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GEOTECHNICAL BASELINE REPORTS – APPLYING THE GUIDELINES TO MICROTUNNELING

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ABSTRACT: Over the last two decades, Geotechnical Baseline Reports (GBRs) have become increasingly common for trenchless construction projects using the American Society of Civil Engineers (ASCE) Guidelines (Essex, 1997, 2007). The Guidelines have been established to provide assistance for owners, authors, and users of GBRs. These guidelines have been extremely useful for educating owners and contractors in the role and application of the GBR in the distribution of financial risk for geotechnical parameters. However, the guidelines have typically been written for conventional tunneling. This has resulted in some pitfalls when the baseline statements are applied to microtunneling projects. This paper discusses the considerations for applying GBRs to microtunneling, specific baselines that are typically included in GBRs and their impact on microtunneling projects. Specifically, boulders, rock strength, soil separation, and debris are addressed. Several case studies on which GBRs have been implemented on microtunneling projects are presented and the effectiveness of the GBR statements on the outcome of the project are discussed.

1. INTRODUCTION

In recent years, the use of geotechnical baseline reports (GBRs) on microtunneling projects has become increasingly popular. Although originally developed for use on large diameter tunneling projects, GBRs have been implemented on a number of microtunneling projects. The American Society of Civil Engineers (ASCE) has published a set of guidelines to aid in the development of GBRs (1997, 2007). Generally speaking, the GBRs for microtunneling have been implemented in accordance with these guidelines, often with inadequate adaptation for microtunneling applications. As with the advent of any new construction contract document, there have been some growing pains associated with the application of the GBR for microtunneling and choosing the appropriate information to include in a GBR related to microtunneling.

It is important that engineers, owners, and contractors thoroughly understand the intent and use of a GBR in order to write and apply the document effectively. When a differing site condition (DSC) clause is included as part of the general conditions for the project, the intent of a GBR is to clearly and contractually define the geotechnical conditions through which tunneling will occur in order to evaluate a DSC and to be used as a basis of bid for the contractor. By affirmatively defining the geotechnical conditions and baselines in the contract, the contractor is given a basis from which to prepare their bid and select their means and methods.

An important function of the GBR is that the baseline conditions do not necessarily reflect the actual conditions, they are not geotechnical fact to be encountered. Rather, they represent the owner's determined risk allocation on the project. The owner must have substantive knowledge of microtunneling and its related components and carefully consider the recommendations of the design and geotechnical managers when developing baselines. In the evaluation, the microtunnel boring equipment should be considered as an excavation system, taking into account features other than just the microtunneling machine (MTBM). Although the MTBM is very important, its associated equipment, especially the soil separation system, is an integral part of effectively completing the job.

2. APPLICATION TO MICROTUNNELING

The overall philosophy of establishing geotechnical baseline conditions is the same for large diameter tunneling and microtunneling. However, the issues that have arisen in microtunneling projects stem from the many differences between the two forms of tunneling. Small issues that may not be considered a DSC by the contractor in large diameter tunneling can result in large claims on microtunneling projects. For example, microtunneling contractors typically own their MTBMs; therefore, there is a financial incentive to use the contractor's machine, even if the machine is not completely compatible with the ground and GBR. This rarely occurs in conventional tunneling due to the substantial financial risks on most projects. Using a machine that is not optimal can lead to excavation problems, resulting in DSCs. So, it is very important that the writers of the GBR understand these facts and variables, and that they evaluate the risks associated with the work by considering more variables than just geotechnical items. This evaluation can lead to a more focused GBR related to microtunneling, integrated with the specifications and payment provisions. Some of the items to be considered include the following:

- Typically in North America, large diameter tunneling involves earth pressure balance (EPB) methods for excavation whereas microtunneling generally uses a slurry excavation system.
- The face of a large diameter TBM can typically be accessed to change cutters where typical microtunneling machines do not allow face access.
- MTBMs are typically pre-owned or leased machines, and are rarely designed for a specific project.
- Microtunneling specifications tend to be more prescriptive, which can be in conflict with requirements of the GBR.
- Due to long lead times for manufacture, contractors tend to use a machine that is available rather than a machine that is well-suited to the soil conditions.
- Microtunnels are typically designed at a shallow depth (compared to large diameter tunnels) where soils can be highly variable.
- Microtunneling projects seldom attract national contractors due to the comparatively low value of the work.
- The power of the microtunneling machine is limited by the smaller size.

Many of these items can be major considerations when writing the GBR, establishing baselines, allocating risks, and writing the project specifications. Although some of the above items may not seem likely to be included in a geotechnical document, it is important to consider that the GBR is also a contractual document. Statements and requirements in the GBR directly relate to the contractor's selection of the equipment and the bid strategy.

An example of the magnitude of the impact that a DSC would have on the two tunneling methods is face access. Often, the impact of a DSC is determined by the ability to access the face of the machine. In large diameter tunneling, face access is often available. The contractor can access the face of the machine to change cutters, to accommodate wear, or in anticipation of changing material. Generally speaking this is a planned event and a low impact change. In addition, if an obstruction is encountered that stops the forward progress of the tunneling operation, face access

can allow visual observation and removal of the obstruction. This is not the case with most microtunneling applications. Face access on most microtunneling projects is either not available or is extremely limited. Although larger diameter microtunneling machines can have face access (generally machines over 60 inches in diameter), the access typically requires the use of an airlock or soil ground improvement. Also, most microtunneling machines are configured for a particular type of soil condition prior to launch of the machine. If material encountered during tunneling is highly variable, the machine must often be retrieved to either allow changes to the cutter wheel or to clear the microtunnel excavation system of obstructions. Depending on how the GBR was written and the level of risk allocation, this retrieval could be a DSC. In addition, obstructions are very problematic with microtunneling as successful removal of obstructions through the machine is very rare. Therefore, evaluation of each baseline and its potential impacts on microtunnel construction should be considered when writing a GBR for a microtunneling application. Some of the specific considerations are outlined in the following sections.

3. BOULDERS

The presence and number of boulders along a tunnel alignment has the potential to dramatically impact the cost and potential of success of a fully completed project. It is common to baseline boulders and related parameters in GBRs. The ASCE guidelines recommend stating the number of boulders that the contractor should expect to encounter along a tunnel alignment. An example baseline statement from the ASCE guidelines is as follows, "For baseline purposes, ten boulders, between one foot and three feet in maximum dimensions, are expected to be encountered within soil unit 'x' in the tunnel." (Essex, 2007). This recommendation has proven useful in defining DSCs on large diameter EPBM tunnels where boulders can be identified. However, when using slurry based microtunnel machines, measurement is difficult.

On microtunneling projects, the number of boulders encountered by a MTBM during excavation is not readily quantifiable. Due to the nature of the excavation method, boulders are crushed at the face of the machine or within the crushing chamber into small particles to be removed in the slurry system; these crushed particles typically range from one to two inches in diameter. One could use the logged electronic data available from the tunneling, but this is only an indicator and must be used with a corresponding inspection of the slurry separation system. However, one is challenged in using these means to identify the number of boulders that have been encountered during tunneling. Although it may be possible to examine the slurry cuttings and see that rock is being crushed at the face, it is virtually impossible to determine whether the crushed spoils are from boulders or cobbles or how many have been encountered. The contractor needs to be aware that boulders are expected along the alignment so that the appropriate machine and machine face can be configured to excavate boulders. In addition, the frequency of boulders along the alignment is useful for the contractor to determine advance rates of the machine. However, providing a baseline that follows the ASCE guidelines as stated above does not adequately consider the measurement required for determining a DSC as the number and size of boulders cannot be counted.

The important feature to quantify on microtunneling projects is the number of boulders that stop forward progress of the machine, forcing removal of the boulder prior to continued tunneling. Generally, most microtunneling machines are capable of crushing boulders with sizes up to 20 to 30 percent of the outer diameter of the machine. Therefore, the baseline should define the number and strength of boulders that are larger than a percentage of the machine outer diameter that will stop forward progress of the machine. By doing so, the contractor is alerted to include risk cost in the bid documents for removing boulders in front of the MTBM for less than or equal to the number of boulders given in the baseline.

A significant number of construction claims on microtunneling projects have arisen from baseline statements indicating the number of boulders to be encountered. For example, in the Pacific Northwest, a 72-inch microtunnel was designed through glacial till and advanced outwash known to contain boulders. A GBR was prepared for the project that followed the ASCE Guidelines,

containing the following baseline statement; “Ten percent of the total volume of soil excavated along the length of the tunnel alignment will consist of cobbles and boulders.” Further, the baseline report stated; “For baseline purposes, boulders larger than 21-inch size will not be encountered during tunneling operations.” (Shannon and Wilson, 2004). The contractor provided a machine that was capable of excavating boulders up to 20 percent of the outside diameter of the machine, and did not price a rescue shaft into the bid due to the baselined maximum boulder diameter that was established in the GBR. However, the baseline for the percentage of cobbles and boulders was not quantifiable during tunneling.

Microtunneling on the project proceeded without incident, however, from the start of excavation of the microtunneling shafts, the contractor began collecting, measuring, and storing boulders to compare them to the 21-inch baseline. Figure 1 shows some of the boulders that were collected and cataloged by the contractor. Prior to launch of the microtunnel, the contractor verbally notified the owner that they felt that the boulders found in the shaft were in excess of the amount identified in the GBR for the microtunnel. However, collection of bulk samples based on the formation or the calculation of any kind of volumetric comparison was not done. During the microtunneling, a soil separation plant was used to separate excavated material from the microtunneling slurry. The contractor made note and took photos of the crushed rock coming from the shaker screen, as seen in Figure 2. Upon completion of the tunnel, the contractor filed a DSC stating that the percentage of boulders encountered was in excess of the baseline. The claim was for lost production and excessive machine wear due to boulders.

Although the intent of the GBR was to provide a baseline from which a DSC could be evaluated, quantification of boulders by a percentage of the volume excavated did not provide an adequate baseline for determination of a DSC as it could not be measured. In summary, the GBR did provide a baseline as a basis for bidding, but failed to provide a baseline that could be measured.



Figure 1. Boulders collected by the contractor during shaft excavation.



Figure 2. Crushed Rock from the Coarse Shaker Screen of the Soil Separation Plant

4. ROCK STRENGTH

Rock strength is an important geotechnical parameter that is needed for tunneling to determine several cost and time parameters. The contractor uses the unconfined compressive strength (UCS) of the rock as well as the abrasive potential to determine the type of rock cutting bit that can most effectively excavate the formation, and to minimize the cutter wear that can be expected during tunneling. The rock strength is particularly important when excavating full face rock. In the case of full face rock excavation, the cutter is designed to roll on the rock and transmit forces high enough to spall the rock at the face. Cutters are designed at specific spacing on the face to allow the maximum size of rock piece to be cut from the face, maximizing excavation rates, and minimizing cutter wear. For effective rock excavation it is important that the rock is confined and unable to move when the cutter load from the microtunneling machine is applied to the rock. If the rock is not stationary (falls out of the soil matrix), the force applied by the machine will move the rock, and the rock may not spall and be able to be digested into the crusher and removed by the slurry.

Full face rock projects can be challenging for microtunneling. This is largely due to the limited space on the face of the machine due to the small diameter which limits the number, spacing, and configuration of rock cutting bits that can be mounted on the face. It is difficult to design a rock cutter spacing that can effectively excavate full face rock at small diameters. In addition, since microtunneling machines have limited access to the face, most machines do not have cutters that can be changed mid-drive. As a result, either drive lengths must be reduced or cutters selected that can survive the entire length of the drive.

An important variable to consider in a GBR is the specification of rock strengths on microtunneling projects. Again, it is important to consider the size of the microtunneling machines to be used and the mechanism of excavation. Although rock cutters on the face of the machine aid in breaking cobbles and boulders, microtunneling machines are designed to crush cobbles and spall boulders within the crushing chamber of the machine. Cobbles and boulders that enter into the crushing chamber are broken by the rotating action of the crushing bars against the crushing chamber, much like the action of a coffee grinder. In fact, the crushing chamber dimensions largely set the maximum size of cobble or boulder that can be successfully excavated by microtunneling. Therefore, determining a precise strength for cobbles and boulders is not as important for microtunneling applications because those strengths are not used to select the type of cutter on the face. In addition, microtunneling has been successfully completed in glaciated

environments where rock strengths were known to approach 60,000 psi (Staheli and Duyvestyn, 2003).

DSCs involving rock strength have arisen on construction projects in cobble and boulder environments where the baseline maximum strength of the cobbles and boulders was set in the GBR. On such projects, the strength of the cobbles and boulders was questioned whenever the microtunneling machine was unable to progress. However, microtunneling may be stopped for any variety of reasons, including mechanical failure, loss of cutting teeth, excessive wear, inadequate power or torque, binding of the face, etc. When the machine is retrieved, cobbles and boulders at the retrieval site are collected for testing. If the rock tests reveal strengths that are higher than the baseline maximum UCS in the GBR and none of the other reasons for stoppage can be proven, the contractor may have a valid DSC, whether or not the rock strength contributed to the machine failure. The contractor then uses the DSC as a means for recovering costs associated with the recovery and repair of the machine. When considering whether to specify a baseline for cobble or boulder strength, one should consider how the baseline will impact the type and configuration of the microtunneling machine. If the microtunneling configuration will not change whether boulders are baselined at 30,000 psi or 60,000 psi, one should consider the value of establishing the baseline strength.

5. DEBRIS

A number of projects have attempted to baseline debris that will be encountered during tunneling, especially in environments where microtunneling excavation is within fill material. It is critically important to develop a baseline for the amount of tunneling that will be carried out within fill. However, extreme caution should be used when differentiating between establishing a baseline and specifying machine performance. All machine performance requirements should be contained within the specification and should not be addressed within the GBR to avoid conflicts within the contract documents.

One example of debris for which baselines have been set is the existence of wood along the microtunneling alignment. As with all other baselines, the capabilities of the construction method as well as the means to quantify the excavated material should be considered when establishing an appropriate baseline. Microtunneling machines have had varying degrees of success tunneling through woody debris. Many machines have successfully tunneled through wood such as logs, piles, etc. However, a number of machines have become stuck on woody debris, requiring face access to allow continued construction. When establishing a baseline for wood or other debris it should be understood that microtunneling machines are not designed to excavate debris. As such, the owner should expect that machine retrieval may be necessary within a debris environment. The identification that such debris exists does not relieve the owner of the risk that is associated with encountering the debris. If wood or other debris is expected along the alignment, it may be advantageous to include a line item in the bid for machine retrievals in order to limit the contingency that a contractor places in the bid due to the existence of debris.

When establishing baselines for debris, clear definition of the debris should be included. For example, tunneling through scattered fragments of wood is very different than tunneling through a log or a trunk. The geotechnical investigation should be structured to define the nature and amount of the debris to the greatest practical extent. Baselines should then be focused on material that would stop the forward progression of the machine, requiring access either from within the machine or from the surface to remove the wood or clear the woody debris from the face and the crushing chamber. Debris that impacts the excavation process should be given the most attention in the baseline as it has the highest impact on the bid price.

It is also important that the GBR does not address machine requirements. All machine parameters should be included in the specification and not within the GBR. On one project in the Pacific Northwest, a tremendous amount of fill was identified during the design of a microtunnel. The owner elected to use a GBR on the project and was careful to completely divulge all

information to the contractor about the risks associated with the fill material. The baseline described the fill as generally consisting of a mixture of soil and debris. To provide the contractor with a definitive baseline, it further stated that the debris would not exceed 30 percent of the total excavated volume of the fill material where it was encountered (URS Greiner Woodward Clyde, 2000). The GBR also identified the presence of buried bridge and plank road in the fill within the limits of the alignment. An area was delineated on the geotechnical cross sections showing the approximate limits of the plank road lying within the alignment. All of this information was important to establish a baseline for the contractor's bid price. However, the document went further to state that "timber posts and remnants thereof, regardless of dimensions shall not be considered obstructions." (URS Greiner Woodward Clyde, 2000). This statement was to alert the contractor that they should bring a microtunneling machine capable of ingesting wood, and that the contractor would not receive additional compensation for encountering the plank road during microtunneling. However, the identification of the plank road did not relieve the owner of the risk of encountering the road. Since the road was within the alignment and microtunneling machines are not designed to excavate through plank roads, the owner should expect that encountering such debris would result in digging in front of the MTBM to clear the obstruction. The owner should be involved in establishing this risk allocation as written in the GBR.

6. SOIL SEPARATION

Soil separation is another variable generally unique to microtunneling that must be considered in the GBR and may lend itself to a baseline. It is well known that separation of soils can be a costly expense in microtunneling when substantial silt and clay are present. This will affect many operational variables that impact costs such as production, settlement, equipment requirements, and wear. These are important parameters that should be considered when writing the GBR. If not considered in the baseline, then the most optimistic assumptions will likely be assumed by the contractor and if substantial costs result, a DSC may follow. The baseline should consider the variables related to soil separation, such as particle sizing amounts. This could result in more quantitative work being required to better understand the range of soil characteristics to best define the baseline and determine the risk allocation. During construction, it is then imperative that measurements take place so that any deviations to the baseline can be quantified.

7. CONCLUSIONS

The ASCE guideline for Geotechnical Baseline Reports provides a tremendous amount of valuable information on the production and implementation of such documents. However, the reader should keep in mind that the document was developed for use in the large diameter tunneling industry and that some of the guidelines may require modification and adaptation for use in the microtunneling industry. When establishing baselines, it is critical to consider how baseline parameters will be measured and evaluated in the field by construction personnel, and how they will affect the selection of equipment. The value of a baseline statement that cannot be directly measured should be carefully evaluated, and the owner should consider ways in which the baseline might be used against them in the event of a claim. If direct measurement of the baseline is not possible, the statement may cause considerable confusion during the evaluation of a DSC. The reader should also consider how the baseline impacts the bid price of the project. If the baseline does not impact the contractor's choice of machine configuration or the bid price, the value of the baseline statement should be carefully evaluated. As the use of GBRs becomes increasingly popular on microtunneling projects, lessons will continue to be learned from projects where claims are evaluated from baselines. Successful microtunneling projects can occur more often with the consideration of the unique issues and potential failures of the microtunneling operation, by properly identifying the variables and parameters and their effects on the work, and by integrating the GBR with the specifications to obtain the right equipment and limit the owner risk.

8. REFERENCES

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