chapter 6, *Cast-In-Drilled-Hole Piles*, as it contains information about inspection duties and responsibilities of the Engineer for construction of all CIDH piles. This chapter contains modifications to inspection duties and responsibilities of the Engineer necessary for the construction of CIDH piles using the slurry displacement method.

9.1.1 History

The use of drilling slurry is commonly associated with methods used by the oil well drilling industry for more than 100 years, which provided much of the technical and practical knowledge concerning their use in drilled foundation applications. Use of the slurry displacement method for constructing drilled shafts began in Texas in the years following World War II. This early method involved the use of soil-based drilling slurries to advance drilled holes deeper than they could have without, after which a casing was used to stabilize the drilled hole for shaft construction. In the 1960's, processed clay mineral slurry was introduced as a means of eliminating the need for casing to stabilize the drilled hole. However, the properties of the mineral drilling slurries were not controlled. Initial information on the properties of mineral drilling slurries was obtained from the Reese and Touma Research Report, which was a cooperative research program conducted in 1972 by the University of Texas at Austin and the Texas Highway Department. Due to the numerous failures that occurred, in the mid-1970's more attention was paid to the physical properties of mineral drilling slurries and appropriate methods of preparing and recirculating drilling slurries.

There are still many unknowns about the use of drilling slurries, among them the effect of the drilling slurry on the ability of a pile shaft to develop skin friction. Research on the use of mineral slurry has indicated potentially adverse effects of mineral slurry on drilled

shaft side resistance; however, this impact can be avoided by following proper construction procedures. On the other hand, research has also shown that development of side resistance does not appear to be a problem with the use of synthetic slurry, with the possible exception of hard rock where the sides of the drilled hole are smooth. The design method used by Caltrans for determining the pile capacity adequately accounts for possible loss of pile capacity when drilling slurry is used. Research funded in part by the Federal Highway Administration (FHWA) is ongoing at universities around the United States. Caltrans has also conducted research on several contracts in recent years, which lead to the development and continual improvement of contract specifications for use of the slurry displacement method of CIDH pile construction.

Processed clay mineral slurries are considered environmentally hazardous and are difficult to dispose of. In the 1980's, the drilled shaft industry began a trend towards the use of synthetic drilling slurries. These drilling slurries are less hazardous to the environment and are easier to dispose of.

Caltrans first used the slurry displacement method on a construction contract in 1984 and has increasingly used this method since then. A change in Caltrans seismic design philosophy has resulted in the use of more and larger CIDH piles. Because of this, ground conditions have become less of a factor in the pile type-selection process. Other factors such as lower construction costs and construction in urban environments with restricted access and noise limitations have also led towards the expanded use of CIDH piles. Because of these factors, Caltrans started inserting the slurry-displacement method specifications into all contracts with CIDH piles in 1994.

9-2 Slurry Displacement Method

The slurry displacement method of construction is similar to that of ordinary CIDH pile construction until groundwater or caving materials are encountered. When groundwater or caving materials are encountered during the drilling operation, the Contractor must have a plan in place to decide whether to use a casing to stabilize the drilled hole, dewater the drilled hole, or drill the hole and place concrete under wet conditions using the slurry displacement method. In most cases, the site conditions are known to be wet or unstable. These conditions should have been shown on the *Log of Test Borings (LOTB)* or in the *Foundation Report*. Sometimes experience on adjacent projects may also give an indication of the site conditions.

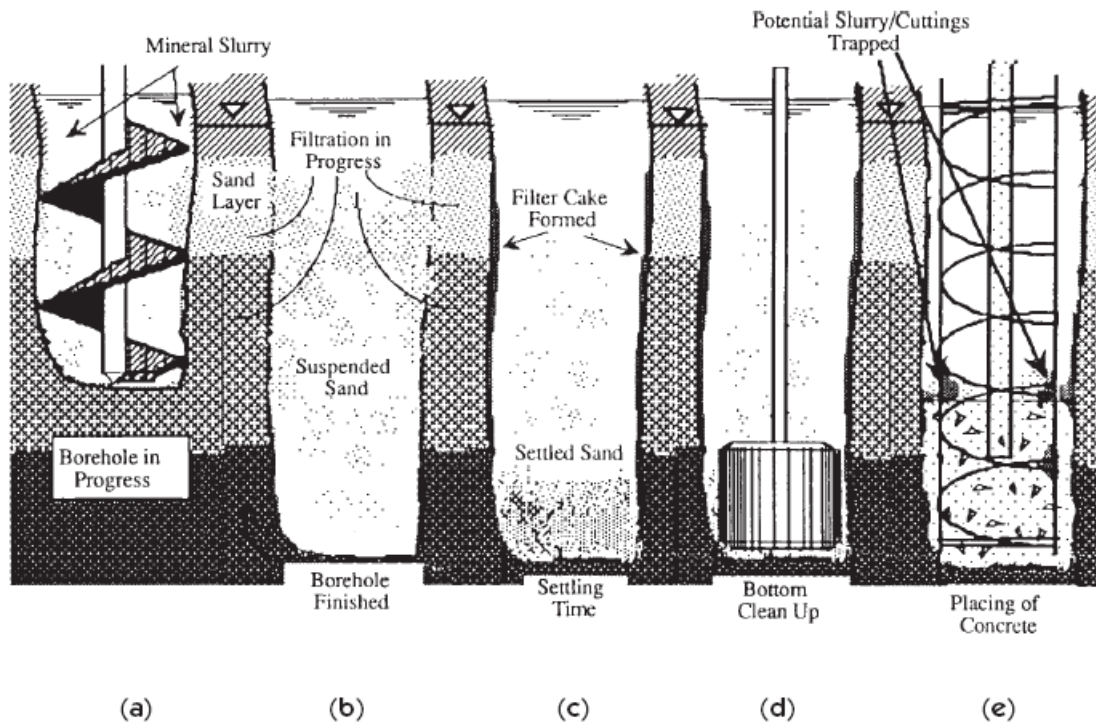


Figure 9-1. Slurry Displacement Method.

Drilling slurries are generally introduced into the drilled hole as soon as groundwater or caving materials are encountered. As drilling continues to full depth, the drilling slurry is maintained at a constant level at least 10 feet above the piezometric head until the tip elevation of the drilled hole is reached (Figure 9-1(a)). Because the drilling operation mixes soil cuttings with the drilling slurry, it is necessary to remove the soil cuttings from the drilling slurry. Depending on the type of drilling slurry used, removing the soil cuttings may be accomplished by physically cleaning the drilling slurry, or by allowing a settlement period for the soil cuttings to settle out of the drilling slurry (Figure 9-1(c)). If the drilling slurry is cleaned such that its physical properties are within the specified limits for the particular type of drilling slurry, the bottom of the drilled hole is cleaned of any settled materials using a cleanout bucket (Figure 9-1(d)). Since the action of the cleanout bucket may cause soil cuttings to contaminate the drilling slurry, cleaning the bottom of the drilled hole and the drilling slurry may take several iterations. Additional cleanings of settled materials from the bottom of the drilled hole may be performed with a cleanout bucket, pumps, or an airlift. After the final cleaning has been accomplished, the drilling slurry is retested to make sure its properties are within the specified limits. Once the drilling slurry is ready, the pile bar reinforcement cage may be placed. The slurry is again retested immediately prior to concrete placement and the bottom of the hole is re-cleaned using a pump or airlift. Once the slurry's physical properties are within the specified limits and the bottom of the hole is clean, concrete is placed, either by a rigid tremie tube or by a rigid pump tube delivery system. Concrete is placed through the tube(s), starting at the bottom of the drilled hole (Figure 9-1(e)). The tip of the rigid

delivery tube is maintained at least 10 feet below the rising head of concrete. As concrete is placed, the displaced drilling slurry is pumped away from the hole and prepared for reuse or disposal. Concrete placement continues until the head of concrete rises to the top of the pile and is then wasted until all traces of settled material or drilling slurry contamination in the concrete are no longer evident. Under circumstances where contaminated concrete cannot be wasted from the top of the pile, such as having a pile construction joint within a permanent casing below grade, pile concrete is placed to a predetermined level above the planned concrete placement elevation, and the contaminated concrete above the planned concrete placement elevation is either mucked out immediately after placement or chipped out at a later time.

9-3 Principles of Slurry Usage

All slurries keep excavations open by the use of positive hydrostatic pressure. In order to exert hydrostatic pressure against the walls of an excavation, a pressure transfer medium must be present. With mineral slurries (e.g. bentonite mud) the deposited filter cake of clay solids on permeable formations is the pressure transfer mechanism (the thing against which the hydrostatic pressure can push). In the case of properly formulated synthetic slurries, the pressure transfer mechanism is the zone of viscous permeation that surrounds the excavation. This zone is preferably permeated (and plugged) by viscous polymer slurry. The depth of the zone around the excavation can be inches or feet.

Positive hydrostatic pressure refers to the excess pressure exerted by a column of fluid against the interstitial or pore pressure of a soil layer (Figure 9-2(a)). A column of water 33 feet tall exerts a hydrostatic pressure of 1.0 atmosphere or 14.7 pounds per square inch. It has been determined by experience that a positive hydrostatic pressure of about 6 to 7 feet of water head is normally sufficient to keep an excavation open. This is equivalent to 0.2 atmospheres or about 3 pounds per square inch. A more useful way to consider 3 pounds per square inch is that it equals 432 pounds per square foot of excavation wall area. This is apparently sufficient to keep most holes open when proper operating practices are in use.

“Positive hydrostatic pressure” also refers to hydrostatic pressure above and beyond that exerted inward on an excavation by ground water (Figure 9-2). Thus if the static ground water table is at 15 feet below ground level, and if we want to maintain a column of slurry 7 feet higher than that, we will need to keep the slurry level at 8 feet below ground level. If excessive fluid loss is not a concern, we may want to keep the hole full of fluid, but this is probably not necessary in most cases. Excessive hydrostatic pressure can accelerate non-useful, unwanted loss or permeation of slurry into granular permeable soil layers.

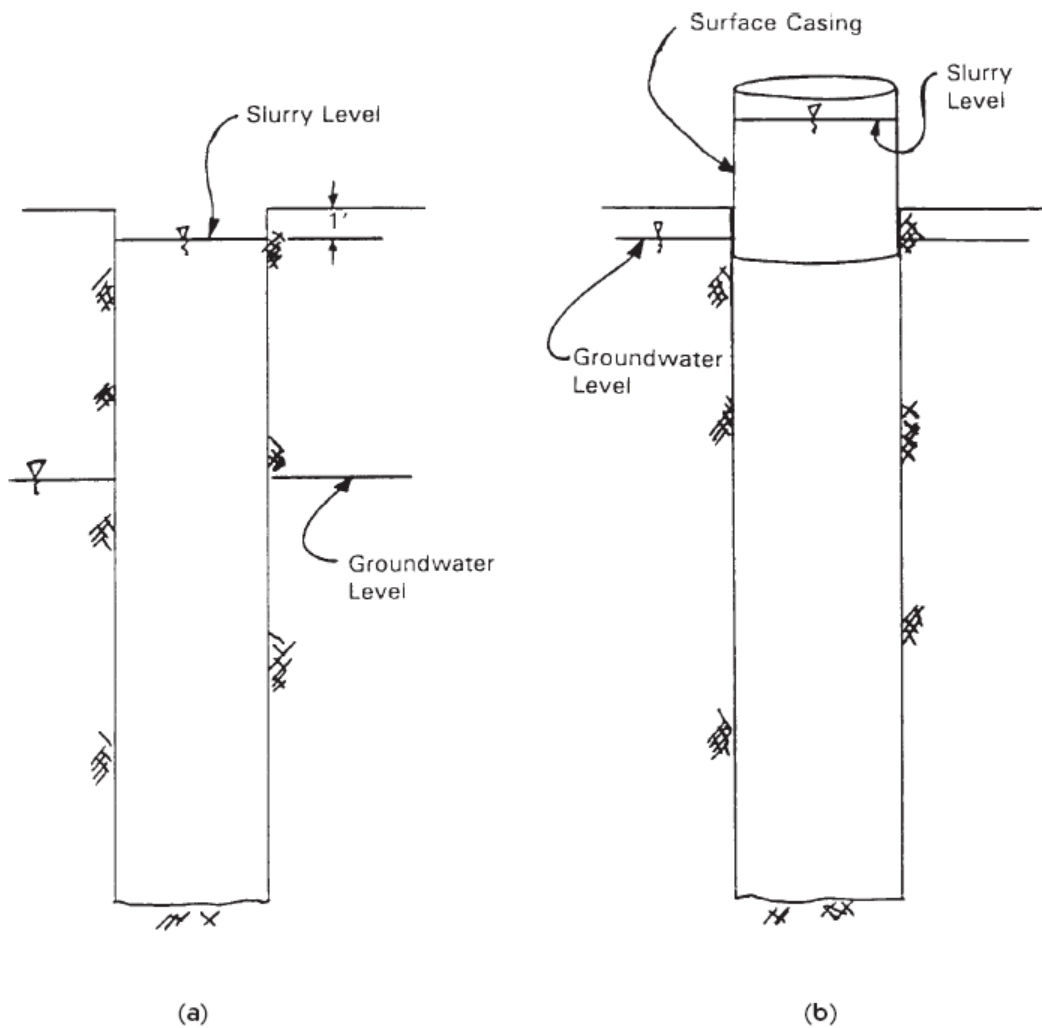


Figure 9-2. Positive Hydrostatic Pressure.

As mentioned previously, the filter caking process created by mineral or solid-laden slurries is called filtration. When drilling slurry is applying positive hydrostatic pressure to the sides of the drilled hole, some of the drilling slurry and soil cuttings may be forced out of the excavation and into the ground formation. When this material enters the formation, particles of the drilling slurry may be trapped or “filtered” by the individual soil grains of the formation. This process results in the development of filter cakes on the sides of the drilled hole. These filter cakes are referred to as “mudcakes” and help to temporarily stabilize the sides of the drilled hole.

The filtration process is dependent upon many variables. These include the nature of the ground formation, the type of mineral drilling slurry used, the amount of time the drilling slurry is in the drilled hole, the presence of contaminants or groundwater in the ground formation, and the chemical additives used in the drilling slurry, just to name a few. The

nature of the ground formation and the amount of time the drilling slurry is in the drilled hole are the two important variables.

The nature of the ground formation has an effect on the thickness of the filter cake that mineral slurries or other solids-laden slurries develop on the sides of the drilled hole. In general, thicker cakes will form on permeable granular ground formations, such as sands. Since the pore spaces between the individual soil grains are larger, drilling slurry with entrained soil particles can infiltrate further into the ground formation driven by the same positive hydrostatic pressure (Figure 9-3). Eventually, the infiltration slows as drilling slurry and particles build up against and beyond the exposed faces of the permeable formations. In tighter ground formations, such as dense sands and cohesive soils, the pore spaces between the individual soil grains are much smaller. The drilling slurry particles tend to fill in the pore spaces at the exposed wall face preventing further infiltration (Figure 9-4). Drilling slurry cannot be forced into the ground formation by positive hydrostatic pressure. This causes the build-up of the filter cake to cease; resulting in a thinner filter cake than would be observed in looser ground formations.

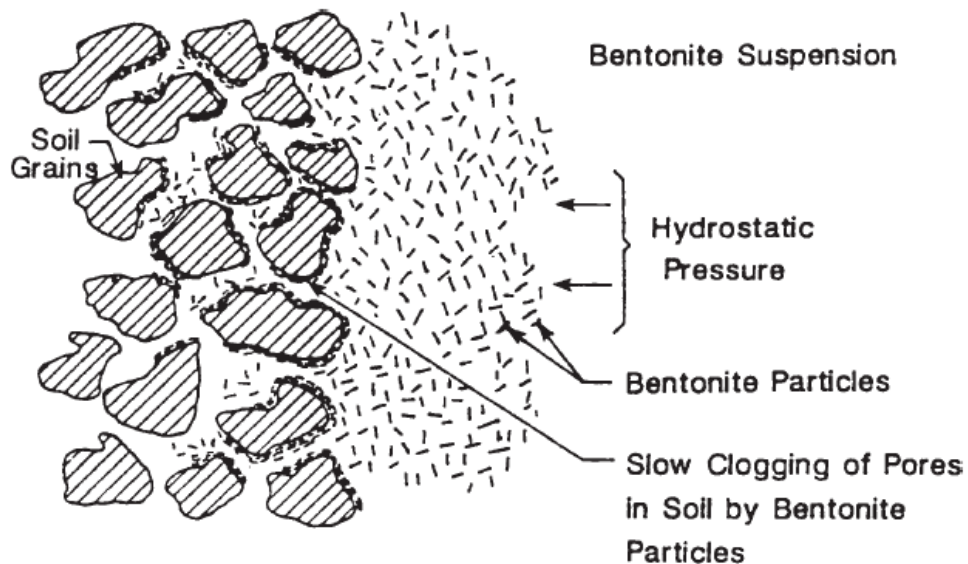


Figure 9-3. Filtration—Loose Ground Formation.

The amount of time that the drilling slurry is in the drilled hole also has a direct effect on the thickness of the filter cake that develops on the sides of the drilled hole. As long as positive hydrostatic pressure is continuous, the build-up of filter cake will continue so long as the infiltration continues. In general, the longer the drilling slurry is present in the drilled hole, the more filter cake will accumulate on the sides of the drilled hole. Sometimes this results in the presence of excess filter cake buildup, which must be removed before concrete can be placed in the drilled hole.

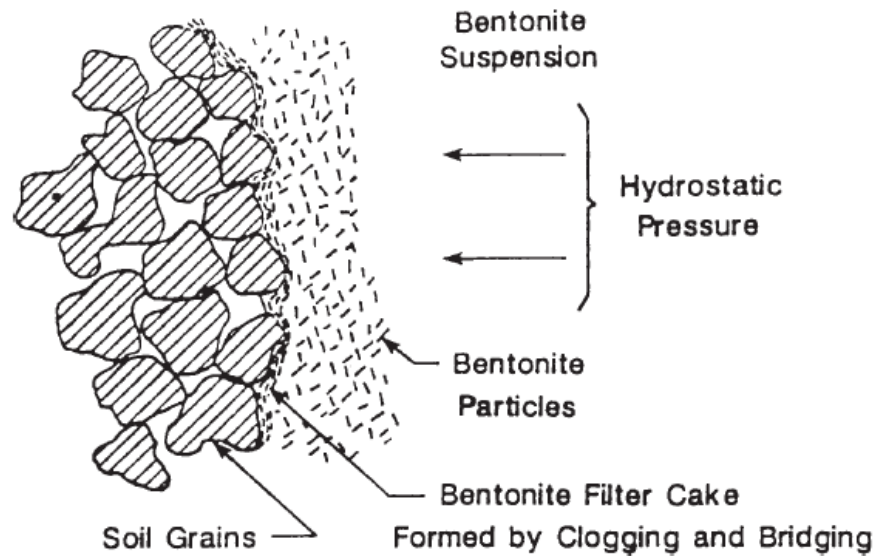


Figure 9-4. Filtration-Tight Ground Formation.

The important thing to remember about filtration is that it mainly pertains to mineral slurries or other solid-laden slurries and its filter cake helps to temporarily stabilize the sides of the drilled hole before concrete is placed. Filter cake is not meant to be left in place during concrete placement operations. If the filter cake is thin enough, the rising column of concrete will scrape it off the sides of the drilled hole. However, if the filter cake has excessive thickness, the rising column of concrete may not scrape all of it off the sides of the drilled hole. The remaining filter cake may act as a slip plane between the pile concrete and the sides of the drilled hole, resulting in the reduced skin friction capability of the pile. Excess filter cake must be removed prior to concrete placement.

With synthetic slurries, these fluids permeate and exert hydrostatic pressure against the walls of an excavation in order to keep the excavation open during drilling or digging and concrete placement. Synthetic slurries consist of very long, chain-like hydrocarbon molecules (polymers) that do not deposit a conventional wall cake or filter cake as with mineral slurries because the fluids are not laden with fine plate-shaped particles, such as bentonite.

Instead, a properly prepared synthetic polymer slurry permeates granular soils to a relatively shallow penetration around an excavation with long, hair-shaped strands of slurry molecules (Figure 9-5). This permeation has a gluing effect and stabilizes an excavation due to drag forces and cohesion formed from the binding of the soil particles in the formation by the polymer strands that tend to keep the soil particles in place.

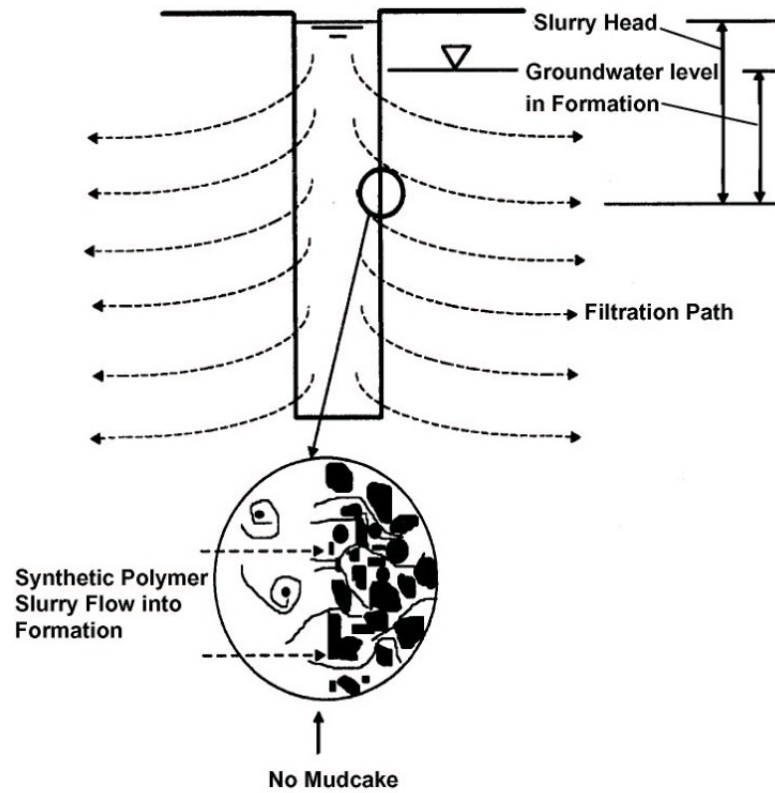


Figure 9-5. Stabilization with Synthetic Polymer Slurry.

The phrase “properly prepared” refers to slurry that is well-dispersed, lump-free, and viscous enough to impede filtration into granular formations. In some cases partially-hydrated, dry synthetic polymer (viscous slurry full of “pearls” of incompletely dissolved dry synthetic polymer product) may be useful in plugging coarse granular soils and appears to be more effective than emulsion synthetic polymers at controlling unwanted excessive fluid loss. These long chain polymers also inhibit hydration, swelling and distortion of clay components or layers in the soil formation.

9-4 Sampling and Testing Drilling Slurry

Sampling and testing of drilling slurry is an important quality control requirement. Responsibility for testing and maintaining drilling slurry of high quality is placed on the Contractor by the contract specifications. The Engineer is responsible for performing quality assurance testing on the drilling slurry.

The apparatus used to sample drilling slurry must be capable of sampling the drilling slurry at a given elevation in the drilled hole without being contaminated by drilling slurry from a different elevation in the drilled hole. This is necessary because the contract

specifications require the drilling slurry to be sampled at different levels in the drilled hole. The sampler must also be large enough to contain enough drilling slurry to perform all the required tests. The apparatus generally consists of a hollow tube with caps positioned above and below the tube on a cable that is used to lower the sampler into the drilled hole (Figure 9-6). Once the sampler has been lowered to the desired level, the drilling slurry contained in the hollow tube (at that level) is contained by activating the caps so that the ends of the tube are sealed. The sampler is then removed from the drilled hole and the drilling slurry contained is tested.

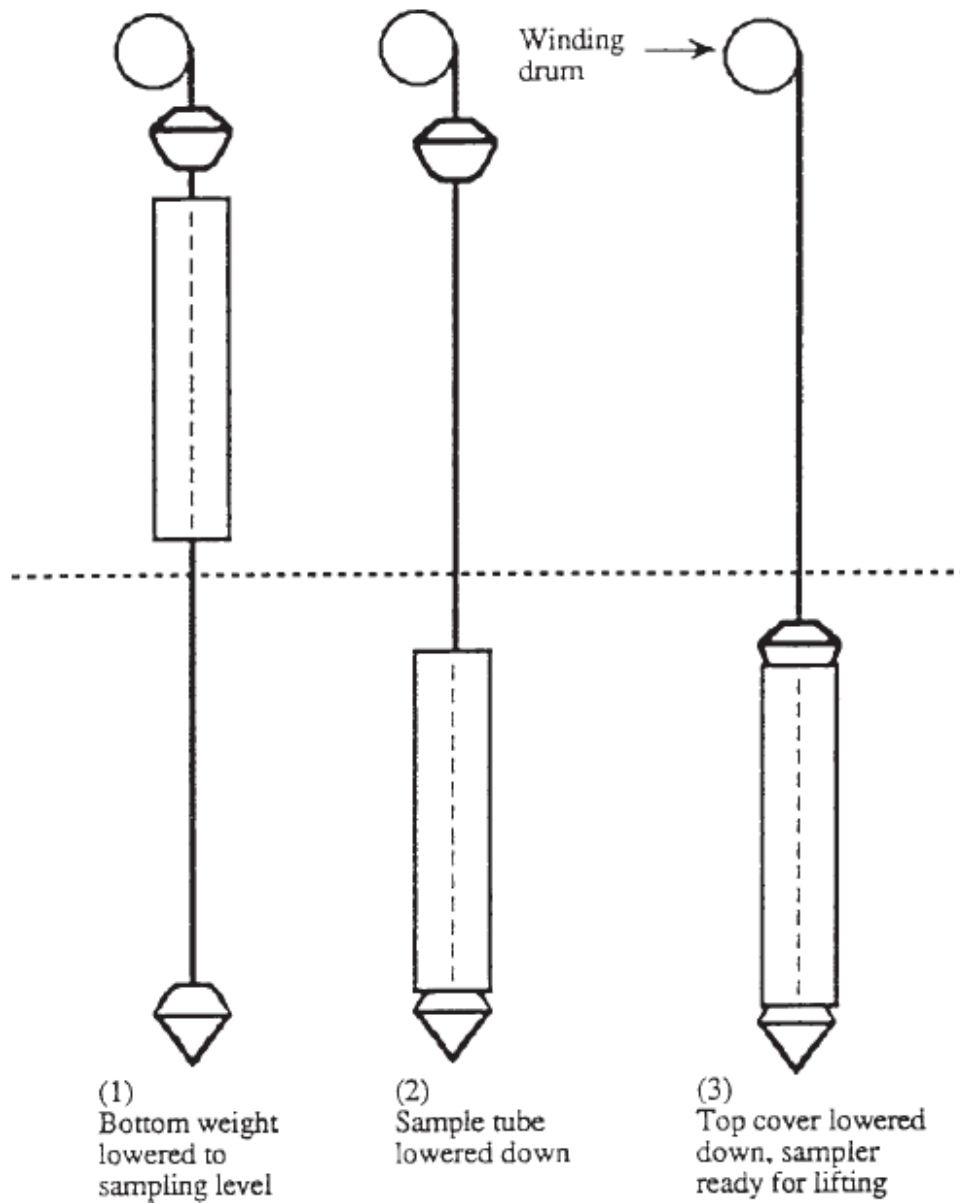


Figure 9-6. Slurry Sampler Schematic.

One of the responsibilities of the Contractor is to verify that the sampler used seals properly. The Engineer may require the Contractor to verify this before allowing the construction of slurry displacement piles to commence.

The primary engineering reason for testing drilling slurries is to make sure that no suspended material in the drilling slurry settles out during concrete placement. A secondary reason for testing drilling slurries is to control their properties during the drilling of the hole. This helps to stabilize the drilled hole. Drilling slurries that have physical properties within the parameters described in the contract specifications should have negligible settlement of suspended materials during concrete placement provided the pile's bar reinforcement cage and concrete are placed promptly.

The contract specifications set parameters for some of the physical properties of drilling slurries. The four specified physical properties are density, sand content, pH, and viscosity.

9-4.1 Density

Density, or unit weight, is a function of the amount of solids held in suspension by the drilling slurry. Since mineral slurries will hold solids in suspension for long periods, the allowable density value is higher than that permitted for synthetic slurries and water, which do not hold solids in suspension as well. Its viscosity may affect the density of the drilling slurry since a more viscous fluid will suspend more solids. The reason for having an upper limit on the allowable density value is that drilling slurries with higher densities are unstable with respect to their ability to suspend solids. These solids could settle out during concrete placement and cause pile defects.



Figure 9-7. Density Test Kit.

Density is tested using the test kit shown in Figure 9-7 in conformance with the test method described in Section 4 of the American Petroleum Institute (API) Recommended Practice for Field Testing Water-based Drilling Fluids (ANSI/API Recommended Practice 13B-1). Access to this test method is available through Structure Construction Intranet¹ under Field Resources/ASTM, AWS Spec downloads and searching for Document Number API RP 13B-1.

9-4.2 Sand Content

Sand content is an important parameter to keep under control, particularly just prior to concrete placement. Sand is defined as any material that will not pass through a No. 200 sieve. Since mineral slurries will hold sand particles and other solids in suspension, the allowable sand content value is higher than that permitted for synthetic slurries and water, which do not hold these solids in suspension as well. The primary reason for setting an upper limit on the sand content value is to prevent significant amounts of sand from falling out of suspension during concrete placement. A secondary reason for setting an upper limit on the sand content value is that high sand content can increase the amount of filter cake on the sides of the drilled hole in mineral slurries. This increased filter cake might have to be physically removed before concrete could be placed in the drilled hole. Allowing the filter cake to remain would decrease the skin friction value of the pile, thereby reducing the pile capacity.



Figure 9-8. Sand Content Test Kit.

Sand content is tested using the test kit shown in Figure 9-8 in conformance with the test method described in Section 9 of the ANSI/API Recommended Practice 13B-1. Access to this test method is available through Structure Construction Intranet¹ website under Field

¹ <http://onramp.dot.ca.gov/hq/oscnet/>

Resources/ASTM, AWS Spec downloads and searching for Document Number API RP 13B-1.

9-4.3 pH Value

The pH value of drilling slurry is important to ensure as its value indicates whether or not the drilling slurry is functioning properly. Mineral slurries that have pH values outside the allowable range will not fully hydrate the clay mineral and will not develop the expected viscosity. Synthetic slurries that are mixed in water having pH values outside the allowable range may not become viscous at all. Even though drilling slurries may be mixed in a controlled environment (such as in a mixing tank), they will be affected by acids and organic material from the groundwater or the soil once it is introduced into the hole. Mineral slurries may flocculate and form a thick, soft filter cake if the slurry becomes too acidic or too alkaline. Synthetic slurries may lose their viscosity and their ability to stabilize the sides of the drilled hole if the slurry becomes too acidic or too alkaline.

The pH value of drilling slurry is tested using either a pH meter or pH paper.

9-4.4 Viscosity

Viscosity refers to the “thickness” of the drilling slurry. This property is measured to determine whether the drilling slurry is too “thick”, allowing the suspension of more solids than permitted, which would affect the density and sand content values. On the other hand, some soils may require drilling slurry with a higher viscosity during drilling to permit the formation of filter cake or to stabilize the sides of the drilled hole in loose ground formations such as gravels. Thinner drilling slurry tends to flow through a loose ground formation without building a filter cake or providing stability. After the hole is drilled and a filter cake has formed or the sides of the drilled hole have stabilized, the drilling slurry can be thinned as required prior to concrete placement.



Figure 9-9. Marsh Funnel Viscosity Test Kit.

The viscosity of drilling slurry is tested using the test kit shown in Figure 9-9 in conformance with the test method described in Section 6 of the ANSI/API Recommended Practice 13B-1. Access to this test method is available through Structure Construction Intranet² under Field Resources/ASTM, AWS Spec downloads and searching for Document Number API RP 13B-1.

9-5 Types of Slurry

It is important to note that the type of drilling slurry to be used will depend on the ground conditions encountered. Use of different types of drilling slurries may be necessary to drill through different types of ground formations. It is conceivable that different types of drilling slurries may need to be used on the same contract because of varying ground conditions within the highway right-of-way. Some of the factors that influence the decision of what type of drilling slurry to use include economics, ground and groundwater contamination, ground temperature, air temperature, and the type of ground formation being drilled through.

Ground conditions can also have an effect on drilling slurry behavior. Some of these include acidity or alkalinity of groundwater, grain size of the soil, velocity of groundwater flow through the ground formation, cementation and cohesion of soil, and the presence of rock or clay structures in the ground formation. The drilling slurry's physical properties can be adjusted to account for some of these conditions, or chemical additives may be necessary.

Because most drilling slurries are difficult and expensive to dispose of, they are often reused. Occasionally, drilling slurry is reused on another pile after completion of the previous pile. Sometimes, the drilling slurry is reused on or from another project.

The reuse of drilling slurries requires careful planning on the Contractor's part. Drilling slurries must be cleaned before they are reused. For mineral slurries, this is accomplished through the use of de-sanding units and chemical additives. For synthetic slurries, this is accomplished by allowing the contaminants to settle out.

The contract specifications do not prohibit the reuse of drilling slurry. However, it still must meet the physical property requirements of the contract specifications. Drilling slurries will degrade over time (usually measured in months). If a Contractor proposes to reuse drilling slurry from a different contract, the Engineer may want to have the physical properties of the drilling slurry tested prior to placement in the drilled hole.

The types of drilling slurries that are permitted for use by Caltrans are detailed in the following sections. Three types of drilling slurries are permitted: water, mineral, and synthetic polymer.

² <http://onramp.dot.ca.gov/hq/oscnet/>

9-5.1 Water

Water may be suitable as drilling slurry under the right conditions. Most drilling contractors will try to use water as drilling slurry if the ground conditions are right because it is inexpensive. However, use of water as drilling slurry is limited to ground formations that are strong enough not to deform significantly during drilling. The water level in the drilled hole must be maintained at least 6 to 7 feet above the groundwater level in order to maintain positive effective stress on the sides of the drilled hole. This is the only means of stabilization provided to the sides of the drilled hole since water does not control filtration.

The 2010 Standard Specifications³ state that water may only be used as drilling slurry when a casing is used for the entire length of the drilled hole. Although water has been allowed as drilling slurry in the past by the contract specifications, history has shown that water was inappropriately chosen as drilling slurry for use in holes drilled in unstable ground formations, or even when a fully cased hole is terminated in an unstable ground formation. This resulted in many defective piles that required repair. Because of continuing problems encountered using water as a drilling slurry, water may only be used when a casing is used for the entire length of the drilled hole and the Geoprofessional authorizes its use during the project design phase. This change is stated in the 2015 Standard Specifications, which allow the use of water as a drilling slurry only when specified in the Special Provisions.

The question that arises from these limitations is why the contract specifications allow the use of water as drilling slurry at all. Retaining the limited use of water as a drilling slurry allows a Contractor, who attempts to dewater a drilled hole using a temporary casing and is unable to do so for whatever reason, to have the option of using the water in the drilled hole as a drilling slurry to prevent unstable conditions at the bottom of the drilled hole and to be able to place concrete. Water may also be used as drilling slurry when a Rotator or Oscillator is used to advance the drilled hole, provided the hole terminates in a stable formation.

The physical properties of water used as drilling slurry are not as critical as with other types of drilling slurries. Water is capable of suspending sand and silt only for short periods, usually less than 30 minutes. This allows soil cuttings to settle to the bottom of the drilled hole fairly rapidly. Since the pH of water used as drilling slurry is not important and water will not become more viscous unless a contaminant is introduced, the contract specifications³ set parameters for density and sand content only. Testing these parameters verifies that most of the suspended material has settled before final cleaning of the drilled hole and concrete placement.

Water used as drilling slurry can be easily disposed of onsite after settlement of all suspended materials has occurred unless hazardous materials have contaminated the water.

³ 2010 SS, Section 49-3.02B(6)(d), *Water Slurry*, or Special Provisions for contracts using 2006 SS.

9-5.2 Mineral

Mineral slurries are processed from several different types of clay formations. Although there are a number of different types of clay formations available, the most commonly used consist of bentonite and attapulgite clay formations.

Bentonite (Figure 9-10) is manufactured from a rock composed of clay minerals, named after Fort Benton, Wyoming, where this particular type of rock was first found. Its principal active constituent is the clay mineral montmorillonite, which hydrates in water and provides suspension of sands and other solids.

Bentonite slurry is a mixture of powdered bentonite and water. Bentonite slurry will flocculate (destabilize) in the presence of acids and ionized salts and is not recommended for ground formations where salty water is present without the use of chemical additives.



Figure 9-10. Bentonite Slurry.

Attapulgite comes from a clay mineral that is native to Georgia. It is processed from the clay mineral palygorskite, and is similar in structure to bentonite. However, it does not hydrate in water, will not flocculate in the presence of acids and ionized salts, and can be used in ground formations where salty water is present. Slurries made from attapulgite do not control filtration well, and tend to deposit thick filter cakes on the faces of permeable soils. Due to the transportation expenses and rare usage of this type of slurry in California, its application in Caltrans projects is unlikely.

Mineral slurries stabilize the sides of the drilled hole by positive hydrostatic pressure and by filtration. Mineral slurries will penetrate deeper into more open formations, such as gravels, and will form thicker filter cakes in these formations. While filtration is desirable, a thick filter cake is not desirable because it is necessary to remove it before concrete placement. Continuous agitation or recirculation of the mineral slurry with

removal of sand and other soil solids will help reduce the thickness of the filter cake by reducing the amount of suspended material in the mineral slurry.

The contract specifications⁴ require the removal of “caked slurry” from the sides and bottom of the drilled hole before concrete is placed. “Caked slurry” is considered to be an excessively thick filter cake that has formed on the sides or bottom of the drilled hole. The amount of filter cake that forms on the sides and bottom of the drilled hole depends on so many variables. Research of the effect of filter cake on the ability of the pile to transfer load through skin friction has not been completed. Structure Construction defines excessively thick filter cake as *a filter cake that has formed in a drilled hole where mineral slurry has been continuously agitated or recirculated in excess of 24 hours or a filter cake that has formed in a drilled hole where mineral slurry has been un-agitated in excess of 4 hours*. Due to the fact that each site is different, some engineering judgment should be exercised before implementing this definition. There are other indicators that can be used to assist the Engineer in making a judgment on the amount of filter cake present on the sides and bottom of the drilled hole. One indicator is the level of mineral slurry in the drilled hole. If the mineral slurry level is difficult to maintain at the required level in the drilled hole, this is an indicator that the mineral slurry is continuously being driven into the ground formation through the sides of the drilled hole. This means that filter cake build-up is continuing and it is likely that the thickness of the filter cake is excessive. However, if the mineral slurry level is stable in the drilled hole, this is an indicator that the mineral slurry has clogged up the ground formation on the sides of the drilled hole. This means that the filter cake buildup would have ceased and it is likely that the thickness of the filter cake is not excessive. Removal of excessively thick filter cake is accomplished by slightly over boring the full length of the drilled hole.

The contract specifications⁵ require that mineral slurries be mixed and fully hydrated in mixing tanks prior to placement in the drilled hole. Mixing and hydration of mineral slurries usually requires several hours. One way to determine that the mineral slurry is thoroughly hydrated is to take Marsh funnel viscosity tests at different time intervals. In general, mineral slurries will achieve their highest viscosity value when they have fully hydrated. Once the viscosity test values have stabilized at their highest level, the mineral slurry can be assumed to be fully mixed and fully hydrated, providing that the mineral slurry is smooth, homogeneous and not flocculated or “clabbered”.

The physical properties of the mineral slurry should be carefully monitored while the mineral slurry is in the drilled hole. The mineral slurry’s density, sand content, and viscosity should be tested and the values maintained within the limits stated in the contract specifications⁵. This will prevent excessive suspended materials and keep the filter cake thickness on the sides of the drilled hole to a minimum. The mineral slurry’s pH should be tested and maintained within the limits stated in the contract specifications to prevent flocculation or destabilization. It should be noted that it usually takes the

⁴ 2010 SS, Section 49-3.02B(6)(b), *Mineral Slurry*, or Special Provisions for contracts using 2006 SS.

⁵ 2010 SS, Section 49-3.02B(6)(b), *Mineral Slurry*, or Special Provisions for contracts using 2006 SS.

Contractor some time to get the mineral slurry's properties within the limits stated in the contract specifications. The important factor is to verify that the mineral slurry's properties are within the limits stated in the contract specifications prior to concrete placement.

While mineral slurries are present in the drilled hole, they must be agitated in order to maintain their physical properties and to reduce the amount of filter cake buildup on the sides of the drilled hole. In order to accomplish this, the contract specifications⁶ require mineral slurries to be agitated by either of two methods: (1) the mineral slurry is to be continuously agitated within the drilled hole, or (2) the mineral slurry is to be recirculated and cleaned. Either of these methods will provide the necessary continuous agitation of the mineral slurry. The method that is chosen will depend on the cleanliness of the mineral slurry in the drilled hole. This is typically influenced by the ground conditions encountered.

Recirculation and cleaning of mineral slurries is accomplished by removing the mineral slurry from the drilled hole, running it through specialized cleaning equipment, and then placing the cleaned mineral slurry back in the drilled hole. To meet all of the specification requirements, a slurry "plant", which is approximately the size of a railroad boxcar, must be located adjacent to the work area (Figure 9-11). The slurry plant contains screens, shakers, de-sanding centrifuges (Figure 9-12), and agitators, and is capable of mixing, storing, and cleaning the mineral slurry. Figure 9-13 shows a typical recirculation and cleaning process. It is very important to remove the mineral slurry from the bottom of the drilled hole. This is because excessive amounts of suspended materials will eventually settle to the bottom of it. These materials must be removed in order to fully clean the mineral slurry. Typically, it will take several hours to completely clean the mineral slurry of sand and other suspended materials.



Figure 9-11. Mineral Slurry Plant.

⁶ 2010 SS, Section 49-3.02B(6)(b), *Mineral Slurry*, or Special Provisions for contracts using 2006 SS.



Figure 9-12. De-sanding Centrifuges.

Usually, in order for the mineral slurry to meet the physical property requirements of the contract specifications, the mineral slurry will require recirculation and cleaning during and after the drilling operation. Occasionally, without any action on the part of the Contractor, the mineral slurry will meet the physical property requirements of the contract specifications during and after the drilling operation, in which case continuous agitation of the mineral slurry in the drilled hole is acceptable. However, the contract specifications⁷ also require that any mineral slurry that is continuously agitated in the drilled hole and exceeds the physical property requirements must be recirculated and cleaned.

⁷ 2010 SS, Section 49-3.02B(6)(b), *Mineral Slurry*, or Special Provisions for contracts using 2006 SS.

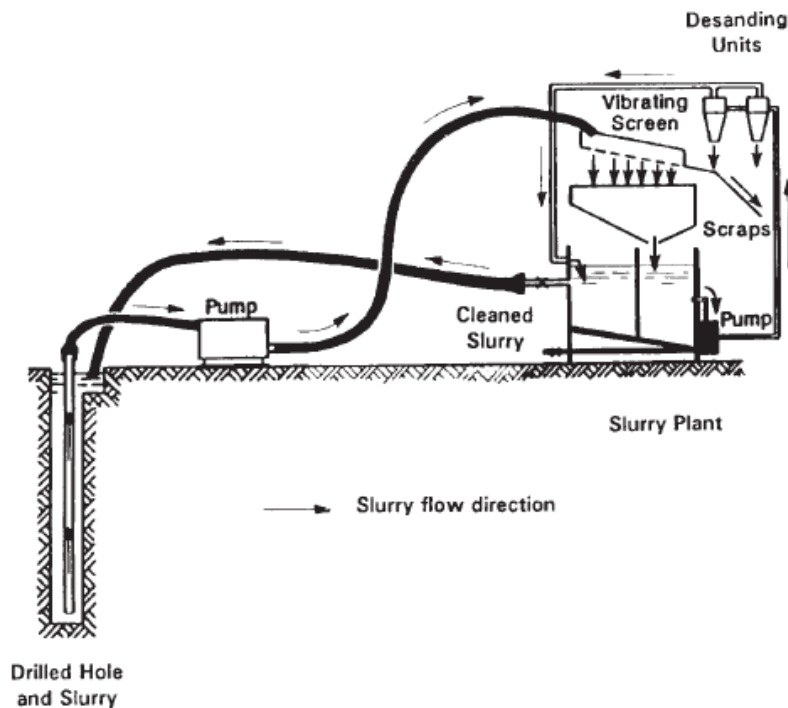


Figure 9-13. Recirculation and Cleaning Schematic.

Should the mineral slurry’s properties change dramatically during the drilling operation, chemical additives are available that can reduce the filter cake thickness, modify the mineral slurry’s pH, and increase the mineral slurry’s viscosity. Additives that reduce the filter cake thickness and increase the mineral slurry’s viscosity include organic colloids such as CMC or starch. Additives that lower the mineral slurry’s pH include pyrophosphate acid (SAPP). Additives such as soda ash and caustic soda (sodium hydroxide) can increase the slurry’s pH and reduce water hardness. Additives that decrease the mineral slurry’s viscosity, reduce gelatin, and improve filter cake quality include tannins, polyphosphates, lignosulfonates, and acrylates. Caltrans has little experience with chemical additives, and their use should be discussed with Structure Construction in Sacramento before authorization is given for their use.

Mineral slurries may be used in most types of ground formations. They work best in cohesionless sands and open gravels. Caution must be taken when using mineral slurries in cohesive materials because they may contain clays that can be incorporated into the mineral slurry and rapidly change the mineral slurry’s physical properties. In addition, these cohesive materials can reduce filtration, and filter cakes may not form.

Disposal of mineral slurries can be difficult. Due to their particulate nature, they are hazardous to aquatic life and cannot be disposed of on site or at locations where they can

enter State waters. The contract specifications⁸ require that any materials resulting from the placement of piles under mineral slurry be disposed of outside the highway right-of-way. Because they often contain chemical additives, mineral slurries can be considered to be hazardous materials that must be disposed of in landfills. This can be very expensive and can defeat the economic advantage of using the slurry displacement method over other means of construction of CIDH piles.

9-5.3 Synthetic

Since the 1980's, synthetic drilling slurries have gained wide acceptance in the construction industry. The main advantage of synthetic slurries is that they are easier and cheaper to dispose of than mineral slurries and do not require slurry plants to physically clean the slurry. Synthetic slurries are grouped into three groups: (1) naturally occurring polymers, (2) semi-synthetic polymers, and (3) synthetic polymers. Synthetic polymers are either dry or emulsified.

Synthetic drilling slurry systems must undergo a rigorous approval process before being allowed for use on Caltrans projects. The synthetic drilling slurry products that are approved by Caltrans at the present time are synthetic polymers mixed with water to prepare viscous slurries for CIDH piles and other foundation elements. These slurries have been shown to have no deleterious effects on concrete-to-rebar bonding, concrete compressive strength and other aspects of the foundation construction processes. The contract specifications currently allow the use of four brands of synthetic slurries. These are: Super Mud, manufactured by PDSCo, Inc.; SlurryPro CDP™, manufactured by KB International LLC; Shore Pac®, manufactured by CETCO Construction Drilling Products; and Terragel (previously named Novagel™), manufactured by Geo-Tech Services, LLC. Because drilling slurries are products used to facilitate construction of CIDH piles and are not incorporated into the permanent work, these products are not listed on the Caltrans Approved Products List.

Super Mud is an emulsified (water-in-oil, liquid form) synthetic polymer product. A liquid form of Super Mud is currently approved for use on Caltrans projects. No other form is approved (Figure 9-14).

⁸ 2010 SS, Section 5-1.20B(4), *Contractor-Property Owner Agreement*, or 2006 SS, Section 7-1.13, *Disposal of Material Outside the Highway Right of Way*.



Figure 9-14. Super Mud Container.

SlurryPro CDP™ is a dry form synthetic polymer slurry product. A dry granular form of SlurryPro CDP™ is currently approved for use on Caltrans projects. No other form is approved. (Figure 9-15)



Figure 9-15. SlurryPro CDP™ Container.

Shore Pac® is a dry form synthetic polymer slurry product. A dry granular form of Shore Pac® is currently approved for use on Caltrans projects. No other form is approved (Figure 9-16).



Figure 9-16. Shore Pac® Container.

Terragel (previously named Novagel) is a dry form synthetic polymer slurry product. A dry granular form of Terragel is currently approved for use on Caltrans projects. No other form is approved (Figure 9-17).



Figure 9-17. Novagel Container.

Synthetic slurries must be thoroughly mixed but do not require additional time to hydrate. This is because these slurries can achieve effectively complete hydration in a short time. Water used to mix with the synthetic polymer should have a pH in the range of 8 to 11 in order to properly disperse the polymer. A more acidic pH will retard hydration of the slurry, causing poor performance. A mixing tank is usually required in order to regulate the water. The manufacturers of the approved synthetic slurries recommend tank mixing, but mixing directly into the drilled hole by introducing these products into the flow of water is also acceptable to the manufacturers.



The physical properties of synthetic slurries should be carefully monitored during drilling of the hole and before concrete placement. Because these slurries in general do not suspend particles, the permissible density and sand content values are generally lower than those allowed for mineral slurries. The density and sand content values should be tested and the values maintained within the limits stated in the contract specifications to allow for quick settlement of suspended materials. The synthetic slurry's pH value should be tested and maintained within the limits stated in the contract specifications to prevent destabilization of the slurry. The allowable limits described in the contract specifications for density, sand content, and pH vary between Super Mud, SlurryPro CDP™, Shore Pac®, and Terragel due to the extensive research that had been done by the slurry system manufacturers during the Caltrans approval process.

The synthetic slurry's viscosity value has a higher level of importance than that of mineral slurry. The viscosity value should be tested and maintained within the limits stated in the contract specifications to prevent destabilization of the sides of the drilled hole. However, synthetic slurries at high viscosities may be capable of suspending sand particles for longer than expected periods, causing the density and sand content values to increase above their allowable limits. For this reason, caution must be practiced when using synthetic slurries at high viscosities so that particulate settlement on the head of concrete during concrete placement can be prevented. The allowable limits described in the contract specifications for viscosity vary dramatically between Super Mud, Shore Pac®, Terragel, and SlurryPro CDP™. This is due to the extensive research that had been done by the manufacturers during the Caltrans approval process. SlurryPro CDP™ and Terragel are approved for very high viscosity values (>70 sec/quart) during drilling operations to further ensure stability of the drilled hole. Only one synthetic slurry, Terragel, with a very high viscosity value up to 104 sec/quart is approved for use during concrete placement.

In general, synthetic slurries will break down when they come in contact with concrete. This is advantageous as long as the synthetic slurry is clean and the rising head of concrete is the only concrete in contact with the synthetic slurry. However, if concrete is allowed to intermingle with the synthetic slurry, the synthetic slurry may break down and cause the sides of the drilled hole to destabilize.

The contract specifications⁹ also require the presence of a manufacturer's representative to provide technical assistance and advice on the use of their product before the synthetic slurry is introduced into the drilled hole. The Engineer must authorize the manufacturer's representative. Assistance on authorization of a manufacturer's representative may be obtained from Structure Construction in Sacramento. The manufacturer's representative can provide assistance with slurry property testing, can test the water to be used for contaminants that may adversely affect the properties of the synthetic slurry and the stability of the drilled hole, and can give advice in the proper disposal of the slurry.

⁹ 2010 SS, Section 49-3.02B(6)(c), *Synthetic Slurry*, or 2006 Special Provisions.

The manufacturer's representative may also recommend the use of chemical additives to adjust the synthetic slurry to the existing ground conditions. Some chemical additives are approved for use with each manufacturer's approved slurry system. Other chemical additives that are not approved may be proposed for use. Use of chemical additives should be discussed with Structure Construction in Sacramento before authorization is given for their use.

The contract specifications also require the manufacturer's representative to be present until the Engineer is confident that the Contractor has a good working knowledge of how to use the product. Once this occurs, the manufacturer's representative can be released. This can usually be accomplished within the completion of one pile.

Synthetic drilling slurries can be used in most types of ground formations. However, the contract specifications¹⁰ state that synthetic slurries cannot be used in soils classified as "soft" or "very soft" cohesive soils. There are two reasons for this. First, synthetic slurries will encapsulate and cause settlement of clay particles from the soil cuttings. These encapsulated clay particles are similar in appearance and size as sand particles and will cause excessively high false readings of the sand content test value. This problem may also occur in soils that are only slightly cohesive. To overcome this problem, the Contractor should use a dilute bleach solution or dilute acid solution instead of water to dilute the slurry sample and wash the fines through the #200 mesh screen during the sand content test. This will avoid agglomeration of clay particles so they will wash through the #200 mesh screen. Second, the synthetic slurry manufacturers have not completed the research necessary to show that their products function properly in soils defined as "soft" or "very soft" cohesive soils. If this research is successfully completed, the contract specifications may be amended to remove this limitation.

Disposal of synthetic slurries is somewhat easier than disposal of mineral slurries. The manufacturers of the approved synthetic slurries are attempting to get approval for different disposal techniques. However, until they do so, the contract specifications require all material resulting from the placement of piles, including drilling slurry, must be disposed of outside of the highway right-of-way as described in the contract specifications¹¹ unless otherwise permitted by the Engineer. The Engineer may allow disposal by other means if the proper permits are secured or permission is obtained from the appropriate regulatory agency. Other means of disposal include placing the synthetic slurry in a lined drying pit and allowing it to evaporate. The dried solids then can be disposed of in a similar fashion as other jobsite spoils. Synthetic slurries can also be broken down to the viscosity of plain water with chemical additives, allow time for solids to settle out, and then be disposed of as clarified waste water. Permission must be obtained from the responsible authority, usually the local California Regional Water

¹⁰ 2010 SS, Section 49-3.02B(6)(c), *Synthetic Slurry*, or Special Provisions for contracts using 2006 SS.

¹¹ 2010 SS, Section 5-1.20B(4), *Contractor-Property Owner Agreement*, or 2006 SS, Section 7-1.13, *Disposal of Material Outside the Highway Right of Way*.

Quality Control Board or the local sanitation district, for this type of disposal. The dried solids can be disposed of as mentioned above.

9-6 Equipment

The equipment used to construct CIDH piles by the slurry displacement method is not much different than that used to construct CIDH piles by ordinary means. However, there are some differences in the drilling tools, drilling techniques, cleaning techniques, and use of casings.

The primary reason that modified drilling tools and drilling techniques are used has to do with the way drilling slurries work. The drilling contractor must be careful not to do anything that would disturb the positive hydrostatic pressure provided by the drilling slurry on the sides of the drilled hole. The drilling tool can produce rapid pressure changes above and below it, similar to the effect of a piston, if it is lifted or lowered too quickly. When these pressure changes are produced, the drilled hole can collapse (Figure 9-18). This problem can be remedied through the use of drilling tools that allow the drilling slurry to pass through or around the tool during lifting and lowering. For augers, special steel teeth are added to over bore the drilled hole so the diameter of the drilled hole is larger than the diameter of the auger. For drilling buckets and cleanout buckets, special steel teeth are added to over bore the drilled hole, or the bucket itself may be vented. Even with these modifications, the drilling technique must be modified so that the drilling tool is not lowered or raised too rapidly through the drilling slurry.

For reverse-circulation drills, rapid pressure changes due to raising or lowering the drill head are reduced considerably. The drill stem acts as an airlift that removes drill cuttings from the bottom of the hole as it is being excavated. This allows the drill to remain in the hole and, barring malfunctions, eliminates the need to raise or lower it until the excavation is complete.

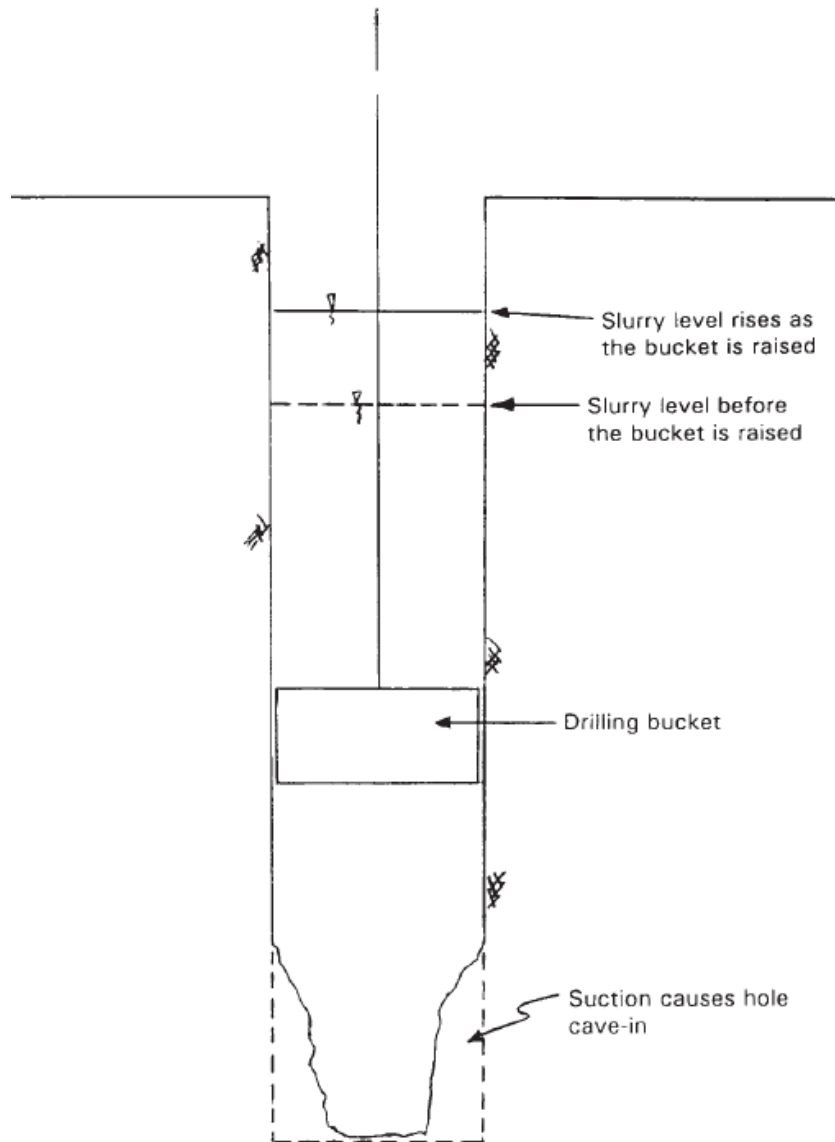


Figure 9-18. Hole Collapse Induced by Pressure Changes.

The techniques used to clean the bottom of the drilled hole are also modified for use in drilling slurries. The initial cleaning of the bottom of the drilled hole is done with a cleanout bucket so that the bottom of the drilled hole has a hard flat surface (Figure 9-19). However, as sand particles settle out of suspension in the drilling slurry, additional cleanings may be required. These additional cleanings can be accomplished with a cleanout bucket, the combined use of a cleanout bucket and pumps, or with a device known as an airlift (Figure 9-20). The airlift device operates with air that is supplied to the bottom of the drilled hole by an air compressor. This causes the settled sand particles to be lifted off the bottom of the drilled hole and vented.



Figure 9-19. Cleanout Bucket.

For projects that utilize reverse circulation drills, typically the drill head is left at the specified tip and allowed to spin for a certain amount of time. This allows the airlift built into the drill stem to remove all large and small particles from the bottom of the drilled hole. Once the drill stem and drill head are removed from the hole, it may be necessary to remove more fine particles that may have settled out of the slurry during removal of the drilling equipment. For these settled particles, a separate smaller airlift or pump is typically used.

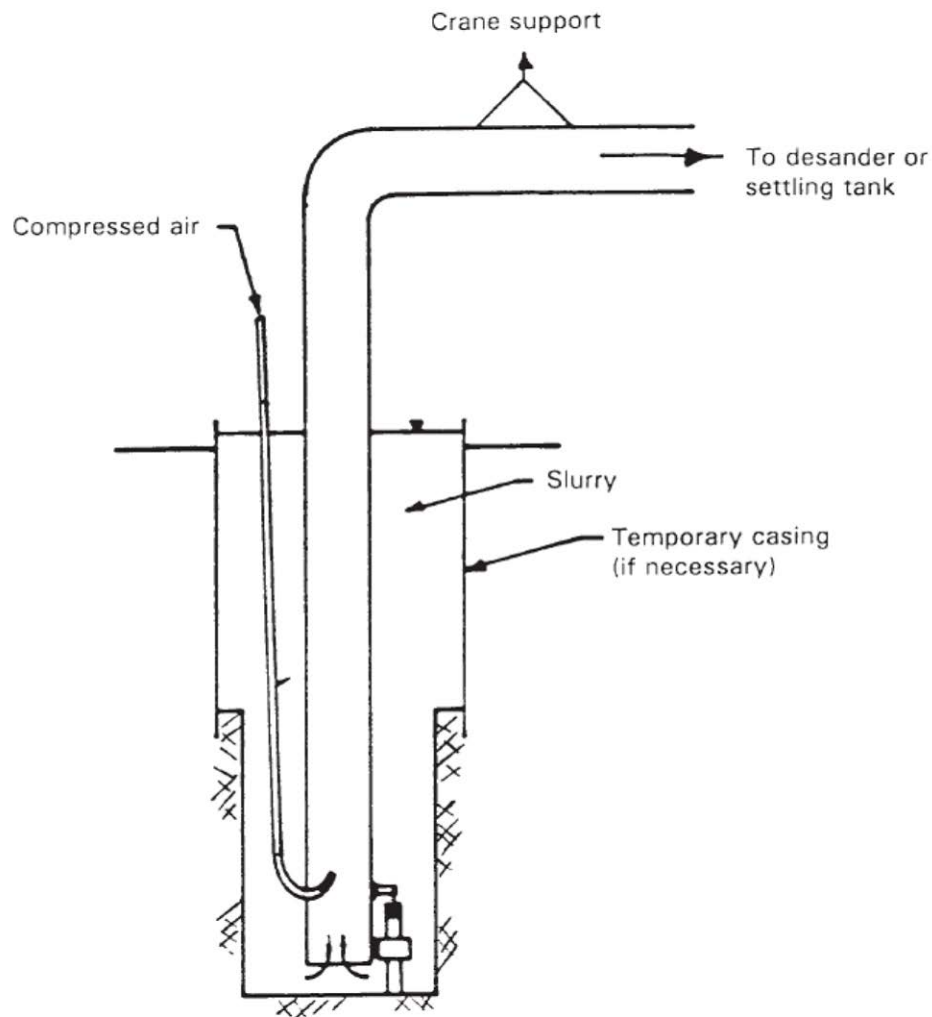


Figure 9-20. Airlift Schematic.

The use of temporary casing may be appropriate in certain situations when the slurry displacement method is used. Temporary casing may be necessary if a dry loose material stratum or a loose material stratum with flowing groundwater is encountered during drilling (Figure 9-21). Even drilling slurries with viscosity values at the allowable maximum limit may not be able to stabilize a drilled hole in these situations. It may be necessary to place temporary casing only where the dry loose material strata or the loose material strata with flowing groundwater is located and use mineral or synthetic drilling slurries to stabilize the remainder of the drilled hole. Another option is to place a full-length temporary casing in the drilled hole and use water as the drilling slurry, if allowed by the specifications, in order to avoid a quick condition at the bottom of the drilled hole.

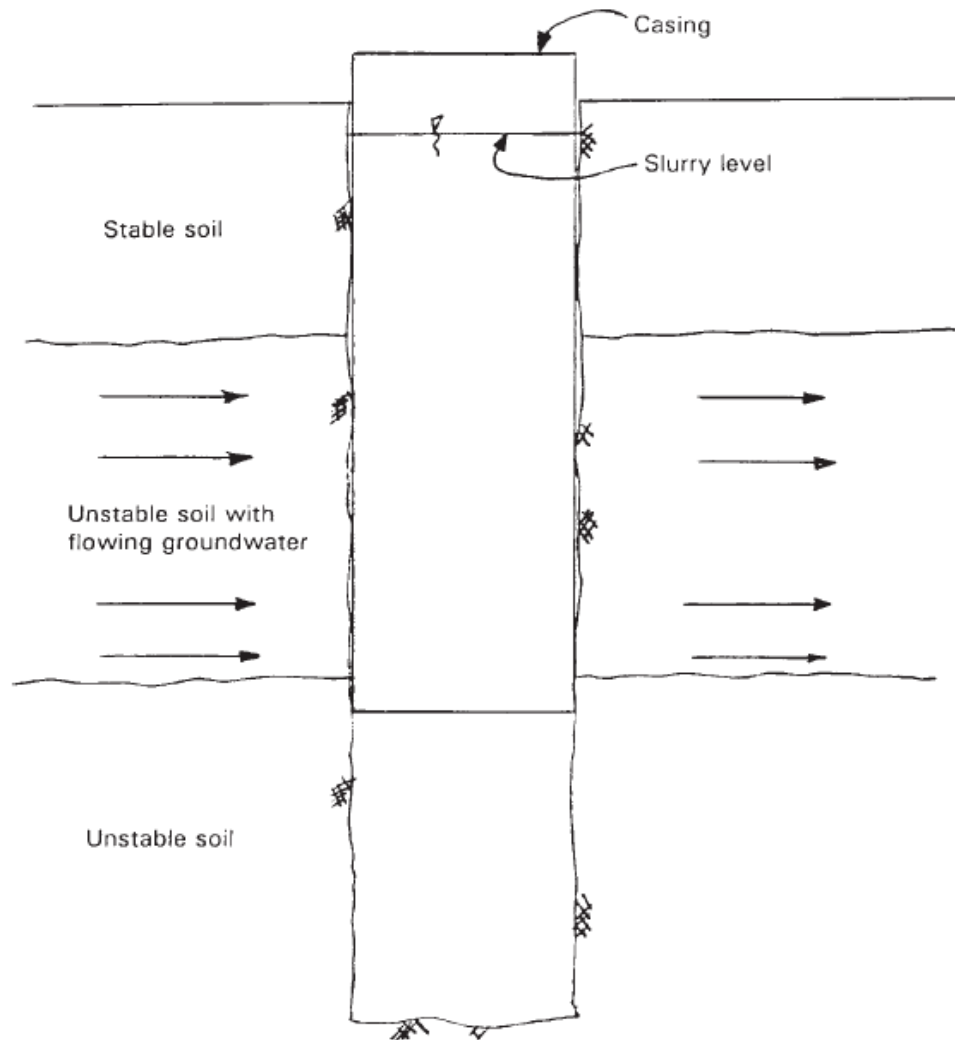


Figure 9-21. Use of Casing.

9-7 Specifications

Because of the nature of slurry displacement construction, visual inspection of the drilled shaft is not possible for much of the time. Most of the drilling and concrete placement is done “in the blind”. As a result, the contract specifications for this work are quite stringent in an attempt to minimize the risks and to ensure that the pile has structural and geotechnical integrity. Some of the more critical requirements of the contract specifications are discussed in the following sections.

9-7.1 Minimum Pile Diameter Requirements

Only piles 24 inches in diameter or greater may be constructed by the slurry displacement method. This is because a pile with a lesser diameter does not contain enough room for the pile bar reinforcement cage, inspection pipes, and the large concrete delivery tubes. If

a contract specifies the use of piles with a diameter of less than 24 inches, the Contractor may propose to increase the diameter of the pile to at least 24 inches by the provisions described in the contract specifications¹² if use of the slurry displacement method of construction is desired. However, the diameter of the pile bar reinforcement cage would have to be increased from the original size in order to accommodate the items mentioned above.

9-7.2 Concrete Compressive Strength and Consistency Requirements

Before any pile construction work using the slurry displacement method can begin, the Contractor must demonstrate the concrete mix design can meet the required compressive strength requirements and consistency requirements. This is accomplished by producing a concrete test batch in accordance with the contract specifications¹³. The concrete test batch must demonstrate the proposed concrete mix design achieves the specified nominal slump at the time of placement. For piles where the concrete placement operation is expected to be 2 hours or less, the test batch must demonstrate that the proposed concrete mix design achieves a slump of at least 7 inches after twice the time of the proposed concrete placement operation. For piles where the concrete placement operation is expected to be longer than 2 hours, the test batch must demonstrate that the proposed concrete mix design achieves a slump of at least 7 inches after the time plus 2 hours of the proposed concrete placement operation. The intent of this specification is to make sure the first load of concrete placed in the drilled hole will remain sufficiently fluid as it rises to the top of the pile. The concrete must also have a high fluidity in order to flow through the pile bar reinforcement cage, to compact and consolidate under its own weight without the use of vibration, and to deliver high lateral stresses on the sides of the drilled hole in order to keep the drilled hole from collapsing as the drilling slurry is displaced and the filter cake (in the case of mineral slurries) is scoured from the sides of the drilled hole by the rising column of concrete. The concrete test batch and compressive strength requirement gives the Engineer and the Contractor the opportunity to observe how the concrete mix will behave before it is used.

9-7.3 Slurry Testing and Cleaning Requirements

During pile construction work, the contract specifications require the Contractor to sample and test the drilling slurry in order to control its physical properties. The contract specifications also require that each type of drilling slurry be sampled and tested at different intervals and locations.

9-7.3.1 Mineral

For mineral slurries, samples must be taken from the mixing tank for testing prior to the mineral slurry's introduction into the drilled hole. Once the mineral slurry has been introduced into the drilled hole, the contract specifications¹⁴ require the mineral slurry to

¹² 2010 SS, Section 49-3.02C(1), *Construction General*, or 2006 SS, Section 49-4.03, *Drilled Holes*.

¹³ 2010 SS, Section 49-3.02A(4)(c), *Concrete Test Batch*, or Special Provisions for contracts using 2006 SS.

¹⁴ 2010 SS, Section 49-3.02B(6)(b), *Mineral Slurry*, or Special Provisions for contracts using 2006 SS.

undergo either recirculation or continuous agitation in the drilled hole. The Contractor must address which method of agitation will be used in the Pile Installation plan.

If the recirculation method is used, the contract specifications require the mineral slurry to be cleaned as it is recirculated. This is done using a slurry plant, which stores, recirculates, and cleans the mineral slurry. Samples for testing must be taken from the slurry plant storage tank and the bottom of the drilled hole. As the mineral slurry is recirculated and cleaned, samples must be taken every two hours for testing until the test values for the samples taken at the two testing locations are consistent. Once the test samples have consistent test values, the sampling and testing frequency may be reduced to twice per work shift. As the recirculation and cleaning process continues, the properties of the mineral slurry will eventually conform to the specification parameters. Once the test samples have properties within the specification parameters, the bottom of the drilled hole can be cleaned.

If the continuous agitation in the drilled-hole method is used, the contract specifications do not require the mineral slurry to be physically cleaned. Samples for testing are taken at the mid-height and at the bottom of the drilled hole. As the mineral slurry is continuously agitated, samples are taken every two hours for testing. If the samples at the two locations do not have consistent test values, the mineral slurry must be recirculated. This means that the continuous agitation in the drilled-hole method is failing to keep the suspended particles in the mineral slurry from settling. This is also an indication that the mineral slurry is not clean enough to meet the specification parameters. Therefore, the Contractor must abandon this method and use the recirculation method. However, if the test samples do have consistent test properties within the specification parameters, the bottom of the drilled hole can be cleaned.

Once the bottom of the drilled hole has been initially cleaned, recirculation or continuous agitation in the drilled hole may be required to maintain the specified properties of the mineral slurry. Usually the initial cleaning will stir up the settled materials at the bottom of the drilled hole, thus requiring the mineral slurry to be re-cleaned so it meets the requirements of the contract specifications. Several iterations may be required before both the mineral slurry and the bottom of the drilled hole are clean. To verify the cleanliness of the mineral slurry, the contract specifications require additional samples to be taken for testing. Samples are taken at the mid-height and at the bottom of the drilled hole. Once the test samples show the mineral slurry's properties to be within the specification parameters, and there is no settled material on the bottom of the drilled hole, the last cleaning of the bottom of the drilled hole can be considered to be the final cleaning. At this point, the pile bar reinforcement cage can be placed. The contract specifications require that samples for testing be taken just prior to concrete placement to verify the properties of the mineral slurry. Samples are taken at the mid-height and at the bottom of the drilled hole. If the test samples have consistent test properties within the specification parameters, concrete may be placed. Otherwise, additional cleaning of the mineral slurry and removal of settled materials from the bottom of the drilled hole may be required.

The reason for testing mineral slurries at different levels is to make sure the mineral slurries are well mixed and have consistent physical properties throughout the length of the drilled hole. The mineral slurry's physical properties should be the same at both locations. This indicates that the mineral slurry is completely mixed and that any sand or particles contained are in suspension.

9-7.3.2 *Synthetic*

For synthetic slurries, sampling for testing must be conducted before, during, and after the drilling operation, and as necessary to verify and control the physical properties of the slurry. Samples are taken at the mid-height and at the bottom of the drilled hole. Once the drilling operation has been completed, additional samples for testing must be taken. When the synthetic slurry's physical properties are consistent at the two sampling locations and meet the requirements of the contract specifications, the bottom of the drilled hole can be cleaned.

Synthetic slurries are cleaned by allowing for an un-agitated settlement period, usually of about 30 minutes in length. Because synthetic slurries in general will not suspend sands, the sands will settle to the bottom of the drilled hole during the settlement period.

Once the bottom of the drilled hole has been initially cleaned, further settlement periods may be required. Usually, the initial cleaning will stir up the settled materials at the bottom of the drilled hole, thus requiring the synthetic slurry to be re-cleaned so it meets the requirements of the contract specifications. Several iterations may be required before both the synthetic slurry and the bottom of the drilled hole are clean. To verify the cleanliness of the synthetic slurry, the contract specifications require additional samples to be taken for testing. Samples are taken at the mid-height and at the bottom of the drilled hole. Once the test samples show the synthetic slurry's properties to be within the specification parameters, and there is no settled material on the bottom of the drilled hole, the last cleaning of the bottom of the drilled hole can be considered to be the final cleaning. At this point, the pile bar reinforcement cage can be placed. The contract specifications require that samples for testing be taken just prior to concrete placement to verify the properties of the synthetic slurry. Samples are taken at the mid-height and at the bottom of the drilled hole. If the test samples have consistent test properties within the specification parameters, concrete may be placed. Otherwise, additional settlement periods and removal of settled materials from the bottom of the drilled hole may be required.

The reason for testing synthetic slurries at different levels is to make sure the synthetic slurries are well mixed and have consistent physical properties throughout the length of the drilled hole.

The intent of these specifications is to ensure that the drilling slurry is properly mixed in order to provide stability to the drilled hole and to control the amount of suspended materials in the drilling slurry that may settle during placement of the pile bar reinforcement cage and concrete.

9-7.4 Pile Acceptance Testing Access Requirements

During pile construction work, the contract specifications¹⁵ require the installation of inspection pipes at specific intervals around the perimeter of the pile bar reinforcement cage. This is necessary to provide access for acceptance testing.

9-7.5 Pile Concrete Placement Requirements

During pile construction work, the contract specifications¹⁶ require that concrete must be placed through rigid tremie tubes with a minimum diameter of 10 inches or through rigid pump tubes. The tubes are required to be capped or plugged with watertight plugs that will disengage once the tubes are charged with concrete. The tip of the concrete placement tube is required to be located a minimum of 10 feet below the rising head of concrete.

The concrete placement operation for a CIDH pile constructed under drilling slurry is an operation that requires much preplanning. Before the work begins, the contract specifications¹⁷ require the concrete mix design to meet the trial batch requirements for compressive strength concrete. The concrete mix must contain at least 675 pounds of cementitious material per cubic yard. It is also important to ensure that the clear rebar spacing is not less than 5 inches, except at locations of PVC inspection pipes where the clear spacing between adjoining vertical rebars should be no less than 8.5 inches as explained in Section 9-8, *Inspection and Contract Administration*. The Designer should be contacted if this is not the case. A concrete test batch is also required to show the concrete mix design meets the consistency requirements of the contract specifications. The concrete consistency requirements are to ensure that the concrete will remain fluid throughout the length of the pour. The Engineer does not allow the Contractor to exceed the maximum allowable water requirement to achieve this goal. Chemical admixtures will most likely be necessary. It is also important for the concrete mix to be properly proportioned to prevent segregation and excess bleed water due to the high fluidity of the concrete.

The method of concrete placement should not allow the intermingling of concrete and drilling slurry. The contract specifications allow placement of concrete through rigid tremie tubes, or through rigid tubes connected directly to a concrete pump. In order to prevent intermingling of concrete and drilling slurry, the concrete placement tubes must be capped with a watertight cap or plugged such that the concrete will not come into contact with the drilling slurry within the concrete placement tube. The cap or plug should be designed to release when the placement tube is charged with concrete. Charging the placement tube with concrete must not begin until the capped or plugged tip of the placement tube is resting on the bottom of the drilled hole. Once the placement tube has been charged, the pour is initiated by lifting the tip of the placement tube 6

¹⁵ 2010 SS, Section 49-3.02A(4)(d)(ii), *Vertical Inspection Pipes*, or Special Provisions for contracts using 2006 SS.

¹⁶ 2010 SS, Section 49-3.02C(8), *Placing Concrete Under Slurry*, or Special Provisions for contracts using 2006 SS.

¹⁷ 2010 SS, Section 49-3.01B(1), *Materials General*, or Special Provisions for contracts using 2006 SS.

inches above the bottom of the drilled hole. This allows the concrete in the placement tube to force the cap or plug out of the placement tube and discharge.

Once the pour has started, it is important to place the concrete at a high rate until the tip of the placement tube is embedded in the concrete. If concrete placement operations slow or stop before the tip of the placement tube is embedded in concrete, there is nothing to prevent the intrusion of drilling slurry into the placement tube. If this happens, the likely result will be a defect at the tip of the pile.

In accordance with the contract specifications¹⁸, when concrete placement begins, the tip of the concrete placement tube must not be raised from 6 inches above the bottom of the drilled hole until a minimum of 10 feet of concrete has been placed in the pile. After this level is reached, the tip of the concrete placement tube must be maintained at a minimum of 10 feet below the rising head of concrete. The best way to verify that the tip of the concrete placement tube is being maintained at this is for the Contractor to mark intervals of known distance on the placement tube and to measure the distance from the top of the pile to the rising head of concrete with a weighted tape measure.

If for some reason concrete placement is interrupted, such that the placement tube must be removed from the concrete, the placement tube must be cleaned, capped, and pushed at least 10 feet into the concrete head before restarting concrete placement in accordance with the contract specifications²⁰. Concrete placement continues in this manner until the rising head of concrete reaches the top of the pile. Concrete is then wasted until all traces of particle settlement and drilling slurry contamination are no longer evident. Under circumstances where contaminated concrete cannot be wasted from the top of the pile, such as having a pile construction joint within a permanent casing below grade, pile concrete is placed to a predetermined level above the planned concrete placement elevation, and the contaminated concrete above the planned concrete placement elevation is either mucked out immediately after placement or chipped out at a later time.

Vibration of the pile concrete is not necessary because concrete with high fluidity self-consolidates under the high hydrostatic pressure provided.

The intent of these specifications is to prevent the concrete from intermingling with the drilling slurry during concrete placement and avoid pile defects.

9-8 Inspection and Contract Administration

The reader is advised to review this section in Chapter 6, *Cast-In-Drilled-Hole Piles*. All inspection and contract administration information listed therein, with the exception of items that are precluded by the presence of slurry in the drilled hole, are applicable to

¹⁸ 2010 SS, Section 49-3.02C(8), *Placing Concrete Under Slurry*, or Special Provisions for contracts using 2006 SS.

CIDH piles constructed using the slurry displacement method. This section outlines the additional requirements for CIDH piles constructed using the slurry displacement method.

The contract specifications¹⁹ require the Contractor to submit to the Engineer a Pile Installation Plan for review and authorization. The Pile Installation Plan should provide sufficient detail for the Engineer to grasp the means, methods, and materials the Contractor plans to use to successfully complete pile installation. Typical requirements include those listed in Chapter 6, *Cast-In-Drilled-Hole Piles*, as well as additional requirements including the following:

Table 9-1. Additional Pile Installation Plan Requirements.

ITEM	PILE INSTALLATION PLAN REQUIREMENT & REASONING
1	Concrete batching, delivery, and placing systems, including time schedules and capacities. Time schedules will include the time required for each concrete placing operation at each pile. Reasoning: This gives the Engineer advance knowledge of how, when, and how long it will take for the Contractor to place concrete in each pile and whether the proposal is appropriate. Time schedules are also necessary to determine the amount of time required for the concrete test batch.
2	Concrete placing rate calculations. If requested, base calculations on the initial pump pressures or static head on the concrete and losses throughout the placing system, including anticipated head of slurry and concrete to be displaced. Reasoning: This gives the Engineer additional knowledge of how the Contractor proposes to place concrete in each CIDH pile and is considered supplementary information for Item 1. This information is especially important for large deep piles as it will be used to verify whether the proposed concrete delivery system has enough pressure to displace the anticipated head of slurry and the fluid concrete placed in the pile.
3	Suppliers' test reports on the physical and chemical properties of the slurry and any proposed slurry chemical additives, including Material Safety Data Sheets (MSDSs). Reasoning: This gives the Engineer advance knowledge of the slurry and any chemical additives that the Contractor proposes to use and whether the proposal is appropriate for each pile.
4	Slurry testing equipment and procedures. Reasoning: This gives the Engineer advance knowledge of the slurry testing equipment and procedures to verify that they are in accordance with the requirements of the contract specifications.
5	Methods of removal and disposal of excavation, slurry, and contaminated concrete, including removal rates. Reasoning: This gives the Engineer advance knowledge of the means the Contractor proposes to use for disposal of spoils from CIDH pile construction and whether the proposal is appropriate and in conformance with the contract specifications ²⁰ .
6	Methods and equipment for slurry agitating, recirculating, and cleaning.

¹⁹ 2010 SS, Section 49-3.02A(3)(b) *Pile Installation Plan*, or Special Provisions for contracts using 2006 SS.

²⁰ 2010 SS, Section 5-1.20B(4) *Contractor-Property Owner Agreement*, or 2006 SS, Section 7-1.13, *Disposal of Material Outside the Highway Right of Way*.

ITEM	PILE INSTALLATION PLAN REQUIREMENT & REASONING
	<p>Reasoning: This gives the Engineer advance knowledge of the means the Contractor proposes to use for mixing, circulating, cleaning and reusing the slurry. This is especially important if the Contractor proposes to use mineral slurry.</p>

In order to facilitate pile testing, the contract specifications²¹ require the installation of inspection pipes (Figure 9-22). Before the rebar cage is placed in the drilled hole, the Engineer should verify the inspection pipes are installed inside the spiral or hoop reinforcement and are at least 3 inches away from the vertical reinforcement of the pile bar reinforcement cage. Figure 9-23 shows a typical inspection pipe layout and spacing pattern within the pile bar reinforcement cage. These pipes must be placed in a straight alignment, securely fastened in place, and be watertight. These pipes permit the insertion of a Gamma-Gamma Logging test probe that measures the density of the pile concrete. The most commonly used test probe is 1.25 inches in diameter and 54 inches in length. If the inspection pipes are not placed in a straight alignment or are not securely fastened, the test probe will not fit in the inspection pipe. One way of testing the pipe would be to try to deflect it by hand. If it can be deflected by hand, it may be deflected by the placement of concrete. It is also recommended that the Contractor install a rigid rod in each inspection pipe prior to concrete placement to ensure that the inspection pipes remain straight during and after concrete placement. Inspection pipes need to be filled with water prior to or immediately after completion of the concrete placement. The reason for this is to prevent the inspection pipe from separating from the pile concrete (debonding) or overheating during the curing process. This helps keep the inspection pipe intact so that it can be used for crosshole sonic logging at a later point if necessary. Once the inspection pipe has separated or had airspace created between it and the pile concrete, crosshole sonic logging can no longer be performed because the airspace registers as an anomaly.

The contract specifications also require the Contractor to log the locations of any inspection pipe couplers and submit the log to the Engineer. This is necessary because inspection pipe couplers show up as areas of lower density when a gamma ray scattering test is performed. Testing personnel can ignore these areas if they are aware of the coupler locations.

²¹ 2010 SS, Section 49-3.02A(4)(d)(ii), *Vertical Inspection Pipes*, or Special Provisions for contracts using 2006 SS.



Figure 9-22. Inspection Pipes.

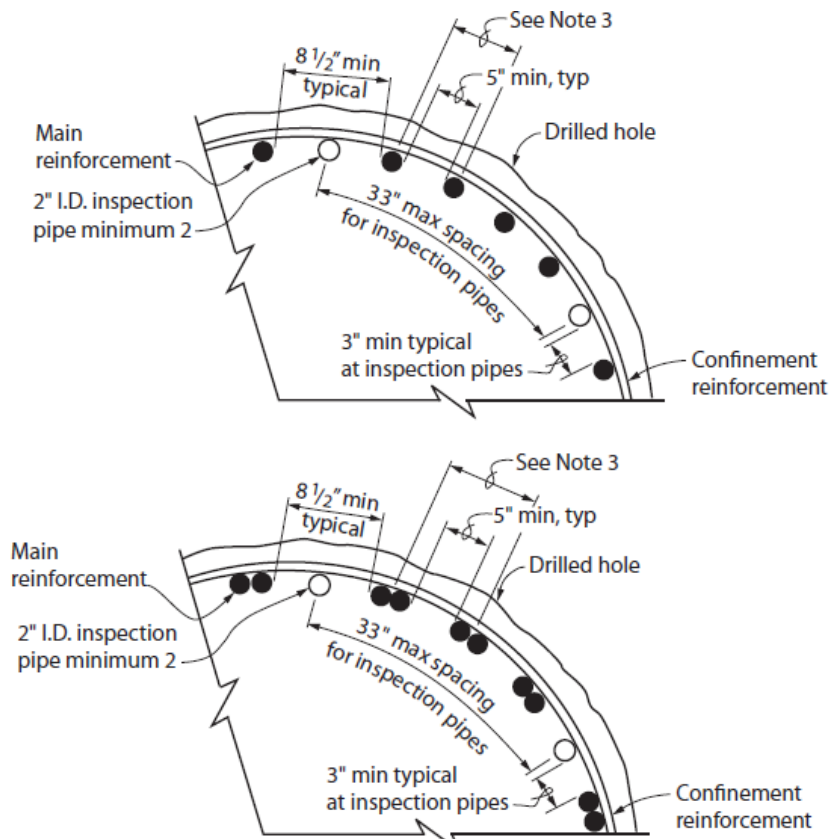


Figure 9-23. Location of Inspection Pipes within the Pile.



The Engineer will notify Geotechnical Services, Foundation Testing Branch (FTB) as soon as the proposed pile concrete placement date is known, in accordance with the provisions of Bridge Construction Memos 130-1.0, *Foundation Testing Branch* and 130-10.0, *Testing of CIDH Piling*. This places the FTB on notice that acceptance testing will be required and approximately when it will be needed.

The Engineer should be present when the slurry manufacturer's representative is on site to verify the slurry is mixed, placed, tested, and disposed of or cleaned in accordance with the provisions of the authorized Pile Installation Plan and the contract specifications. The Engineer should also perform side-by-side slurry tests with the Contractor or manufacturer's representative at least once per project. Slurry testing equipment is available from the Bridge Construction Engineer.

During drilling operations, the Engineer should monitor the height of the slurry in the drilled hole to verify that positive hydrostatic pressure is being maintained on the sides of the drilled hole.

Prior to placement of concrete, the Engineer should verify the properties of the slurry are within the specification requirements and that the bottom of the drilled hole is clean in accordance with the provisions of the authorized Pile Installation Plan. This is very important because settled materials left at the bottom of the pile cause over 50% of all pile defects.

Concrete placement warrants continuous inspection. The Engineer should verify that all equipment needed to measure the height of the concrete placed in the pile, the depth of the concrete placement tube within the head of concrete, and the volume of concrete placed in the pile in accordance with the provisions of the Pile Installation Plan are on site and ready for use. During concrete placement operations, the Engineer should verify that the concrete placement tube is always at least 10 feet below the free surface of the in-place concrete. The specifications require the Contractor to maintain a log of concrete placement for each pile and to deliver the completed log to the Engineer after completion of concrete placement in each pile. This log is used to pinpoint any potential problem zones within the pile that may have occurred during concrete placement. Potential problem zones are denoted on the log by marked differences between the actual amount of concrete placed and the theoretical amount of concrete that should have been placed at the same elevation within the pile.

9-9 Pile Acceptance Testing

After concrete placement and before acceptance testing is performed, the inspection pipes must be checked by the Contractor for blockages and straightness by passing a rigid cylinder (dummy probe) that is the same size and shape as the gamma ray scattering test

probe in accordance with the contract specifications²². The Contractor must demonstrate to your satisfaction that the dummy probe passes freely through each inspection pipe without the application of any force. For reasons mentioned below, the FTB will not test any inspection pipe that cannot pass the dummy probe. Inspection pipes that cannot accept the dummy probe must immediately be refilled with water. They must also be replaced with a 2 inch diameter cored hole the full length of the pile. The Engineer should discuss this requirement with members of the Division of Engineering Services (DES) CIDH Pile Committee before any coring is performed. The reason the inspection pipes must be refilled with water is to eliminate pipe-to-concrete debonding problems that can render crosshole sonic logging unusable.

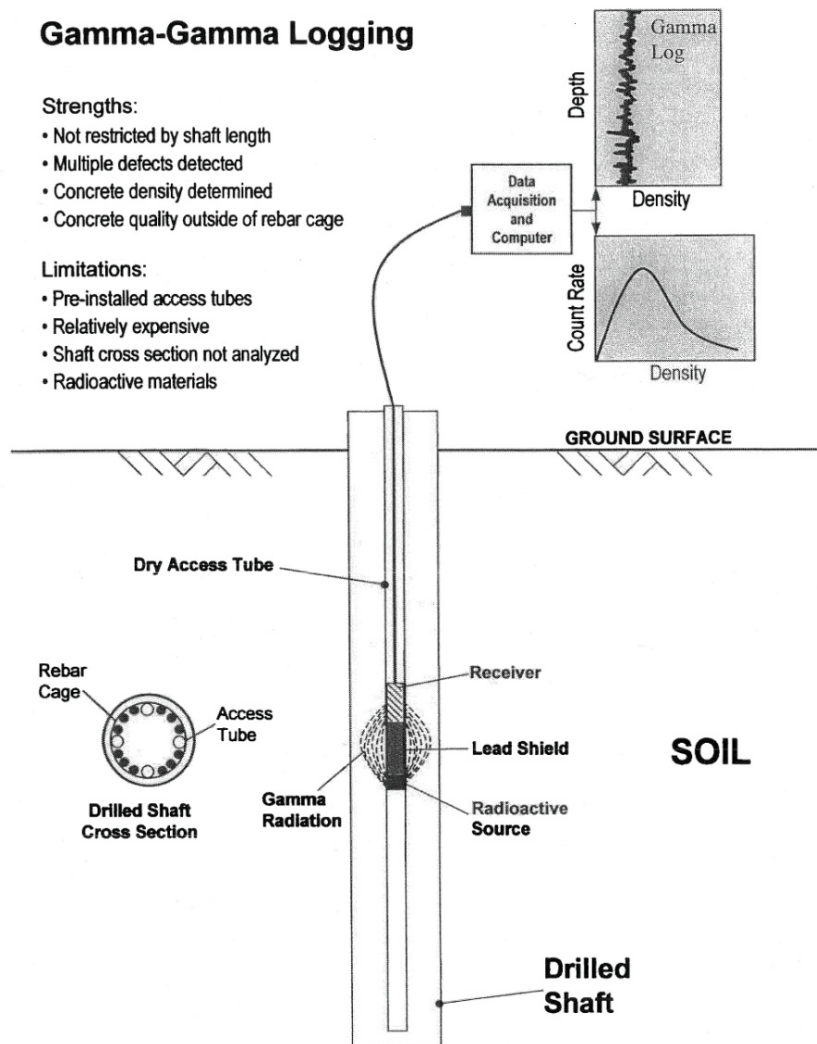


Figure 9-24. Gamma-Gamma Logging Test Schematic.

²² 2010 SS, Section 49-3.02A(4)(d)(ii), *Vertical Inspection Pipes*, or Special Provisions for contracts using 2006 SS.

Determining the soundness of slurry displacement piles is important. There are a number of methods that may be used to test the soundness of these piles. One method is the use of external vibration, which measures stress wave propagations in the pile using either internal or external receivers. This requires a variety of expensive electronic gear and skilled operators, as well as the placement of instrumentation on the pile bar reinforcement cage prior to concrete placement. Another method uses an acoustical technique, which is commonly referred to as crosshole sonic logging. This involves lowering sender and receiver probes into the inspection pipes to measure the velocity of sonic waves through the concrete. Defective concrete is registered by the increased amount of time it takes for the sonic wave to be received by the receiver probe, as opposed to the shorter amount of time it takes for the sonic wave to be received across a solid medium (sound concrete). A third method would be to core the pile and recover the physical cores for inspection. This method may be the most conclusive, but is very time consuming and is destructive. A fourth method uses a radiographic technique called Gamma-Gamma Logging (GGL) (Figure 9-24).

The contract specifications²³ state the GGL method of testing piles constructed using the slurry displacement method is used to determine acceptance of the pile, in accordance with the provisions of California Test 233.

During GGL testing, scatter counts are taken and compared to counts taken on a standard containing the same material being tested. By this means, relative densities can be ascertained. In general, the lower the scatter count, the denser the material. The nuclear probe used in these tests contains a source that is relatively weak and its effective range of sensitivity is limited to a 3-inch radius of concrete around the inspection pipe. Because of the nature of the data acquired, proper assessment or determination of the existence of defective concrete or voids is subject to interpretation of the results. Typical testing consists of continuous counts taken as the test probe is raised from the tip of the pile at 10 to 12 feet per minute. This procedure requires about 2 hours to log all of the inspection pipes for a 4 foot diameter pile 100 feet in length.

Because GGL uses a nuclear probe, radiation safety is of paramount importance. The FTB is permitted to use this testing equipment by State and Federal government regulators by establishing and following strict radiation safety protocols. These protocols include no unauthorized persons within 25 horizontal feet of the nuclear probe and no possibility of getting the nuclear probe stuck in the inspection pipe due to inspection pipe misalignment. The FTB can lose their permit to use nuclear materials if radiation safety protocols are not followed. Consultant testers under the auspices of the FTB must also follow strict radiation safety protocols. Radiation safety is the primary reason the Contractor is required to pass a dummy probe through each inspection tube prior to the FTB arriving on site to test the piles.

²³ 2010 SS, Section 49-3.02A(4)(d)(iii), *Gamma-Gamma Logging*, or Special Provisions for contracts using 2006 SS.

The contract specifications²⁴ also state that crosshole sonic logging or other means of inspection may be used to further evaluate a rejected pile. Typically, crosshole sonic logging or other means of inspection are used to complement the results of GGL testing and are only performed after GGL testing has been performed and the pile has been rejected.

All test methods used to accept CIDH piles constructed under slurry are performed by Caltrans personnel from Geotechnical Services, Foundation Testing Branch (FTB), or by consultant personnel under the auspices of the FTB. The results of such testing, which include a recommendation of acceptance or rejection of the pile, are reported to the Engineer in writing. An example of these results can be found in Appendix G, *Slurry Displacement Piles*. Further information on pile acceptance testing may be found at the FTB web page.²⁵

The Engineer has the responsibility for accepting or rejecting a pile based on the recommendations of the FTB. If the pile is accepted, the inspection pipes may be cleaned and grouted, and the pile is complete.

9-10 Defective Piles

What causes piles constructed by the slurry displacement method to be defective? One of the primary reasons for pile defects is a problem caused by the presence of settled materials at the bottom of the drilled hole. These are materials that were held in suspension by the drilling slurry that settled out of suspension either before or during the concrete placement operation. These materials can also be the result of improper cleaning of the base of the drilled hole. These materials can be trapped at the bottom of the pile by concrete placement as shown in Figure 9-25(a) or they can be enveloped and lifted by the fluid concrete only to become caught by the pile bar reinforcement cage or against the sides of the drilled hole and not displaced by the fluid concrete as shown on Figure 9-25(b). These materials can also fall out of suspension and settle onto the head of concrete during concrete placement, become enveloped by the concrete as it rises, and attach to the pile bar reinforcement cage or the sides of the drilled hole as previously described. During pile testing, these deposits will register as areas of lower density than that of sound concrete. Excessive amounts of settled materials can occur in mineral slurries that were not properly cleaned or agitated and carry inordinate amounts of suspended materials. Excessive amounts of settled materials can occur in synthetic slurries when not enough time is allowed for the materials to settle out before the final cleaning of the bottom of the drilled hole or if the synthetic slurry becomes contaminated from clay-particle encapsulation.

²⁴ 2010 SS, Section 49-3.02A(4)(d)(iv), *Rejected Piles*, or Special Provisions for contracts using 2006 SS.

²⁵ http://www.dot.ca.gov/hq/esc/geotech/geo_support/foundation_testing/ftb.html

Another reason for pile defects is due to improper drilling slurry handling. If mineral slurries are not properly mixed and are not allowed to properly hydrate, they can form balls or clumps that can become attached to the pile bar reinforcement cage and not be removed by concrete placement as is shown in Figure 9-26. Mineral slurries that remain in the drilled hole for too long can form a filter cake that is too thick for the fluid concrete to scour off the sides of the drilled hole as is shown in Figure 9-27. Mineral and synthetic slurries that carry an excessive load of suspended materials can be subject to precipitation if an unexpected chemical reaction takes place. This is possible if the concrete is dropped through the drilling slurry.

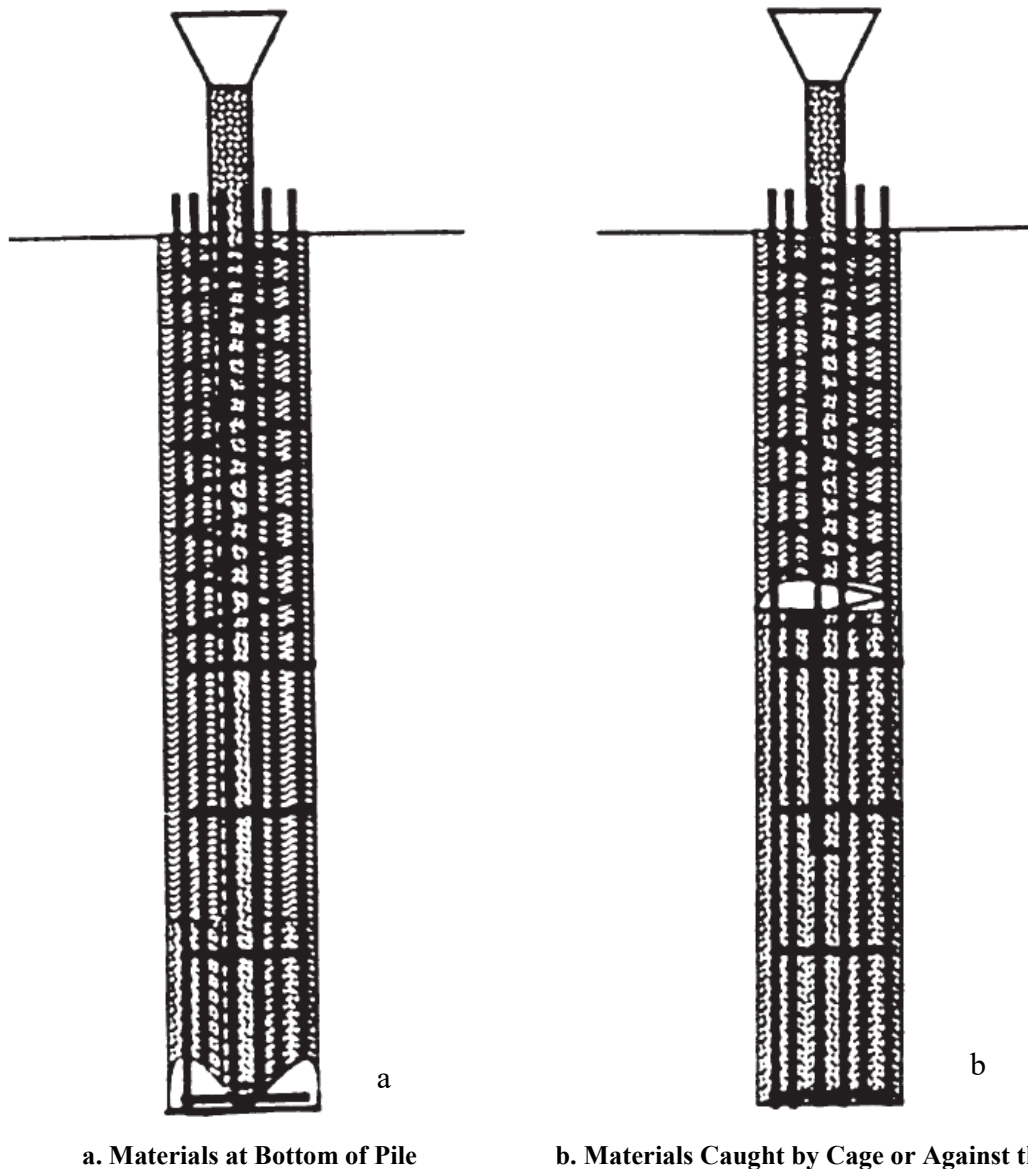


Figure 9-25 (a) (b). Defects from Settled Materials.

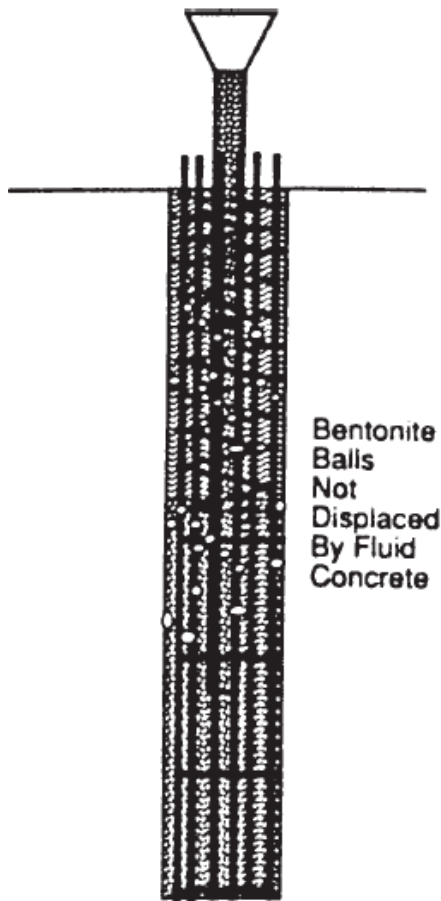


Figure 9-26.
Defect from Improperly Mixed Mineral Slurry.

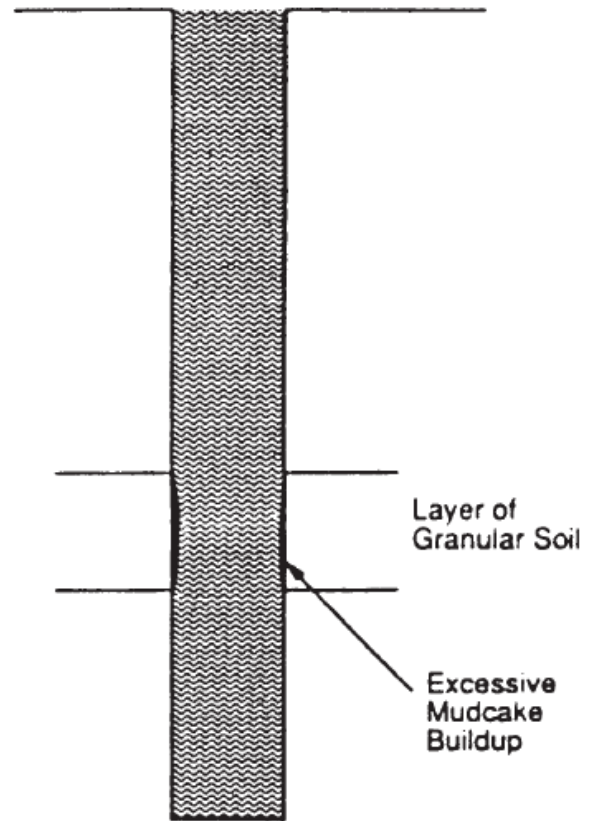


Figure 9-27.
Defect from Excess Filter Cake Buildup.

A third reason for pile defects is concrete mix design and placement problems. The most common defect of this type occurs when an insufficient amount of slurry-contaminated concrete is wasted from the top of the pile during concrete placement, resulting in a defective pile top. To avoid this type of defect, it is recommended that the volume of concrete to a depth of one pile diameter within the pile be wasted. A less common defect can occur when the seal between the head of concrete and the drilling slurry is lost. This is because entrapment of drilling slurry within the concrete is almost inevitable under this circumstance (Figure 9-28). If the concrete placement tube loses its seal and allows concrete from the placement tube to drop through the drilling slurry onto the head of concrete, the drilling slurry and any settled material on the head of concrete could be trapped between the concrete layers, causing a pile defect. Typically this occurs when the concrete placement tube is removed too rapidly and pulled out of the concrete head. Another less common defect can occur if the concrete head begins to set, resulting in the concrete “folding” over as it rises through the pile bar reinforcement cage and entrapping drilling slurry and any settled materials as previously described. Yet another type of pile defect can result due to concrete mix design problems. The Engineer should not permit

the use of excess water in the concrete mix design or allow additional water to be mixed with the concrete at the jobsite to provide the necessary fluidity. This may result in severe bleed water from the concrete after placement, which could indicate segregation and subsidence of the pile concrete. This may cause the entire pile to be defective. If excess free water in the concrete is present when synthetic slurries are used, the excess free water will attract the polymer chains from the drilling slurry into the concrete and produce a material contaminant known as oatmeal at the concrete-slurry interface. This material can potentially be caught on the pile bar reinforcement cage and cause pile defects.

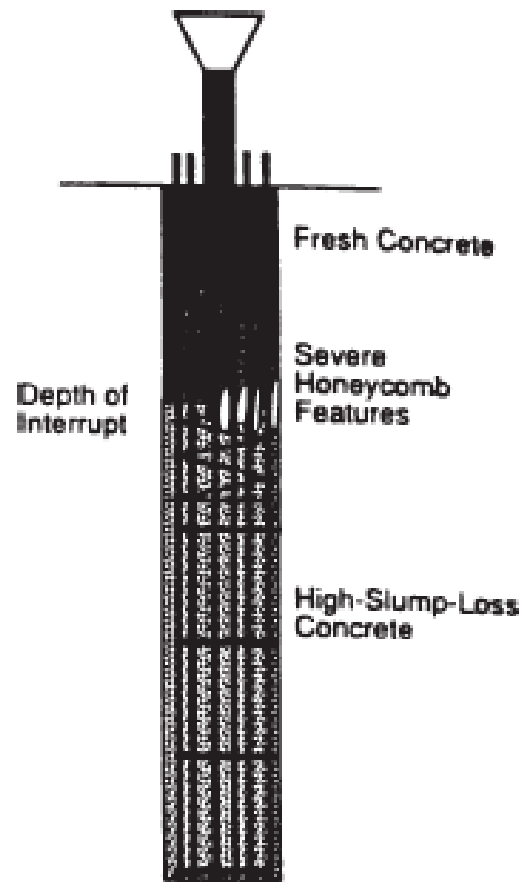


Figure 9-28. Defect from Concrete Placement Problems.

These types of problems can be avoided if the Contractor and the Engineer closely follow the parameters specified in the contract specifications. These specifications help to ensure the proper mixing and properties of drilling slurries, the proper qualities of the concrete mix design, and the proper methods of concrete placement.

If the FTB recommends rejection of the pile and the Engineer rejects the pile, the Contractor must be informed in writing that the pile is rejected and given a copy of the

GGL test results. The contract specifications²⁶ also require suspension of the placement of concrete under drilling slurry until written modifications to the method of pile construction are submitted to and authorized by the Engineer. This is to prevent additional failures due to the method of pile construction.

9-11 Pile Mitigation and Acceptance

9-11.1 What Happens When a Pile is Rejected

Once a pile has been rejected and the Engineer determines the rejected pile requires repair, the Contractor has several options. The defect can be accessed and repaired, the pile can be supplemented, the pile can be replaced, or the Contractor may propose a solution that allows the pile to remain in place. The Contractor's proposal is submitted to the Engineer in the form of a Pile Mitigation Plan.

When a pile has been rejected, the Engineer should confer with the FTB and decide if the FTB will perform crosshole sonic logging on the rejected pile. Typically, the GGL test report will indicate whether the FTB will perform crosshole sonic logging. Crosshole sonic logging is used to further delineate the nature of the defective area within the rejected pile. Generally, this test method is used to determine whether the defective area is within the core of the pile or at the perimeter surrounding the bar reinforcement cage. If crosshole sonic logging is performed, the results of this test should be made available to the Contractor to aid in the preparation of their Pile Mitigation Plan.

The Contractor may also perform an investigation on the rejected pile. They may perform their own non-destructive testing or may core the pile to further determine the nature of the defective area of the rejected pile. The Contractor should submit the results of their investigation to the Engineer and use the results of their investigation in preparation of their Pile Mitigation Plan.

9-11.2 Pile Mitigation Methodologies

There are several ways to mitigate a pile once it has been determined to have anomalies and has been rejected. Mitigation of defective CIDH piles can be grouped into four methodologies:

1. Unearth and Recast (Basic Repair).
2. Pressure Grout (Grouting Repair).
3. Structural Bridging.
4. Supplement/Replacement.

The following sub-sections address how to take corrective action on a rejected pile.

²⁶ 2010 SS, Section 49-3.02A(4)(d)(iv), *Rejected Piles*, or Special Provisions for contracts using 2006 SS.

9-11.3 Repairs

9-11.3.1 Basic Repair

Basic repair is simply the mechanical removal and replacement of any concrete within the defective zone of the pile, as defined by the pile acceptance test results. When a basic repair is performed within 5 feet of the top of the pile, it is known as a Simple repair, as defined in Bridge Construction Memo 130-11.0, *Simple Repair of CIDH Piling*.

Typically, a basic repair is used to mitigate pile defects caused by not wasting enough concrete from the top of the pile during concrete placement. However, basic repairs can be performed deeper down the length of the pile, provided shoring is in place to permit access to the defect. Should the Contractor propose a basic repair below 5 feet from the top of the pile, the Engineer must consult with the Geoprofessional to assess the effect of accessing the defect upon the skin friction capacity of the pile.

9-11.3.2 Grouting Repair

Grouting repairs are used to mitigate defective concrete within the pile. These repairs, when applicable, can be performed at any location within the pile, but are generally not performed within 5 feet of the top of the pile, since it is more effective to use a basic repair at this location. Grouting repairs are performed using three types of grouting procedures: (1) permeation grouting, (2) replacement grouting, or (3) compaction grouting.

Several operations are common to permeation and replacement grouting repairs. First, the Contractor must access the defective area. This is usually done through the existing inspection pipes. Generally, the inspection pipe is removed at the defective area using a high-pressure water jet, which cuts the inspection pipe into small pieces that are then flushed out through the top of the inspection pipe. Once the inspection pipe has been removed at the defective area, the Contractor will wash the defective area using high-pressure water jets and observe the discharge for soil, fragmented concrete, or other contaminants. After the initial washing operation is complete, the Contractor will evaluate the defective area using water flow testing.

Water flow testing is used to assess the nature of the defective area and determine whether permeation or replacement grouting is appropriate. If water can be injected into a defective area at low pressure and relatively high volume, then permeation grouting may be the appropriate grouting repair technique. If the defective area is large enough and permeable, communication with other inspection pipes may be observed, meaning the water injected into one inspection pipe may return to the ground surface through adjacent inspection pipes. Water may also flow into the soil formation if the defective area extends to the edge of the pile concrete. However, if water cannot be injected into a defective area, replacement grouting may be the appropriate grouting repair technique. This is an indicator that the defective area is contained within the pile concrete and the concrete surrounding the defective area is sound.

Once water flow testing has been conducted, the Contractor will typically flush the defective area using low pressure flowing water to remove any remaining loose material. The Contractor may then use a down-hole camera or other means to verify loose materials were adequately removed from the defective area.

9-11.3.2.A Permeation Grouting.

Typically used to repair a “soft tip” within the pile concrete, to increase frictional resistance along the side of the pile, or to address corrosion issues at the side of the pile. Usually, permeation grouting is used to repair defects caused by excessive settled materials not removed from the bottom of the drilled hole prior to concrete placement. First, the inspection pipe is removed at the location of the defective area. Then the area is washed with high-pressure water jets to remove any contaminants and loose materials. The discharge from the washing operation is evaluated. Generally, permeation grouting is recommended only if soil is present in the washing discharge or water flow testing verifies the permeability of defective area. High-pressure grout injection is performed, usually through one of the inspection pipes, with the grout permeating the soil or concrete formation, displacing any pore water that may be present, resulting in a solid matrix of cement grout and defective concrete or soil. Permeation grouting is only successful if the pore water present in the formation can be forced out by the grout, meaning that the pore water must be able to escape into the adjacent soil or through an adjacent inspection pipe. Permeation grouting also requires the presence of sufficient confining pressure to conduct grouting operations without grout returning to the surface. For these reasons, permeation grouting is not recommended for repair of defects completely within the pile or within 10 feet of the ground (or working) surface.

9-11.3.2.B Replacement Grouting.

Typically used to repair a void area or an area of unconsolidated concrete within the pile. Typically, replacement grouting is used to repair defects caused by concrete placement problems. As with permeation grouting, access to the defective area is usually provided through the existing inspection pipes. First, the inspection pipe is removed at the location of the defective area. Then the area is washed with high-pressure water jets to remove any contaminants and loose materials. This generally results in the creation of a void within the pile concrete. The discharge from the washing operation is evaluated. Generally, replacement grouting is recommended only if soil is not present in the discharge or water flow testing indicates the defective area is impermeable. All water resulting from the washing operation must be removed from the void prior to placement of grout. This is typically done with compressed air. Grout is then pumped into the void, in effect, “replacing” the voided area with grout. Replacement grouting cannot be used if the grout has a means of escaping the void area. If a side of the void area includes the side or bottom of the drilled hole, replacement grouting generally cannot be used to repair the pile defect.

9-11.3.2.C *Compaction Grouting.*

Typically used to enhance the load-bearing capacity of the soil at the tip of the pile. Because of the inherent difficulty of employing grouting methods below the tip of a pile, compaction grouting is only used when the pile defect consists of a “soft tip” and end bearing is required in the design. Access to the defective area is usually provided through the existing inspection pipes. Generally, only the bottom of the inspection pipe is removed and the area below the inspection pipe is not washed or flushed. Grout is then pumped at high pressure into the loose soil formation at the tip of the pile, resulting in a “bulb” of soil-grout matrix at the tip of the pile. In order to be successful, compaction grouting must be performed through each inspection pipe.

On some projects, “tip grouting” is specified to enhance the end bearing capacity of the pile. Compaction grouting differs from tip grouting in that tip grouting is shown on the contract documents and has additional pipes and other equipment for grout access to the tip of the pile, whereas compaction grouting is a remedial procedure. The problem that arises concerning compaction grouting and tip grouting is there is no way to evaluate the pile end bearing capacity gained as a result of these operations.

Depending on the nature and number of defective areas within the pile, one or more of the grouting procedures described above may be required.

9-11.4 **Structural Bridging**

Structural bridging can be performed to increase the structural strength of a defective pile without complete removal of the defect. It is typically performed by coring the center of the pile and installing a structural steel section, rebar cage, or combination of both, cast into the central portion of the pile. This additional member may be designed to restore the structural strength of the pile to meet the project requirements. It may also be possible to extend a central drilled section into the bearing formation below pile tip to increase the geotechnical strength of the pile.

9-11.5 **Supplemental and Replacement Piles**

Occasionally, piles can be so riddled with defects that repair of the pile is not feasible. If the Engineer determines repair of the rejected pile is not feasible, the contract specifications²⁷ require the Contractor to submit a pile mitigation plan for replacement or supplementation of the rejected pile. If space exists, the Contractor may propose to place supplemental piles to enhance the load-bearing capacity of the defective pile. If there is no space available for supplemental piles, the Contractor may be required to remove the defective pile and replace it.

²⁷ 2010 SS, Section 49-3.02A(4)(d)(iv), *Rejected Piles*, or 2006 Special Provisions.

9-11.6 Pile Mitigation Plan Development and Authorization Procedures

Once a pile is rejected and it is determined that the pile requires mitigation, the contract specifications²⁸ require the Contractor to submit a Pile Mitigation Plan for review and authorization. A Pile Mitigation Plan is required for any type of repair proposed by the Contractor, or when supplemental or replacement piling is necessary.

The Association of Drilled Shaft Contractors (ADSC), which is an industry group composed of member drilling contractors, has developed several Standard CIDH Pile Anomaly Mitigation plans. These plans are intended to address the most common types of pile anomalies encountered, which generally consist of 80-90% of all pile anomalies. These plans encompass Basic Repair, Permeation Grouting and Replacement Grouting repair methods. Caltrans has authorized these plans for statewide use. The Engineer should expect to receive a Standard CIDH Pile Anomaly Mitigation plan when applicable. The Standard Plan should be incorporated into the Contractor’s Pile Mitigation Plan submittal to address the pile-specific Pile Mitigation Plan requirements of the contract specifications. The intent of the Standard CIDH Pile Anomaly Mitigation plans is to reduce the amount of time needed for the Contractor to develop the Pile Mitigation Plan and for the Engineer and DES Pile Mitigation Plan Review Committee to review and authorize the Pile Mitigation Plan.

To aid the Engineer, a copy of these Caltrans-authorized standard mitigation plans can be obtained by contacting Structure Construction in Sacramento or accessing the Intranet website.²⁹

Development and review of the Pile Mitigation Plan is a shared responsibility between the Engineer, the Contractor, the FTB and the DES Pile Mitigation Plan Review Committee.

9-11.7 Responsibilities of the Engineer

The Engineer is responsible for the following:

Table 9-2. Pile Mitigation Plan – Responsibilities of the Engineer.

ITEM	RESPONSIBILITY
1	Arranging for acceptance testing with the FTB. Based on the results of acceptance testing, accept or reject the pile and notify the Contractor in writing and supply the Contractor with a copy of the test results.
2	Once the pile has been rejected, determine in consultation with the FTB whether additional acceptance testing will be performed. Typically the pile acceptance test report will indicate if Caltrans intends to perform any additional testing. If additional acceptance testing is performed, notify the Contractor in writing and supply the Contractor with a copy of the test results. The Contractor may perform their own additional testing.
3a	Use the Pile Design Data Form provided with the test results to determine whether the pile requires mitigation for structural, geotechnical, or corrosion reasons. If the pile requires

²⁸ 2010 SS, Section 49-3.02A(3)(g), *Mitigation Plans*, or Special Provisions for contracts using 2006 SS.

²⁹ http://onramp.dot.ca.gov/hq/oscnet/FTB_Resources.htm

ITEM	RESPONSIBILITY
	mitigation, discuss with the CIDH Pile Mitigation Committee, the Designer, the Geoprofessional, and the Corrosion Engineer and come to a consensus on acceptable mitigation methodologies (Unearth and recast, pressure grout, structural bridging, supplement or replacement).
3b	If the results of the discussion described in Item 3a determine that mitigation is not required, notify the Contractor in writing that mitigation is not required. Per the contract specifications ³⁰ , the Contractor can either mitigate the pile or accept an administrative deduction for the pile as described in the contract specifications.
4	If the pile requires non-standard mitigation (i.e. structural bridging, supplement or replacement), hold a CIDH Pile Non-Standard Mitigation meeting with the Contractor as described in the contract specifications and Bridge Construction Memo 130-21.0, <i>CIDH Pile Non-Standard Mitigation Meeting</i> .
5	Upon receipt of the Contractor’s Pile Mitigation Plan, review the plan to ensure that it includes all of the requirements listed in the contract specifications ³¹ . If the plan does not include all of the requirements, return the plan to the Contractor for resubmittal. Once the Contractor submits a Pile Mitigation Plan that includes all of the requirements listed in the contract specifications, send the plan to the FTB and the DES Pile Mitigation Plan Review Committee for technical review.
6	Upon the recommendation of the FTB and the DES Pile Mitigation Plan Review Committee, either return the Pile Mitigation Plan to the Contractor for resubmittal or authorize the Pile Mitigation Plan.

9-11.8 Responsibilities of the Contractor

The Contractor is responsible for developing and submitting the Pile Mitigation Plan to the Engineer for review and authorization. The Contractor develops the plan using the acceptance testing results and the Pile Design Data forms provided by the Engineer, and in accordance with the outcome of the Non-Standard Mitigation Meeting (if applicable). Pile Mitigation Plans must contain the following information:

Table 9-3. Pile Mitigation Plan – Responsibilities of the Contractor.

ITEM	REQUIREMENT & REASONING
1	Designation and location of the rejected pile. Reason: Self-explanatory.
2	Review of the structural, geotechnical, and corrosion design requirements of the rejected pile. Reason: This information is provided to the Contractor by the Engineer via the Pile Design Data form. Requiring the Contractor to address the pile design requirements in the Pile Mitigation Plan ensures that the Contractor understands why the pile requires mitigation and that the proposed mitigation addresses the deficiencies in the pile to meet the design requirements.
3	Step-by-step description of the mitigation work to be performed, including drawings if necessary. Reason: This gives the Engineer advance knowledge of the means and methods the Contractor proposes to employ to mitigate the pile and to assess whether the proposed means and methods are sufficient to mitigate the deficiencies in the pile to meet the design requirements.

³⁰ 2010 SS, Section 49-3.02A(4)(d)(iv), *Rejected Piles*, or Special Provisions for contracts using 2006 SS.

³¹ 2010 SS, Section 49-3.02A(3)(g), *Mitigation Plans*, or Special Provisions for contracts using 2006 SS.



ITEM	REQUIREMENT & REASONING
4	<p>Assessment of how the proposed mitigation work will address the structural, geotechnical, and corrosion design requirements of the rejected pile.</p> <p>Reason: This is an expansion on Item 2 above. Requiring the Contractor to address the pile design requirements in the Pile Mitigation Plan ensures that the Contractor understands why the pile requires mitigation and that the proposed mitigation addresses the deficiencies in the pile to meet the design requirements.</p>
5	<p>Methods for preservation or restoration of existing earthen materials.</p> <p>Reason: Some mitigation methods, such as Basic Repair, may disturb the soil around the pile. Disturbance of the soil may affect the skin friction load carrying capacity of the pile. This requirement ensures that the Contractor considers the effect of the proposed mitigation upon the skin friction load carrying capacity of the pile.</p>
6	<p>List of affected facilities. Include methods and equipment to be used for the protection of these facilities during mitigation.</p> <p>Reason: There may be existing facilities, such as utilities, around or above the pile. This requirement ensures that the Contractor takes these facilities into account when developing the proposed mitigation.</p>
7	<p>In accordance with the contract specifications³² for Shop Drawings, the State assigned contract number, bridge number, full name of the structure as shown on the contract plans, District-County-Route-Postmile Post, and the Contractor's (and Subcontractor's if applicable) name on each sheet.</p> <p>Reason: This requirement ensures that the Pile Mitigation Plan is developed specifically for the rejected pile in question and that all sheets of the plan can be identified and referenced for that specific pile.</p>
8	<p>List of materials with quantity estimates for the mitigation work and a list of personnel with qualifications who will be performing the mitigation work.</p> <p>Reason: This requirement ensures that the Contractor is aware of how much material to have on site when the mitigation work is performed. It also ensures that the Contractor uses personnel who have done mitigation work in the past and are familiar with the mitigation procedures proposed in the Pile Mitigation Plan.</p>
9	<p>The seal and signature of an engineer who is registered as a Civil Engineer in the State, if required by the contract specifications³³.</p> <p>Reason: This ensures that the Pile Mitigation Plan is developed or at least reviewed by a registered civil engineer. This is necessary to ensure that the structural, geotechnical, and corrosion design requirements of the rejected pile are met.</p>
10	<p>For rejected piles to be repaired, an assessment of the nature and size of the anomalies in the rejected pile.</p> <p>Reason: Using the information provided in the acceptance test report, the log of concrete placement and other available information, the Contractor should be able to assess the nature of the anomalies in the rejected pile. This is necessary to determine what type of repair method is appropriate. The size of the anomaly may determine whether a basic or grout repair is appropriate. The nature of the anomaly, be it an area of unconsolidated concrete within the pile or a soil inclusion at the side of the pile, may determine whether a basic or grout repair is appropriate.</p>
11	<p>For rejected piles to be repaired, provisions for access for additional pile testing, if requested.</p> <p>Reason: Generally, pile mitigation methods utilize the existing inspection pipes for accessing the defective zone. This is almost always the case for grout repairs. The repair generally renders the inspection pipe unusable for the purposes of additional acceptance testing. Should the pile require additional acceptance testing after mitigation work has been</p>

³² 2010 SS, Section 5-1.23, *Submittals*, or Special Provisions for contracts using 2006 SS.

³³ 2010 SS, Section 49-3.02A(3)(g), *Mitigation Plans*, or Special Provisions for contracts using 2006 SS.

ITEM	REQUIREMENT & REASONING
	performed; the Contractor must address how to preserve the existing inspection pipes or provide new access, usually new-cored holes.
12	For rejected piles to be replaced or supplemented, the proposed location and size of additional piles. <i>Reason:</i> When rejected piles have to be supplemented or replaced, the Contractor is responsible for the design of these additional piles. The Engineer has to evaluate the design impact of the location and size of additional piling on the structure being constructed and any existing facilities or new facilities to be constructed during the life of the contract.
13	For rejected piles to be replaced or supplemented, structural details and calculations for any modification to the structure to accommodate the replacement or supplemental piles. <i>Reason:</i> See Item 12 above.

9-11.9 Responsibilities of the DES Pile Mitigation Plan Review Committee

The DES Pile Mitigation Plan Review Committee is responsible for the following:

Table 9-4. Pile Mitigation Plan—Responsibilities of the DES Pile Mitigation Plan Review Committee.

ITEM	RESPONSIBILITY
1	Provide advice to the Engineer regarding pile mitigation procedures and methods.
2	Coordinate with the FTB to provide a technical review of the Pile Mitigation Plan submitted by the Engineer. Advise the Engineer in writing whether the Pile Mitigation Plan should be authorized or returned to the Contractor for correction and resubmittal.
3	Act as keeper of information for all CIDH piles constructed under slurry.

Once all responsibilities of completion and review of the Pile Mitigation Plan have been completed, the Engineer authorizes the Pile Mitigation Plan.

After authorization of the Pile Mitigation Plan, the Contractor can proceed with the work of mitigating the pile in the field.

9-11.10 What to Expect in the Field During Pile Mitigation

Personnel involved with the pile mitigation work and inspection of the pile mitigation work should be thoroughly familiar with the details of the authorized Pile Mitigation Plan. Evaluation of the acceptability of the pile mitigation work is dependent upon whether the procedures described in the authorized Pile Mitigation Plan were followed.

A good Pile Mitigation Plan will allow for alternatives should the initial procedure not work. For example, if it is determined during the pile mitigation work that replacement grouting is no longer appropriate because soil was encountered in the flushing discharge, the Pile Mitigation Plan should allow an alternative for permeation grouting. Occasionally, actual conditions in the field determine that grouting repair is no longer appropriate, and the whole mitigation effort may have to be abandoned and a revised Pile Mitigation Plan submitted for authorization.

For grouting repairs, the Contractor should monitor and record observations of inspection pipe removal, the nature of the discharge from the washing operation, the pressure and flow rate of water flow testing, photos or video from the down-hole camera, and the volumes and pressures of grout placement.

For grouting repairs, the Engineer should be present to monitor the results of inspection pipe removal, assessment of the defective area of the pile, all flushing operations, and any grouting repair work performed.

For basic repairs, the Engineer should be present to verify the Contractor only removes the soil for which removal has been authorized in the Pile Mitigation Plan. The Engineer should also verify the Contractor has removed all contaminated or deleterious materials from the defective area of the pile. Finally, the Engineer should verify the Contractor replaces the soil around the repaired pile as prescribed in the authorized Pile Mitigation Plan.

9-11.11 Procedures for Authorizing the Pile Mitigation Work Performed in the Field and Pile Acceptance

The authorized Pile Mitigation Plan addresses how the pile mitigation work will be accepted. Generally, the pile can be accepted if the mitigation work is performed in accordance with the provisions of the authorized Pile Mitigation Plan. However, there are circumstances when the pile must be retested. Procedures for access for retesting are provided in the authorized Pile Mitigation Plan.

For all types of pile mitigation, once the mitigation work is complete, the contract specifications³⁴ require the Contractor to submit a Mitigation Report to the Engineer for review. The Mitigation Report should contain information on the Contractor's observations recorded during the mitigation work, including grout volumes and pressures if a grouting repair was performed. It is especially important that any deviations from the authorized Pile Mitigation Plan be included in the Mitigation Report. This is necessary so the Engineer can determine whether the deviations resulted in an effective repair. The results of any retesting should also be included in the Mitigation Report.

Once the pile mitigation work is accepted, any remaining open inspection pipes are grouted and the pile can be accepted.

9-12 Safety

Safety concerns to be considered during the construction of CIDH piles by the slurry displacement method are similar to those to be considered when CIDH piles are constructed by ordinary means. For specific information, refer to Chapter 6, *Cast-in-*

³⁴ 2010 SS, Section 49-3.02A(3)(h), *Mitigation Report*, or Special Provisions for contracts using 2006 SS.



Drilled-Hole Piles. However, there is one additional item that requires further attention; and that is the drilling slurry.

Some of the components of drilling slurries, especially chemical additives, are considered hazardous materials. It is advisable to avoid skin contact and to avoid breathing in vapors. The Construction Safety Orders require the Contractor to provide Material Safety Data Sheets (MSDS) for all drilling slurries and chemical additives. The Engineer should obtain these MSDS as part of the submittal of the Pile Installation Plan. During the tailgate safety meeting prior to CIDH pile construction, be sure to discuss the contents of the MSDS and discuss how Caltrans employees, the Contractor's employees, and any manufacturer's representatives that may be present will adhere to the safety precautions.

During construction, do not permit the use of drilling slurries or chemical additives for which a MSDS has not been submitted.