Protection of Embankments During Drilling and Grouting

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ABSTRACT: According to the USACE National Inventory of Dams, there are nearly 84,000 dams in the United States. More than 30% of these are Significant or High Hazard, and nearly 50% are more than 50 years old. The USACE estimates that the total cost for needed dam repairs in the US exceeds $50 Billion, with $16 Billion needed for high hazard dams. More than 83% of the dams in the US are earthen embankments. One of the most serious and unacceptable performance problems for embankment dams is excessive seepage. An earthen dam with seepage problems will most likely have experienced some type of damage to the embankment or soil rock interface. Rehabilitating dams with seepage deficiencies often requires drilling through the dam and into the rock foundation for the purpose of constructing a grouted cutoff. Grouting of a rock foundation requires that multiple items of equipment be tripped in and out of a hole multiple times. For this reason, it is common that a hole is cased through the embankment with standpipe and the overburden drill tooling removed. Creating penetrations through an earthen dam and into the foundation has the potential to create hydraulic interconnections that did not exist previously and can result in dam safety concerns. Given that the casings remain in place, proper sealing of the casing annulus is crucial to the long term integrity of the dam. Grouting operations result in significant hydraulic pressures being applied and the sequence of grouting operations and predominant orientation of the rock joints must also be considered to maximize the protection afforded to the embankment.

The authors have been involved in the construction of a majority of the USACE Major Dam Rehabilitations in the last decade where grouting was performed in response to seepage. As part of these projects, more than 500,000 lineal feet of standpipe through overburden was installed in water retaining embankments. This

paper reviews the methods employed for drilling through the embankment, the casing material utilized, means and methods utilized to grout the casing in place, interface treatment protocols, and sequence of grouting operations. Observed defects or issues are identified and the pros and cons of the methods specified or used are evaluated. Recommended means and methods for future projects are presented.

INTRODUCTION

Protection of embankments during subsequent rock drilling and grouting operations is critical to preventing damage along the soil rock interface, and to preserving the integrity of the embankment material. As discussed in Engineering Regulation (ER) 1110-1-1807 by the USACE (USACE, 2006), there have been many cases of damaged embankment or foundations caused by the circulating media while drilling. Loss of circulation has reportedly occurred when using air, resulting in pneumatic fracturing of embankments. Similarly, the use of water as the flushing medium during drilling operations has reportedly caused hydraulic fracturing and erosion in the embankment and foundation materials.

Consideration to protection of the embankment should be given to not only advancement through the embankment itself, but to any subsequent operations in the foundation as well. Damage to the embankment and soil rock interface is certainly avoidable and should be considered unacceptable. This issue should be carefully considered during design, and the best method for advancement through the embankment, treatment of the soil rock interface, and subsequent operations should be provided in the contract specifications. Clearly defining acceptable or required means and methods allows contractors to prepare correct pricing and execution plans, and more importantly, helps ensure the proper and safe execution of the project with respect to protecting the integrity of the embankment.

SEQUENCE OF GROUTING OPERATIONS

Proper sealing of the standpipe within the embankment is necessary prior to performing subsequent operations in the underlying bedrock such as rock drilling, water testing and grouting. Various alternatives exist for properly securing the standpipe within the embankment, but isolating the standpipe grouting (annular space grouting) from the interface treatment is highly advisable.

In the authors' experience, trying to combine these two operations can result in an unfilled annular space around the standpipe and/or an improperly treated interface. Both situations could be problematic in that subsequent flushing and drilling operations could consequently connect to the embankment. The recommended sequence of grouting operations after embankment drilling has been completed is to isolate the two zones via barrier bag inflation, properly seal or grout the standpipe in place, followed by treatment of the interface. Additionally, for further protection of the embankment from potential erosion during deeper drilling and grouting operations, downstaging the first two stages into bedrock is recommended. A schematic of this sequence is provided in Figure 1. Annular space grouting and interface treatment is further discussed in the sections that follow.

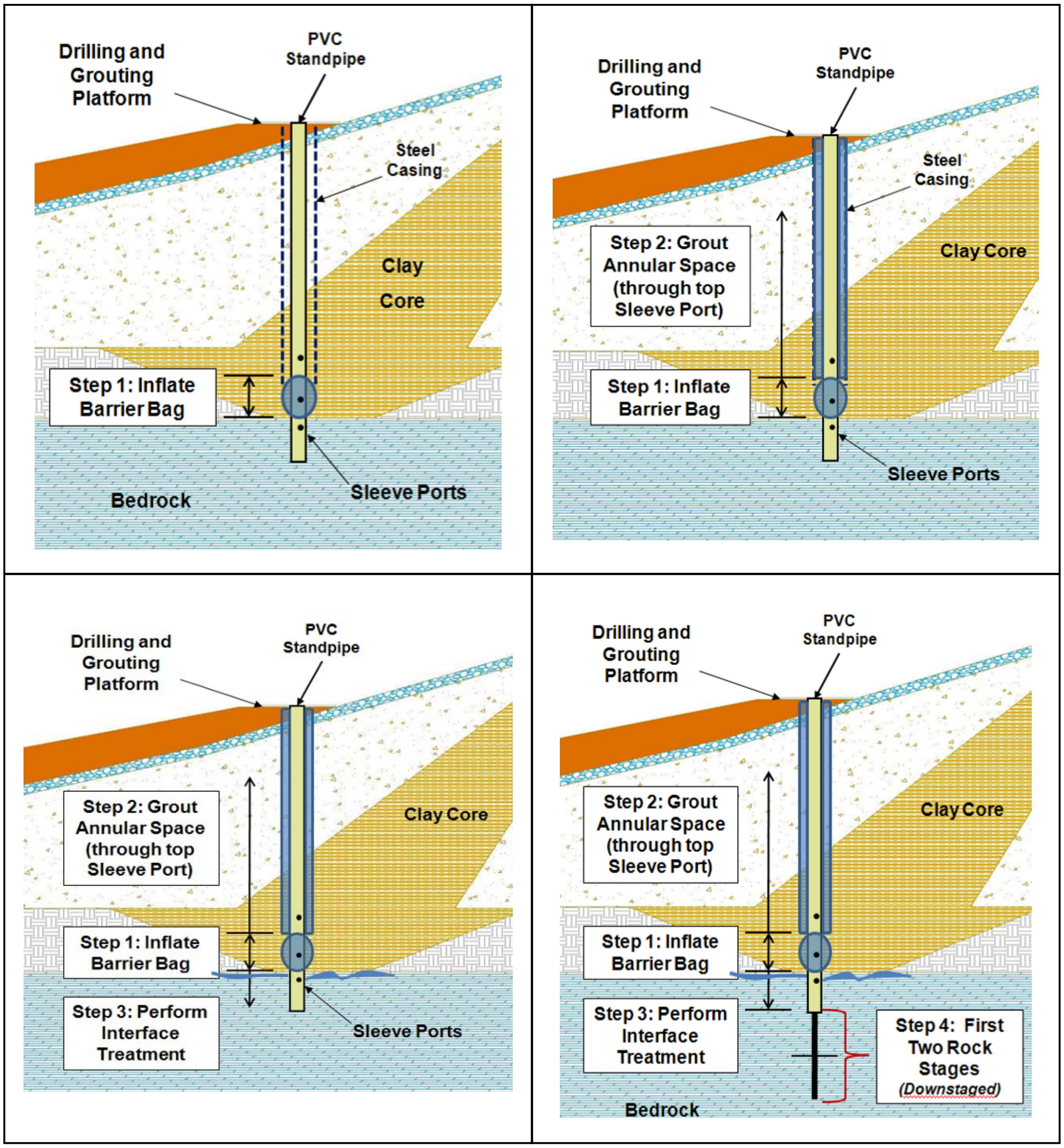

Figure 1: Schematic of Standpipe and Interface Grouting

Additionally, treatment of the upper zones of bedrock without pressure testing is sometimes practiced for increased protection against connections to the embankments through untreated rock discontinuities during subsequent rock drilling stages immediately below the interface.

Annular Space Grouting

Various methods of grouting standpipes in place have been used on past projects. Regardless of whether the overburden material consists of pervious shell material (coarse material), or impervious material (fine material), it is critical that the casing be completely encapsulated with grout. In a worst case condition, incompletely filled annular spaces could provide conduits or connecting paths that otherwise may not have existed from the developed phreatic surface through the embankment to a foundation defect (Bruce and Dreese, 2010). For example, the sinkholes that developed in the nearly 600-foot high WAC Bennett Dam in British Columbia were attributed to hydraulic connections at deteriorated instrument locations that provided a conduit for piping embankment material into the foundation (Jansen, 2004).

Standpipe left unsupported due to the lack of grout encapsulated around the pipe could split or break during subsequent rock drilling operations. Loads and pressures induced while percussing through grout that often remains in the pipe from grout injected in previous stages, could damage the integrity of the pipe. Such damage has been observed on past projects. Breaks in the PVC could expose the embankment to fluids introduced during rock drilling or stage/hole flushing operations. Flushing the standpipe after each grouting operation is recommended to help avoid this situation.

Where interface treatment is required (as is often the case in remedial grouting projects on existing embankments) annular space grouting should be isolated from the interface treatment. Experience on past remedial grouting projects on earthen dams has shown that combining the two operations can result in incompletely filled annular space due to loss of casing grout into the interface zone. This experience has further shown that large quantities of grout have been injected during the annular space grouting operation in the order of 5 to 10 times the annular space volume. The interface, whether it was the soil above the top of rock or the upper zone of untreated bedrock, was obviously accepting a large volume of the grout intended for sealing the standpipe. In addition, these experiences have shown that these casings further accepted large quantities of grout after the standpipe grouting operation was apparently finished.

The recommended method of isolating the two zones is using multiple packer sleeved pipe system (MPSP) (Bruce and Gallavresi, 1988) with a barrier bag attached to the pipe. Examples of both MPSP and textile barrier bags are provided in Figure 2.

Multiple Packer Sleeved Pipe (MPSP)

MPSP with Textile Barrier Bag

Figure 2: MPSP and MPSP with Textile Barrier Bag

MPSP is standpipe that allows grout injection at varying intervals. The pipe includes machined recesses at varying intervals. Intervals are generally at least 2-feet apart with holes typically ½-inch in diameter drilled for grout injection. As shown in Figure 2, thin tight fitting rubber gaskets are placed over the holes (within the recess) to function as a one-way valve. Minimal pressures (typically 5 to 10 psi net effective pressures) are required to open the gasket for grout injection. The sleeve contracts upon relieving the pressure, prohibiting the injected grout from re-entering the pipe.

The inclusion of the textile barrier bag will effectively isolate the interface zone, the grouting of which is further discussed in the following section.

Interface Treatment

With regards to remediation of existing structures, the soil rock interface often requires special attention due to embankment sensitivity when applying pressures for treatment of the underlying bedrock. Caution should be exercised to avoid over-pressuring in the embankment. For this reason, it is highly recommended (but not always practiced) to separate the interface treatment into its own stage and not be combined with annular space grouting.

A well recognized method of isolating the interface is to install MPSP with a geotextile barrier bag. A textile barrier bag is affixed to the outside of the MPSP, over at least one of the sleeve-ports at some pre-determined distance immediately above the soil rock interface. The desired configuration would have at least one port above the bag for annular space grouting, and one port below the bag for interface treatment. The port below the textile bag, would ideally be placed below the soil rock interface. A double-packer assembly is utilized to straddle the port within the barrier bag. The bag is then inflated through injection of a neat cement grout. Pressure filtration occurs through the textile as water is expelled, resulting in dry packing the bag. The bag effectively isolates the annular space grouting from the interface treatment.

Immediately after the barrier bag is inflated, annular space grouting can commence by raising the double packer assembly to the next port above the bag. Grout is injected into the annular space until it is observed at the ground surface. There are no time constraints between inflation of the barrier bag and annular space grouting due to the dry packing that occurs in the former. After the annular space is filled, the remaining treatment through the sleeve-port pipe is interface treatment. Interface treatment can now be performed using a single-packer set above the remaining ports below the textile barrier bag.

Isolation of the interface zone allows the proper suite of grout mixes to be used in treating the formation. In lieu of the neat cement grout used for barrier bag inflation and standpipe grouting, mixes that are appropriately formulated with suitable viscosities, specific gravities, pressure filtration coefficients, and bleed characteristics can be utilized for treatment of the interface zone and the underlying bedrock. In cases where interface treatment was not isolated during standpipe grouting, discontinuities in the upper bedrock zone (often the most critical zone in remedial projects) become contaminated with the neat cement grouts. Openings within this zone potentially connecting to a network of high permeability seepage paths that otherwise would have accepted grout is blocked, or inaccessible. The authors believe that isolation of the interface zone should be mandatory in any remedial grouting contract.

Additional Protection of Embankment

Additional protection of the embankment is recommended for remedial grouting projects. It is common that a higher number of rock defects and fractured zones reside at shallower depths, near the interface. The potential to hydraulically connect to the embankment through these discontinuities with higher than desired pressures associated with deeper drilling and grouting operations is substantial even after interface treatment has been completed unless these upper zones of rock are treated separately in advance. Furthermore, connections to surface have been observed on past projects in deeper stages where proper treatment in the upper zone of bedrock was not completed.

To protect the embankment from erosion during subsequent drilling and grouting operations, designers should consider routinely downstaging the top two stages below the soil rock interface after interface treatment is completed (Bruce and Dreese, 2010). This will help ensure carefully controlled provisions are applied and that no untreated vertical joint is left in direct contact with the embankment. Downstaging the top two stages should be performed in holes on a maximum of 5-foot to 10-foot centers as required to provide complete geometric coverage (Figure 3). On critical projects with an erodible material at the interface, water testing of these top two stages can be omitted to avoid possible connection until the proper level of protection has been achieved.

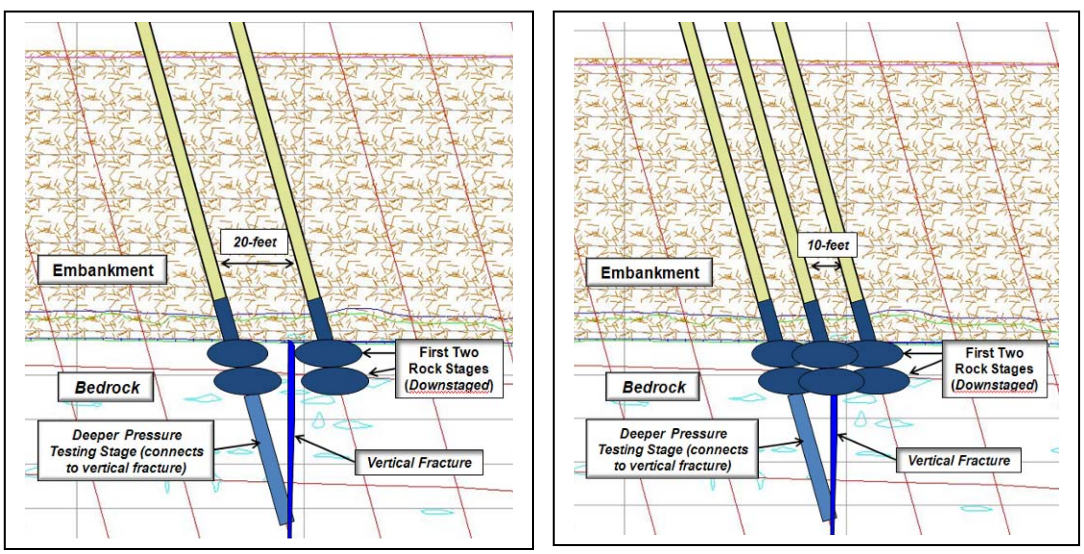

Figure 3 Protection of Embankment by Downstaging

EMBANKMENT DRILLING METHODS

Multiple methods of advancing drill tooling through embankments have been recognized and practiced throughout the industry. Selection of the most appropriate overburden drilling method should be based on the ground conditions that will be encountered and the specific project goals and requirements. Figure 4 (Bruce, 2003) summarizes the various overburden drilling systems normally recognized in the industry.

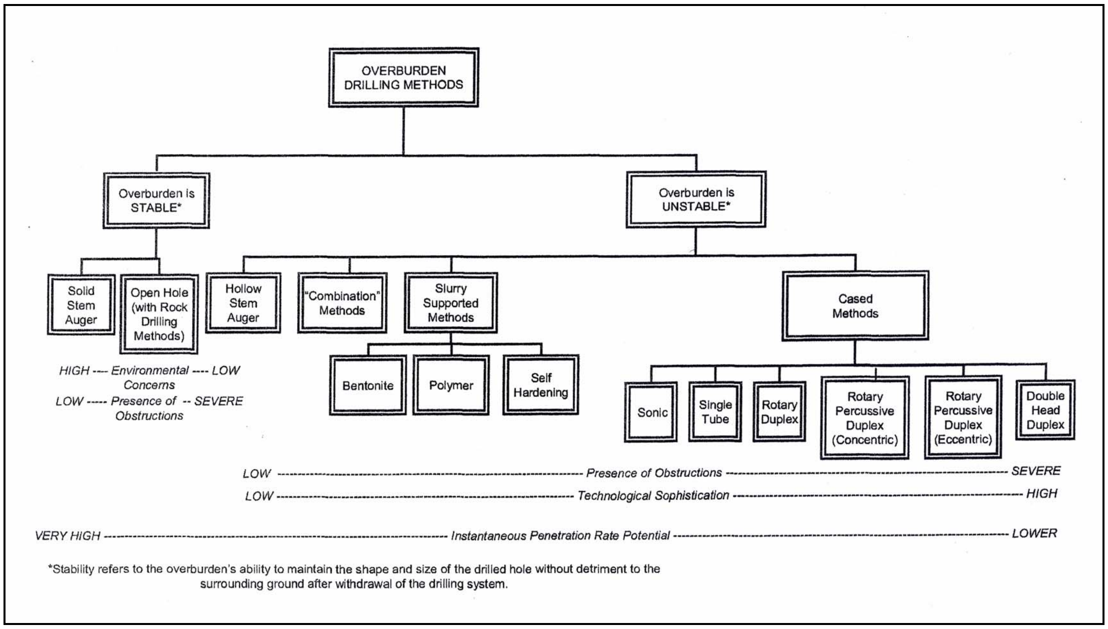

Figure 4: Overburden Drilling Methods (Bruce, 2003)

Although the figure covers a wide array of systems available, this paper only discusses 'Cased' methods where the overburden is considered to be unstable. Acceptable overburden drilling methods where overburden is considered 'unstable', and water usage is not permitted includes rotary sonic and double head duplex with an internal auger (Bruce and Dreese, 2010). With particular regard to remedial curtains below earthen embankment dams, the overburden drilling method must be capable of allowing standpipe to be inserted and grouted in place for protection of the embankment during subsequent rock drilling operations.

Unfortunately, no single drilling system is necessarily the best for every type of ground condition. If ground conditions dictate use of a particular method, requirements should be clearly defined in the contract documents.

Rotary Sonic

Rotary sonic (commonly referred to as sonic drilling) is widely used for casing advancement through embankments due in large part to its ability to penetrate and continuously sample material varying in density from very soft unconsolidated to very hard consolidated. Resonant vibrations and rotary power are transmitted by high frequency mechanical oscillations through the drill tooling to allow drilling advancement without the use of water. A sonic drilling rig is shown in Figure 5.

Figure 5: Sonic Drilling Rig

Sonic drilling uses a multiple casing system. Typically, the inner casing (core barrel) is advanced ahead of the outer casing, and can be used to collect a continuous sample. After the outer casing is advanced to the same depth, the inner casing is removed for extraction of the sample. The sample is generally removed by hydraulically pushing the sample with water, and vibrating the casing. Rotary sonic has the capability of drilling through even the hardest ground conditions. However, the vibratory action pulverizes the rock at the casing shoe that contains carbide button bits, and no meaningful rock core is recoverable. Sonic drilling typically produces accurate holes with respect to deviation through the use of large diameter, stiff casings.

In regards to setting standpipe, the inner casing is removed after drilling a pre-specified distance into bedrock, leaving the outer steel casing in place. The standpipe is then inserted to the bottom of the hole inside the outer casing. Recommended practice is to leave the outer steel casing in the hole during barrier bag inflation and annular space grouting. Typically, the outer casing is pulled back and set at a depth just above the bag during inflation to avoid locking the steel in place. Leaving the steel in during the annular space grouting will reduce risk of collapse around the pipe, and ensure that grout is completely encapsulated around the standpipe. The steel casing is withdrawn after grout begins appearing at the surface.

Sonic drilling is frequently described as having the ability to drill without water. In practice, water is commonly used to lubricate the drill steel during advancement for increased productivity. If water is required only very limited and quantifiable amounts should be utilized. This issue is addressed in ER 1110-1-1807 which prohibits injection of water while drilling and only permits the addition of water through gravity feed to the collar. The amount of water introduced to the hole should be restricted to a volume that would raise the water above the water level in the hole by no more than 15 feet above the phreatic water level (USACE, 2006). However, verification that this requirement is being met is problematic due to the potential impacts that it may have on production and performance. Verification may require stopping drilling operations and measuring the water level after each run. Experience has shown that limited effort is given in verifying that the requirement is actually met. Consequently, volumes higher than permitted (in excess of regulatory requirements) are periodically to commonly used. Based on experience, volume control methods need improvement.

Water injected during the sonic drilling process at inappropriate times could present risks of hydrofracturing in the embankment. Water should not be used while advancing the inner casing. It results in disturbance of the retrieved sample, and more importantly presents the greatest opportunity for hydrofracturing to occur. If water is permitted during inner casing advancement, then it should be demonstrated that the entire length of casing is not obstructed, and the top is open to the atmosphere. Advancement of the outer override casing also presents a risk with regard to hydrofracturing unless the system is open to the atmosphere. Pressurized water should never be fed down the drill string while drilling on an embankment. Aditionally, water should never be poured into the borehole and casing advanced with the top closed to the atmosphere. The top should always be open to the atmosphere to prevent fluid from being pressurized.

Ideally, water would not be used, but if water is mandatory for continued advancement and permitted by the engineer or client, then amounts and procedures should be clearly discussed beforehand.

Duplex Drilling

Various methods and systems are available in regards to duplex drilling, but essentially they are all characterized as having an inner drill string and an outer casing advanced simultaneously. As shown in Figure 3, common duplex systems include rotary duplex, rotary percussive concentric duplex, rotary percussive eccentric duplex, double head duplex, and duplex with auger. With these systems, the majority of the drilling effort is through the inner drill string that may be a top hole percussion system or down hole hammer (DTH). The outer casing can be advanced either with or without rotation, and with or without percussion.

In all systems mentioned above, flushing fluids are required to convey cuttings to the surface through the annular space between the inner drill string and the outer casing. Typically, water is directed uphole within the outer casing, minimizing exposure of water under pressure to the embankment. Inspectors and drillers need to be diligent in their inspection of the flushing process and in particular the ports near the bit. Pressurization at the bit face can occur should the flushing fluid become obstructed causing circulation loss. Additionally, full static head at depth could be induced when drilling stops periodically. However, the water volume that is available in the hole is limited to the amount allowed by the space between the inner and outer tooling.

Water has been permitted as the flushing fluid when advancing through embankments on some projects. Strictly meeting the requirements stipulated in the USACE's ER 1110-1-1807, requires that a commercial drilling mud should be utilized as the circulation medium. However, from a grouting standpoint, use of mud is undesirable due to its potential to block fine fractures.

Similarly to rotary sonic, standpipe is set by removing the inner string once the desired depth is reached, and leaving the outer casing in place.

TYPES OF STANDPIPE

Standpipe installed through embankments can be made of a number of different materials such as metal or plastic, but generally polyvinyl chloride (PVC) is recognized as the acceptable material due to its adequate durability, flexibility, and constructability. Often times, it is more economical to use plastic or light gauge steel. Standpipe diameter commonly varies from 2 to 4 inches when used for permeation grouting, but is largely controlled by the bit diameter specified for subsequent rock drilling after the pipe is secured. The diameter of the packers to be utilized will also need to be sized accordingly as well.

CONCLUSIONS

Protecting the embankment and preserving the integrity of the overburden during remedial curtain projects is mandatory. Rehabilitating dams with seepage deficiencies often requires drilling through the dam and into the rock foundation for the purpose of constructing a grouted cutoff. Grouting of a rock foundation requires that multiple items of equipment be tripped in and out of a hole multiple times. For this reason, it is common that a hole is cased through the embankment with standpipe and the overburden drill tooling removed.

Multiple drilling methods are recognized in the industry for advancing through embankment dams. In remedial projects, the drilling method must be capable of providing a stable borehole that includes installation of a temporary standpipe for continued accessibility of the rock foundation. Various methods of installing standpipe exist, but employing the use of geotextile barrier bags and MPSP is highly recommended for isolating the interface treatment from the annular space grouting. Treating the two operations separately will help avoid extreme issues such as incompletely filled annular space that ultimately could result in dam safety issues.

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