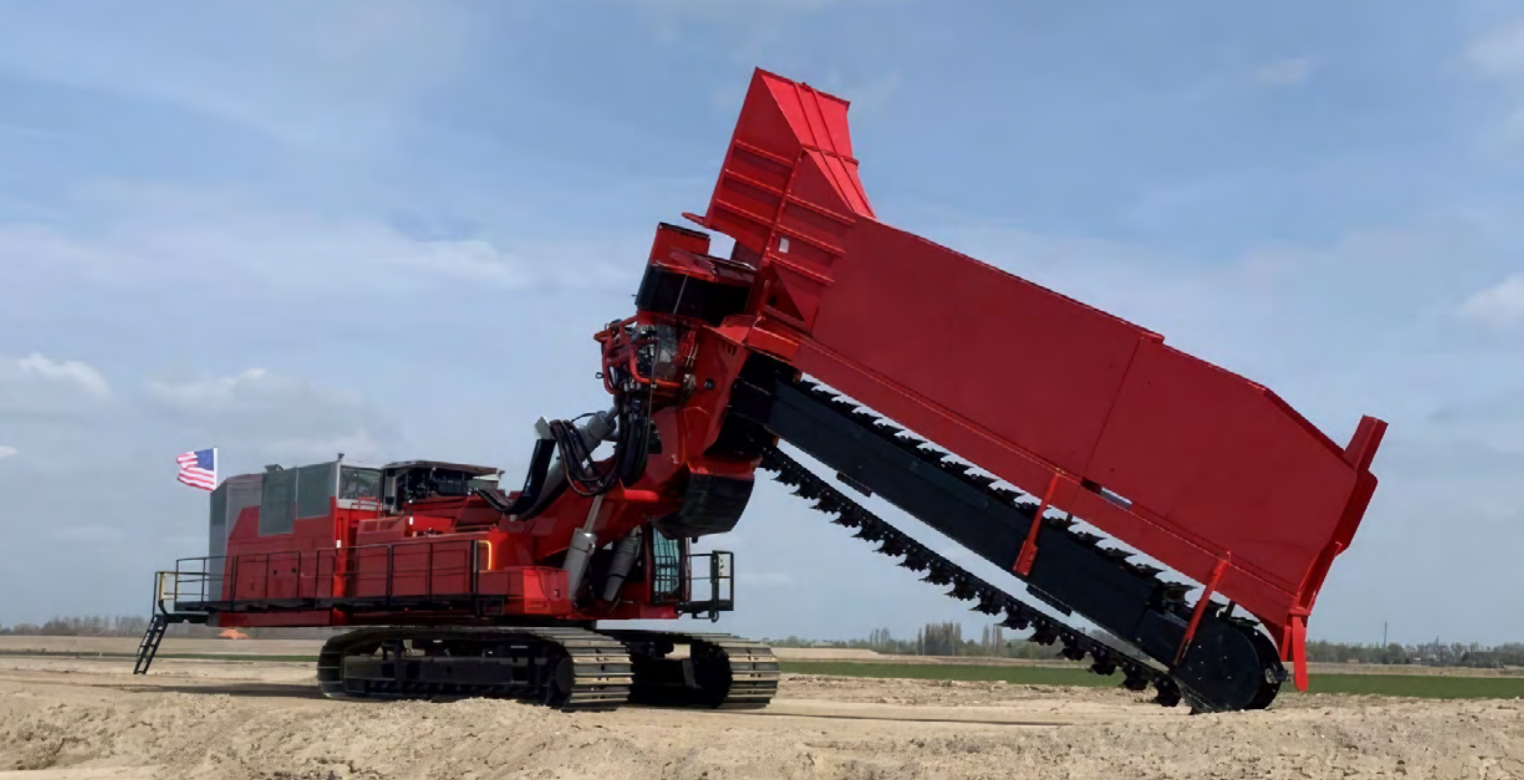

A Comparison of Trencher Method Versus Slurry Trenching and Soil Mixing for Seepage Barriers in Dams

Charlie Krug | Nathan Coughenour, P.E. | Daniel Ruffing, P.E.

ABSTRACT

The chain-style trencher is a relatively new technique to mitigate seepage and stability related potential failure modes in dams and levees. One of the primary uses of the trencher method in dam and levee applications is in-situ mixing to create seepage barriers within earthen embankments. A trencher is a vertical, rotary chain mixing blade fixed to a track-mounted chassis. In-situ mixing approaches can be beneficial to dam and levee projects as cutoff walls can be constructed on the upstream, crest or downstream sides, or combination thereof on the embankment.

Possible seepage barriers constructed with the Chain-Mixing-Method (CMM), also known as the trencher method, includes soil-bentonite or soil-cement-bentonite. In addition to seepage barriers, soil-mixing techniques can be used for stabilization and gravity buttresses. Furthermore, the trenchers can also be outfitted with backfill delivery attachments to install groundwater relief trenches. These relief trenches are typically installed along the toe of the slope by emplacing a granular backfill to provide a planned pathway for seepage without causing erosion issues to the earthen embankment.

The trencher can provide several benefits for these applications relative to conventional slurry trenching and soil mixing, such as operating from the dam crest (minimal width) without the need for mixing ponds or plants due to in-situ technology. Often the embankment does not need to be degraded simply to make construction platform for the seepage barrier. As with all technologies, the trencher method does have limitations. This paper will review recent projects and provide technical considerations for design, installation, and performance of trenchers, conventional slurry excavation, and soil mixing methods. This paper provides information and suggestions to better inform the selection of an appropriate method.

Introduction

The terms slurry trench and slurry cutoff wall are well recognized as conventional method to refer to the installation of nonstructural walls using long, continuous slurry supported excavations (Evans, 1993). Slurry trenching is a commonly used method for the installation of cutoff walls. This method is often referred to as a two-step installation for soil-bentonite cutoff walls, including an excavation step and backfill step. Details and overviews of slurry trenching are the subject of many other publications, such as Ruffing and Evans (2021). Applications include containment of impacted groundwater, control of excavation dewatering at uncontaminated sites, and at dams, levees, and embankments to improve stability (Ruffing & Evans, 2019). This paper's authors previously published findings (Krug & Ruffing, 2020) are updated herein to include more recent information, case studies, and lessons learned.

The development of ground improvement construction methods has naturally followed advances in understanding soil and water behavior, which then fuel innovation in equipment. Recently, the CMM has been gaining popularity in the United States (US). Early versions of trenchers were used to install subsurface drains in the US dating back to the 1950s (US Dept. of Interior Bureau of Reclamation, 2008). These early trenchers used a variety of cutting tools such as wheels, buckets, and so on. The more common bar and cutter chain style trenchers that are used today for soil mixing came into use in the mid 1980s in Europe and Australia (Boersma, personal communication, 2020). Since the early 2000s, specialty contractors in North America and Europe have innovated upon and retrofitted bar and cutter trenchers to handle installations of cutoff walls and collection trenches on specialty civil and environmental projects.

Other contractors in Japan developed a similar bar and chain style cutter called the Trench Remixing Deep (TRD) method. This method is also available in North America. The notable difference between this technique and the trencher is that the TRD bar is segmented whereas the trencher bar is fixed. Although this technology is widely accepted for installation of cutoff walls, it has been excluded from this paper as the intent is to compare conventional slurry trenching methods and soil mixing with trencher style methods for cutoff walls and collection trenches.

To determine effective uses of the trencher, it is important to first review the advantages and disadvantages. First and foremost is the understanding that not all sites, equipment, and conditions are equal. Understanding the site constraints and equipment capabilities will always help determine the best method.

Trencher Versus Slurry Trenching

The trencher is essentially a large mixing chain mounted on a tracked chassis, even more simplistically described as an excavator with the front end replaced with a chainsaw blade. The chain rotates around a steel bar at a high rate of speed in a fixed position while the tracked chassis advances along the alignment. As the chain is moved through the subsurface, the soil is sheared or excavated. In contrast to slurry trenching, trencher installations are more capable of ascending and descending grades (generally 10% or less). Cutoff walls installed using the trencher are mixed in place, and reagent addition can be adjusted along the length of the cutoff wall over short distances, but not vertically. Collection trenches are constructed by excavating the soils while simultaneously emplacing the specified backfill through a narrow trench box fixed to the trencher's arm. Conversely to low permeability cutoff walls, collection trenches or relief trenches are designed to pass water and fluids (high permeability).

Advantages of the Trencher Versus Slurry Trenching:

- Eliminates the "open" slurry-filled trench reducing the risk of trench cave-in and assumed excavation hazards
- Installations are less dependent on the water table location or consideration of groundwater flow
- More suitable for narrow work platforms
- There is generally less equipment operating on site as in-situ mixing eliminates backfill mixing/transporting
- Can be lower cost and shorter schedule in the right conditions
- Less handling of contaminated materials in environmental applications
- Can accommodate low headroom once in the ground (<20-ft.)

Disadvantages or Limitations of the Trencher:

- The bar and chain are designed for shearing soil, not rock, which makes excavation of large objects such as cobbles and boulders an increased risk of substantial equipment damage or successful installation, if possible at all. Bedrock keys can also be infeasible.

- Trencher depth is generally limited to 50-ft. or less. A very limited number of trenchers exist that can handle depths greater than 50-ft. Depth is a function of the trencher chain bar whereas other in-situ mixing techniques are more readily available beyond 50-ft. deep and excavator slurry trenching methods are more readily available up to 90-ft. Clamshell slurry trenching methods can be used beyond 90-ft.
- The bar/chain length is fixed, limiting the ability to install a wall with varying bottom depth. Slight depth variations (2 to 3 m) are possible. Larger variations require removing/adding bar & chain segments or unreplacing with a completely different setup. Changing the bar or setup requires ending and restarting the installation.
- No "key" verification as the in-situ cutting and mixing eliminates the ability to retrieve key materials at depth.
- Underground utilities are challenging.
- Full volume mixing makes it impossible to segregate excavation spoils from undesirable layers, like gypsum, peat, or for potential reuse.

Design Considerations

The design considerations generally relate to the collection of preconstruction data such as geotechnical data, topography, chemistry, and site characteristics. These data are essential to ensure adequacy of the design and when considering what type of installation method to choose. This is especially true for mix-in-place methods such as the trencher method. When scarce or insufficient geotechnical data are provided, the method must be selected using extrapolated data. As the data gaps increase, the risk of a change of condition increases, which raises the potential for claims, an undesirable situation for all parties. Data gathering is often highly driven by cost, often to the detriment of the project. For instance, the cost of change orders from material differences can easily outweigh the cost of the right data collected at the onset of the project.

One of the key features of the trencher is that it can effectively mix below the groundwater table and is mostly independent of the groundwater flow. Understanding the groundwater level and groundwater flow characteristics is specifically important. Sites with high groundwater levels can be problematic for slurry trenching or require costly ancillary tasks, such as dewatering or work platform modification. As such, trenchers have a strong history in countries like the Netherlands and Belgium where the groundwater table is generally near the surface.

Another consideration in the design should be the need for and extent of a "key." One of the main disadvantages of CMM is the inability to verify the "key" soils. Thus, when the trencher is used, more extensive geotechnical investigation is required to pre-determine the depth and makeup of the "key" strata. This is generally accomplished by soil borings that extend into the target key at more frequent linear spacing than typical geotechnical explorations require. The additional borings can offset some of the cost advantages of the trencher.

In relation to gathering geotechnical data in the design phase, obstructions must be on the list. Understanding the presence or likely presence and severity of underground obstructions is critical. Obstructions can be the detriment of even the best subsurface wall design. Obstructions can be boulders, bedrock outcroppings, debris, old tree trunks, or prior site features such as foundations, building slabs, and so forth. Slurry trenching excavation methods are more capable of mitigating subsurface obstructions than the trencher. Not all obstructions are encountered underground, however. Above grade obstructions can be anything that would impede the construction equipment used to install the designed remedial system.

Stability of the work area should also be considered during design. For example, an unstable dam or levee that requires a seepage barrier may be restricted to mix-in-place installation methods such as the CMM. During installation of the slurry trenching method, a narrow slurry filled trench condition is present for a limited time along portions of the alignment. Typical slurry unit weights are around 64 pounds per cubic foot (pcf) to 70 pcf, compared to the in-place unit weights of in-situ methods which generally resemble wet soil unit weights (105 pcf to 130 pcf). Deep cutoff walls typically require large construction equipment, which can impart a heavy surcharge load to the dam or levee. Stability analysis of the proposed methods should be analyzed.

Treatability studies are bench scale laboratory testing programs that provide suggested amounts of reagent(s) needed for the seepage barrier to meet the performance objectives. These can be complex yet are an important part of the design. The cost of even a complex and thorough treatability bench scale study pales in comparison to the price of a cutoff wall project, thus a worthy investment. For cutoff walls, the CMM incorporates the below grade materials with appropriate binders to create the

barrier wall product with vertical mixing being a significant feature of the CMM. Although binder content and mixing energy cannot be varied with depth, the mixed materials are very well mixed due to the mixing energy imparted by the speed of the chain coupled with the prevalence of teeth on the chain (Stare, et. al. 2017). The soil and groundwater that will be incorporated in the final mix must be considered for CMM and its full vertical mixing action. Collection trenches require a different type of treatability study, but this is still an important piece of the design. In addition to determining cost-effective reagents, a treatability study should also consider that certain products may not be compatible with the site constituents. This could be an important factor for method selection if compatibility issues preclude the use of slurry—as in a slurry filled excavation.

Installation

Numerous considerations for equipment selections exist. The use and availability of the designated primary equipment should be considered during the method selection. Combination of equipment methods (slurry trenching and mix in place) has also become more common on larger scale projects. Is there enough workspace available to operate the equipment? Is the primary equipment and possible backup available for the project schedule? Will construction traffic cause unstable or unsafe conditions? These are just some examples of things to consider. Vibrations, swing radius, overhead clearance, and headroom are a few of the characteristics that vary between the methods.

Responsibility for the spoils or waste materials should also be considered. On many dams and levees, there is not space to incorporate the spoils elsewhere onsite. Thus, a spoils management and/or disposal plan should be developed and incorporated into the overall project plan. The spoils volume and physical composition varies by method. For example, a self-hardening slurry trench will generate a full volume spoils quantity, whereas a soil-mixed option would result in less spoils, on the order of 10% to 40% of the mixed volume.

Self-hardening slurry walls have been popular on dam and levee sites for their strength and low permeability characteristics, as well as their ease of installation. The spoils volume can typically be repurposed on many geotechnical sites. Because all the soil is removed and not used in the cutoff wall, this type of wall is only available from slurry trenching methods and not the in-situ CMM.

In addition to using in-situ (mix in-place) methods for cutoff walls, this technology has been incorporated into many geotechnical and environmental projects for stabilization of subgrade soils. The configuration of stabilized areas is essentially endless. In dam, levee, and slope stability projects, common applications are shear walls, buttresses and mass foundation stabilization. CMM specifically excels at long linear elements, that is, cutoff walls. Shear walls are typically shorter and installed perpendicular to the embankments, typically making elemental soil mixing such as auger or cutter soil mixing (CSM) better suited. Similarly, mass stabilization such as gravity buttresses and foundation stabilization is better accomplished with elemental methods over CMM due to space requirements, overlaps, and verticality.

In-situ mixing methods, whether axially oriented horizontal or vertical, have difficulties connecting soil mixed elements to existing features. Excavation methods can accomplish this task easier and with less damage. To minimize large and heavy construction equipment used in the vicinity of existing structures, jet grouting or other forms of grouting can also be used to connect cutoff wall segments up to and against existing below grade features.

Case Studies

The following case studies demonstrate the evaluation potential of the information presented herein. To condition the reader to understand method selection, the facts of each case are outlined and then the reasons for the selected method are described.

Case Study 1. Mountain Dell Dam

The first case study utilized the slurry trenching cutoff wall method. The project consisted of a seepage barrier to seal the temporary coffer dam to allow rehabilitation to the outlet works.

Summary of Site Criteria:

- Cutoff wall size: 470 lineal ft, up to 40 ft deep
- Soils: typical earthen embankment dam materials, including reservoir sediment
- Groundwater: approx. 10-ft. bgs
- Key requirement: bedrock key
- Limited room to work: access to upstream side not possible
- Treatability/mix: self-hardening slag-cement-bentonite mix
- Cutoff wall type: slag-cement-cement-bentonite (SCCB)

The depth of the cutoff wall varied significantly with relatively shallow ends and up to 40 ft. deep near the middle of the dam. Due to the depth change requirement a slurry trenching/excavator method was selected. Furthermore, the key requirement was important to cutoff bottom seepage at the reservoir sediment; thus, the excavator method advantage of using the bucket cuttings to verify key materials was critical.

Lessons Learned:

- Self-hardening slurry method—this approach was advantageous to promote stability of the trench as well as eliminate the need for additional space for backfill mixing.
- Spoils waste—this volume of materials was not as impactful as initially considered due to subsequent dam construction phases where spoils were reused as fill in suitable areas.

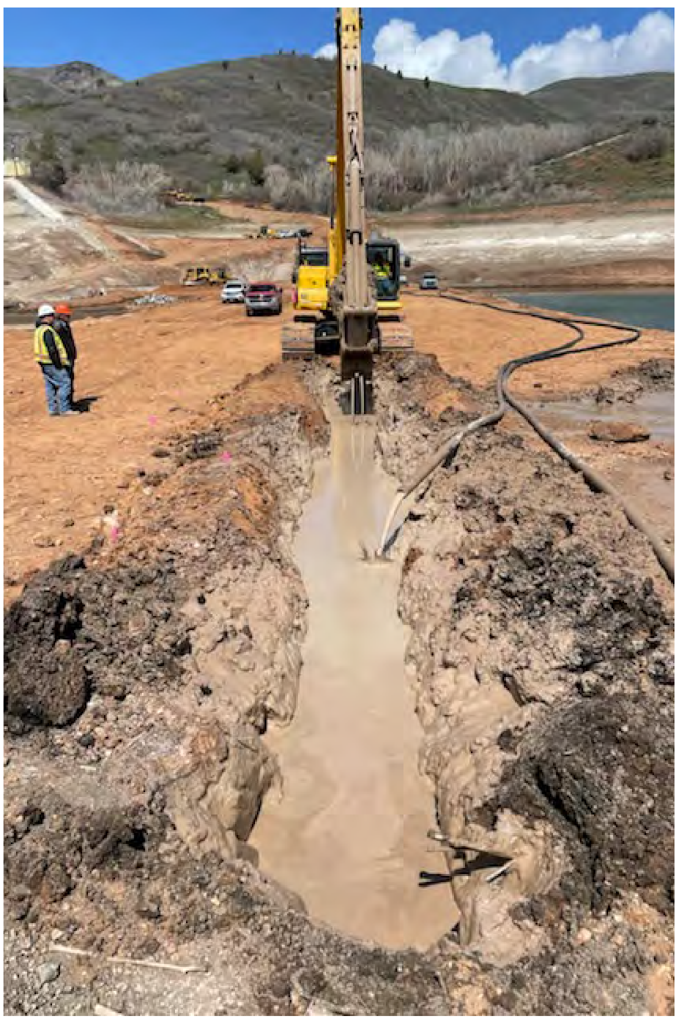

Figure 1 Slurry Trenching Method on a Dam with Self-Hardening Slurry

Case Study 2. Dam Repair → Trencher

This project included a seepage barrier that was designed to mitigate the impounded waters from seeping through an earthen embankment dam. Significant seepage was detected by the facility owner, and an emergency repair project was prepared. The existing workspace available was only the dam crest, which was not much wider than the trencher tracks. This narrow work platform and inability to degrade the crest rendered the conventional slurry trenching method infeasible. Due to the limited width of the berm (Figure 2), the trencher was quickly identified for installation of a soil-bentonite wall for the emergency repair.

Summary of Site Criteria:

- Cutoff wall size: 100 lineal ft, up to 16 ft deep, 1.5 ft wide
- Soils: typical earthen embankment dam materials, various silts, clays, and sands
- Groundwater: 5-ft. bgs
- Key requirement: none
- Limited room to work: cutoff wall installed from dike crest
- Treatability/mix: soil-bentonite mix
- Cutoff wall type: soil-bentonite (SB)

Due to the limited width of the berm, the trencher/CMM was the obvious choice for this installation. The soil did not present any obstructions, key requirements, or need to segregate the excavation spoils, which could have precluded the trencher. Similarly, limited site access challenges were overcome by the in-situ mixing method because the trencher could track onto the alignment easily. By comparison, a slurry trenching method would not have had enough space to excavate the soil and mix and place the backfill, nor would support equipment be able to assist the primary excavator. Mobilizing other in-situ mixing methods for a small quantity of work and setting up a grout plant are not typically cost effective for small volume projects, which is why the trencher was the selected in-situ mixing method.

Lessons Learned:

- Limited workspace and access—these are key advantages where the trencher excels.
- Speed—mobilization, setup, and demobilization were carried out in short succession allowing swift repair of the leaking dam. The entire project was completed in 1 week, including mobilization and demobilization.

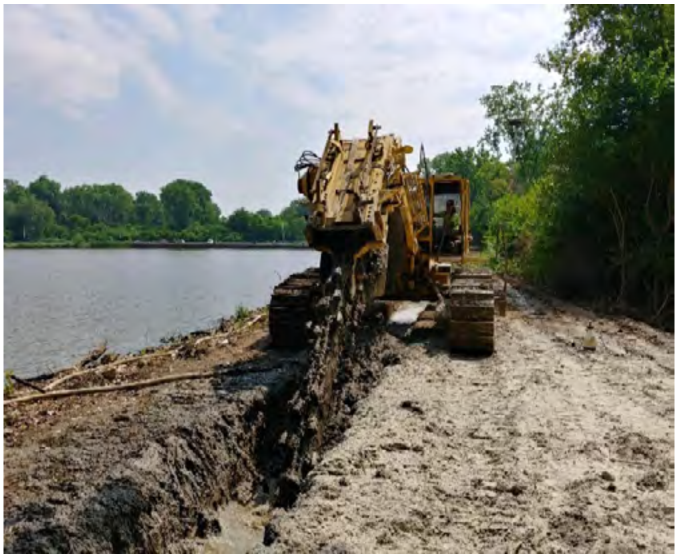

Figure 2 Trencher With Soil-Mixing Blade Visible Halfway Out of Trench

Case Study 3. Embankment Cutoff Wall → Trencher

Based on hydrogeologic modeling, the cutoff wall was designed as a hanging wall, that is, the bottom of the wall was not tied into a lower permeability layer, with relatively shallow depth of 25-ft. A soil-bentonite cutoff wall was installed around the perimeter embankment dam of a large site for the purpose of reducing the transmission of water through the embankment. A newly constructed embankment berm created an operational constraint between the crest and a deep perimeter drainage channel for the control of surface water runoff located approximately 10-ft to 15-ft off the cutoff wall alignment. As such, the cutoff wall was designed at approximately midslope of the embankment. Geotechnical explorations encountered mostly sandy soils with underlying silty sand layers at depth. Stumps were also encountered in several borings and even more commonly in shallow test pits. Groundwater was encountered at about 6-ft. below ground surface along the cutoff wall alignment.

Summary of Site Criteria:

- Cutoff wall size: 6,930 lineal ft, 25.5-ft deep, 2-ft wide
- Soils: sand and silty sands with frequent stumps
- Groundwater: 6-ft. bgs
- Key requirement: none
- Treatability/mix: bentonite was the only reagent required to lower permeability
- Cutoff wall type: soil-bentonite (SB)

Originally the owner pursued a conventional slurry excavation method for the purposes of lowest cost. This is a completely valid selection for this site as there is plenty of room for ex-situ mixing adjacent to the cutoff wall, the excavator method can be used to easily remove any stumps from the cutoff wall alignment, and the groundwater was low enough to accommodate proper stability of the trench during excavation and backfilling operations.

Despite the applicability of slurry trenching to this site, the method was changed to the trencher/CMM (Figure 3) prior to construction. This change was made to improve the site logistics and reduce site disturbance. The trencher method was able to reduce the site disturbance to only a narrow band along the site (bench in the embankment), which allowed the general contractor (GC) to simultaneously work on other critical site tasks along the crest and interior. This change resulted in a schedule pickup for the owner, which also resulted in a lower overall cost to the project. The disadvantages of the trencher method for this site were the risk of stumps/obstructions causing damage, refusal, and possibly schedule delay or claims to the owner. Through preconstruction planning discussions, all parties, owner, GC, and specialty cutoff wall contractor, agreed that the lower overall cost and schedule decrease associated with the CMM outweighed the risks.

Lessons Learned:

- Workspace availability—the site disturbance was greatly reduced by CMM enabling the GC to decrease the overall schedule by utilizing the available workspace to advance the schedule of other tasks simultaneously.
- Possible obstructions—overcome by trencher. This obstruction risk was worth it due to the relatively weak nature of the stumps compared to the robust mixing chain and cutting teeth of the trencher. Furthermore, the depth of the stumps was relatively shallow, which could be extracted from the cutoff wall with other methods if the stumps caused a refusal of the trencher. Mechanical breakages did occur but were infrequent. The stumps did not ultimately cause significant problems and were passed without claims.
- Treatability/mix design—the mix design was initiated during the early phases of the project when conventional slurry methods were proposed. The slurry method and CMM have different mixing techniques, which should be considered during bench scale tests. The bench scale

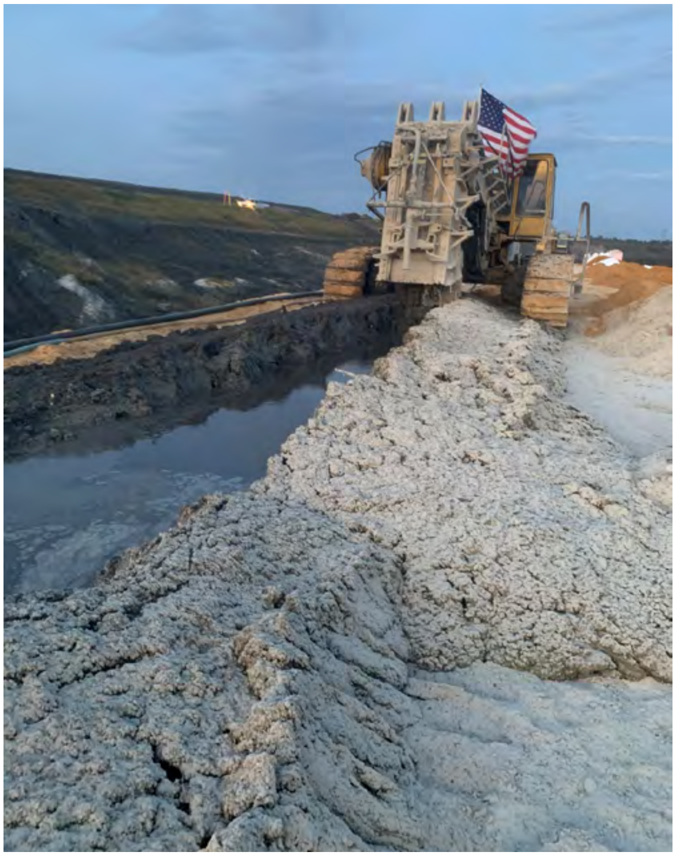

Figure 3 Trencher With Soil-Mixing Blade in the Trench

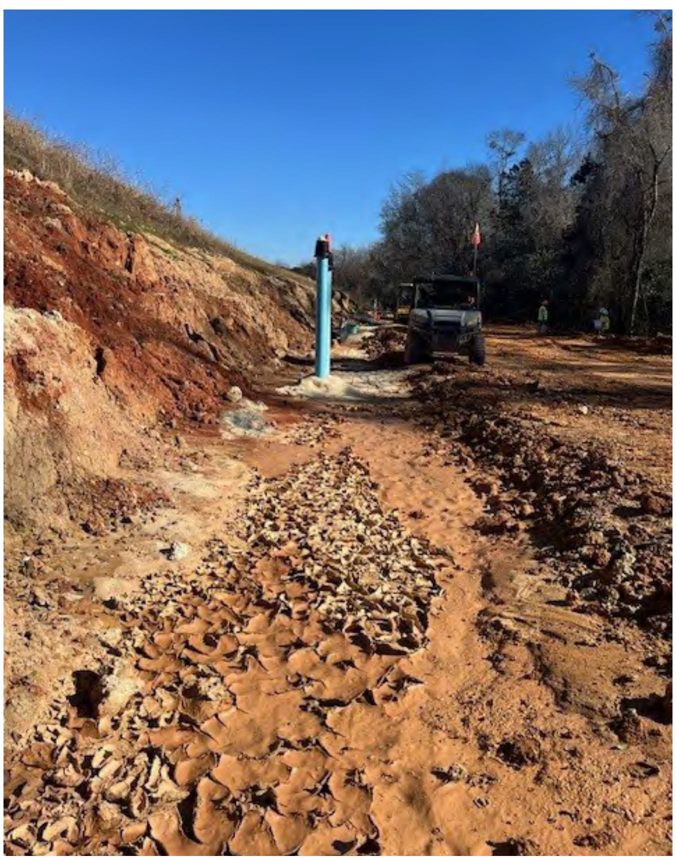

Figure 4 Relief Trench Midslope of Embankment

results dictated the need for a relatively high dosage of bentonite. Although slurry/grout mixing can be used with CMM, adding large amounts of bentonite via slurry is less practical than dry addition. Although dry reagents are delivered via this specific system, it should not be considered a dry mixing method given the simultaneous delivery of water and aggressive mixing action of the chain (Stare, et al., 2017).

Case Study 4. Relief Trench → Slurry Trenching

The existing earthen embankment on this site experienced a slide. The slope stability was compromised due to seepage through the embankment. The engineer designed a passive relief trench to collect the seepage and discharge it to the downstream creek.

Summary of Site Criteria:

- Relief trench size—400 lineal ft, up to 14-ft deep, 3-ft wide
- Soils—fine grained with interbedded seams and layers of sand
- Groundwater—near ground surface, various seepage zones from impoundment water level above work platform
- Pipe—6-in. PVC with two special aggregate encasement zones
- Backfill—sand and gravel

Due to the high hazard condition of the embankment the stability concerns warranted the use of and engineered trench shoring system, which required conventional. A CMM method was not feasible here due to the presence of seepage as well as the pipe network required for the passive system.

Lessons Learned:

- Site history is also important for initial data gathering.
- Precision, quality control, and record keeping with preclearing and collection trench alignment is critical.
- Backfill selection, control of water, and existing soil conditions need to be well understood, for cost considerations.

Case Study 5. Temporary Dewatering Relief → Slurry Trenching

Although this is not a dam or levee project, the method selection and lessons learned are still valid for the purposes of this paper and can be carried over into seepage barrier applications for dams and levees. At this site a cutoff wall was installed around a new commercial building site for the purposes of reducing the influx of water to eliminate an expensive dewatering effort during basement excavation. The cutoff wall was designed to extend just below a porous water-bearing gravel zone near the basement slab elevations. A clay layer underlying the gravel strata served as an aquitard "key." Depths to the aquitard varied between 8-ft. and 20-ft. bgs. The primary intent was to cut off flow during the basement excavations for the new construction. The cutoff wall was designed as a soil-cement-bentonite (SCB) type due to the need for excavation equipment and utility pipes to cross the cutoff wall during construction. The available geotechnical data revealed sandy clay above a gravel layer, underlain by fine grained silty clay at the terminating depths.

Summary of Site Criteria:

- Ample room to work: site is large and flat
- Soils: sandy clay, underlain by a gravel layer, underlain by fine grained silty clay at the terminating depths
- Groundwater: 5 to 10-ft. bgs. in gravel layer
- Key requirement: 2-ft into clay
- Treatability/mix: mix design for slurry method using bentonite and Portland cement
- Cutoff wall size: 3,300 lineal ft, up to 20-ft deep, 2.5-ft wide
- Cutoff wall type: soil-cement-bentonite (SCB)

Given the available data and bids, the owner pursued a CMM method for the purposes of lowest cost. The CMM method could accomplish many of the main criteria with specific advantages in the rate of installation and lower cost. Another advantage of CMM at this site is the full vertical mixing, which uniformly mixes the porous gravel soils with the sandy clay above. During method selection, the disadvantage of the CMM was the inability to verify key soils. Despite its disadvantage, the proposed lower costs were enough for the GC to award the contract. When it was clear that the trencher was the selected method, the owner conducted a more extensive geotechnical investigation to determine more precise bottom elevations for the trencher to follow.

As part of the cutoff wall installer's due diligence, test pits were conducted prior to mobilization to further investigate the soils for the presence of boulders, because these obstructions would present a significant disadvantage to CMM and can cause costly repairs and schedule delays. During this additional test pitting, numerous boulders were encountered at different locations across the site.

Due to the findings of these additional test pits, the method was changed, post-award, but prior to construction to conventional slurry mixing (Figure 5). This proved to be a wise choice as large boulders were frequently encountered along the entire alignment, approximately every 25 to 50 lineal ft. The boulders would have undoubtedly caused refusal of the trencher and significant project delays. In contrast, the boulders were easily removed during the conventional slurry excavation without any project delays or claims for damages.

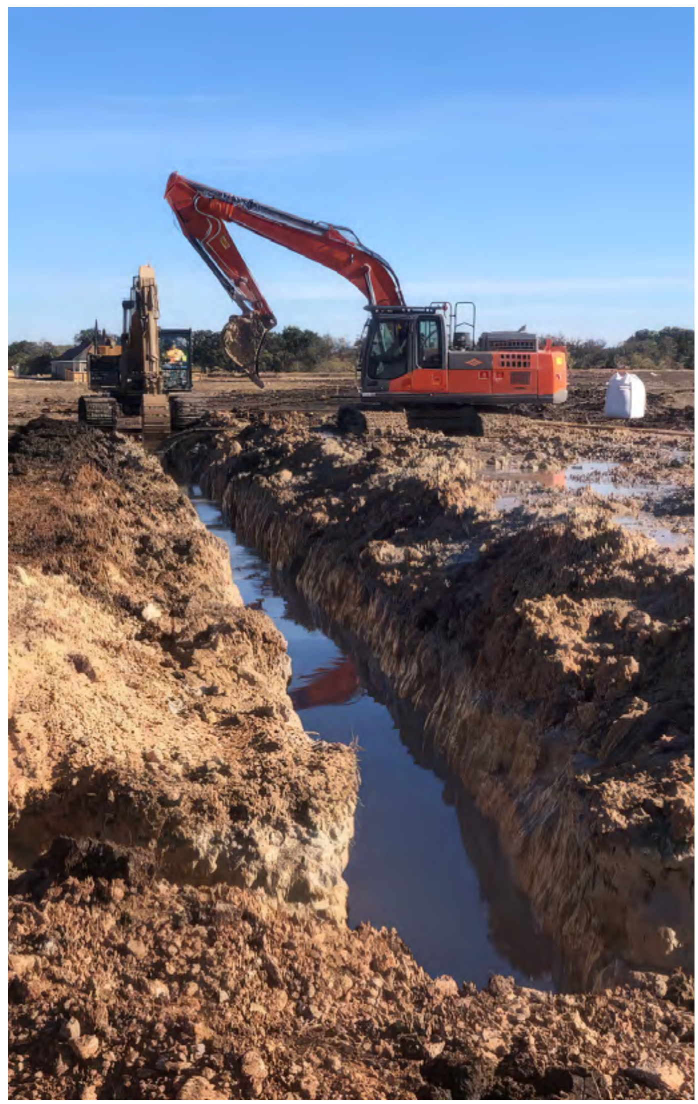

Figure 5 Slurry Trench Method

Lessons Learned:

- Collaborative method selection—site investigations including test pits were carried out by the owner's team without an understanding of the types of soils that are problematic to different methods. Select data were chosen to include in the bid documents, but early collaboration with cutoff wall installers could have eliminated additional investigations, delayed project start, and renegotiation of the contract at the onset of construction.
- Obstructions—frequent large boulders encountered in gravel would have resulted in damage and delays for the trencher/CMM method and change of conditions economic impacts to the owner. Impacts associated with these obstructions were eliminated through proper selection of the conventional slurry trenching method, which was able to extract all obstructions and achieve the designed bottom elevations without additional cost or delay.
- Subcontractor adaptability—utilizing a cutoff wall installer with the ability to adapt to changing conditions and experience and equipment with multiple methods proved invaluable to the client as method selection was changed post-award without significant economic impact.

CONCLUSION

Trenchers vary in design and practical use, and the differences must be considered regarding the specific site constraints during any review and selection process. This equipment has been in use since the 1950s, and recent innovations have made them popular for demanding sites where conventional slurry methods may be more expensive or time consuming. In general, trenchers become a commercially limited resource as wall depth becomes greater than 50-ft. As with all tools, the trencher is effective when used correctly offering a unique opportunity to utilize the advantages of a mix-in-place technology with an agile and easy to assemble rig.

Conventional slurry trenching is a proven technology and is the most common method of installing vertical barriers and for well-known reasons. As demonstrated from the case studies herein, slurry trenching with excavators can be a versatile solution. However, slurry filled trenches can be challenging and are not amenable to all sites. Reviewing the advantages and disadvantages of trenchers above shows the advantages of this mix-in-place technology to supplement or replace slurry trench methods where disadvantages are present. Knowledge of the existing site information and how their attributes weigh against the pros and cons is crucial to method selection. Both methods are acceptable and should be considered as appropriate methods for cutoff walls and collection trenches.

The case studies also highlight that even when it appears that a site is more conducive to a certain technology, all methods must be considered to make the appropriate decision to achieve the intent of the design at the lowest cost. The seemingly logical solution may not be the right solution when the problem is considered in its entirety. ■

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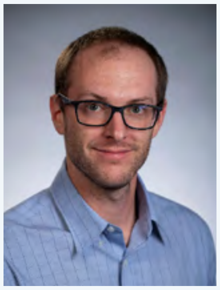

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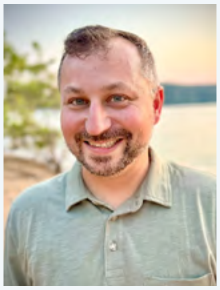

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ASDSO Peer Reviewers

This article was peer reviewed by Khaled Chowdhury, P.E., Ph.D. (U.S. Army Corps of Engineers) and Erik James, P.E., P.G. (U.S. Army Corps of Engineers).