Geotechnical Baseline Reports—A Review

T. Freeman
GeoPentech

S. Klein
Jacobs Associates

G. Korbin
Independent Consultant

W. Quick
Independent Consultant

ABSTRACT

In the past ten years, the Geotechnical Baseline Report (GBR) has arguably become the key document for tunnel construction. This report not only allocates much of the risk involved with the work, it serves as the basis for bid preparation and is used extensively in resolving disputes during construction. This paper discusses some important issues related to the GBR and presents suggestions for improving these vital reports.

INTRODUCTION

The use of Geotechnical Baseline Reports (GBRs) for contractually defining anticipated ground conditions has become a widely accepted practice in the tunneling industry. The importance and the critical nature of these reports have increased the scrutiny they receive to unprecedented levels. The basic premise of a contractual geotechnical baseline has been well developed and communicated to the industry in the Underground Technology Research Council's guideline document titled *Geotechnical Baseline Reports for Underground Construction* (UTRC, 1997) and in the updated version of this document (UTRC, 2007).

Despite the acceptance of GBRs, there is room for improvement. Engineers and geologists struggle to develop specific numerical baselines from a myriad of geotechnical properties, especially where geologic conditions are highly variable. Contractors are frustrated because they are not always provided with the baselines they need. Owners feel taken advantage of when baselines are used to justify claims in a manner not intended or the baselines are not respected in the dispute resolution process.

The intent of this paper is to provide suggestions for improving the effectiveness of GBRs, based on our collective experience with many tunnel projects and their GBRs. It is intended that these suggestions will complement the UTRC guidelines and result in better, more useful GBRs. Our suggestions fall into four categories:

1. Establishing baselines
2. Ground behavior/performance assessments
3. Construction considerations
4. Use of the GBR during construction

ESTABLISHING BASELINES

Two of the greatest challenges in preparing a GBR are determining the ground conditions that need to be baselined and how to quantify these baselines. As stated in the UTRC guidelines, the goal of the GBR is to “translate the results of geotechnical investigations and previous experience into clear descriptions of anticipated subsurface conditions upon which bidders may rely.”

Baselines were intended to provide contractors a mechanism whereby they were not held responsible for unlimited risks involved with unforeseen ground conditions. Contractors have the right to expect that the baselined ground conditions presented in the GBR are reasonable. Ultraconservative baselines (i.e., attempts to shift unreasonable risk to the contractor) may not be successful, and this practice is discouraged because it may distort the bidding process and is contrary to the intent of the GBR.

Owners have the right to expect that contractors will consider the full spectrum of baselined ground conditions when determining appropriate construction means and methods and preparing their bids. Furthermore, owners have the right to expect that Dispute Review Boards (DRBs) will evaluate differing site condition claims against the actual baselines presented in the GBR.

Developing accurate or representative numerical baselines can be difficult, especially considering the natural variability of most geologic formations. In addition, the geotechnical investigations conducted for most tunnel projects only sample and test a small fraction of the soil/rock mass that will be encountered in the tunnel, typically much less than one percent. Considering the variability of Mother Nature and our limited geologic database, it is understandable that developing baselines presents some significant challenges. The following paragraphs discuss issues that have been problematic and suggestions for overcoming these issues.

Appropriate Baseline Topics

It is important to recognize that each baseline presented in the GBR establishes a potential target for a claim. Many GBRs baseline an extensive array of geotechnical parameters (such as unit weight, Atterberg Limits, blow counts, etc.), including parameters not relevant to the tunnel construction. Although this increased level of detail creates the illusion of a comprehensive GBR, and seemingly serves to protect the owner from differing site condition (DSC) claims, in some cases it has come back to haunt owners during construction. In order to justify a DSC claim, some contractors search for a deviation in one of the baselined variables, regardless of its importance in tunnel construction, and devise a creative explanation for how this variable impacted their means and methods and/or progress rate. Therefore, as a general rule it advisable to only baseline the soil/rock properties that are necessary for a contractor to evaluate tunnel excavation means and methods, estimate production rates, and design temporary or initial supports, when required.

After contract award, the GBR may not receive much attention until problems arise and DSC claims appear. Evaluations of DSC claims should be based on a comparison of the actual encountered ground conditions against the ground conditions baselined in the GBR. Accordingly, it is desirable for the baselines to be selected and quantified in terms that are readily measurable or verifiable in the tunnel, considering the means and methods that are likely to be used to construct the tunnel. For example, it can be very difficult to measure the frequency, orientation, and aperture of rock mass discontinuities along the tunnel (certainly not continuously) if the contractor elects to use a shielded tunnel boring machine (TBM) with a segmental concrete lining. Limited access to observe in situ ground conditions hampers both the contractor and owner. The contractor has difficulty demonstrating that ground conditions deviate from the baseline, and the owner cannot easily verify that ground conditions are consistent with the baseline. In some cases, it is better to baseline the end result, such as groundwater inflow into the tunnel, rather than a soil/rock property, such as permeability, which may vary widely and is difficult to measure in the field during construction. In Europe, partly to overcome these limitations, TBM boreability parameters (i.e., penetration rate and cutter wear) are sometimes used to classify the rock mass; however, these parameters can be difficult to interpret if machine operation becomes an issue. As discussed below, in many cases the end result can be significantly influenced by the contractor's selected means and methods and execution of the work; therefore, care is required to ensure that baselines are as independent of the contractor's means and methods as possible.

Quantifying Baselines

After the variables to be baselined have been selected, the next step is to quantify them. As discussed above, quantifying baselines is often a difficult process due to inevitable limitations in the geotechnical database, and these difficulties are even more acute when geologic conditions are complex.

Engineers and geologists tend to baseline the full range of possibilities, arguing that as long as actual conditions fall within that range, a DSC will not be encountered. However, in cases where a physical property can have a wide range, such as rock strength, it is difficult for contractors to select a single or average value on which to base their bid. Contractors must recognize that most tunnels have to be constructed through a range of geologic conditions, often a wide range of conditions. The commonly applied “average value” of a certain ground characteristic may not even be meaningful. It may just be the midpoint between two extremes. Owners must realize the importance of carrying out sufficient geotechnical investigations to develop a statistically representative sampling of the ground prior to bid. If a dispute arises, a similar statistically representative data set of the encountered ground conditions should be collected to allow for a valid comparison between anticipated and actual conditions.

The distribution of the various ground conditions along any given tunnel reach also are generally described by a range of conditions, and if possible, with specific identifiable features, such as fault zones. Similar to the disadvantages of baselining too many individual ground characteristics, as discussed above, dividing the tunnel into too many reaches also can be a disadvantage.

Furthermore, in complex geology the orientation and characteristics of many faults or shears can change significantly horizontally and vertically such that predicting their specific subsurface locations and conditions is quite uncertain. This raises an important question. If a fault zone, anticipated between certain limits in a hard rock tunnel, is described as “poor ground,” is it possible to also baseline some additional randomly located poor ground elsewhere in that reach to accommodate the likely presence of faults and shears that cannot be specifically located? Of course, there is no rational reason why “poor ground” cannot occur randomly in other portions of a reach that is outside specifically delineated fault zones. This condition certainly can be covered by baselining a percentage of the reach as poor ground to accommodate anticipated ground that cannot be specifically delineated. Although, if characterized in this manner, this randomly located poor ground would have to be similar in character to the poor ground associated with the specifically delineated fault zones and be limited to some maximum width.

Average Baselines

As an example of typical geologic variability and the significance of average or mean baselined values, consider the unconfined compressive strength (UCS) data shown in Figure 1 for two sandstones from two projects in which the authors were involved. Sandstone A has strength distribution that roughly resembles the bell-shaped Gaussian distribution that you might expect for a material subject to natural statistical variability. Sandstone B, on the other hand, has an almost uniform distribution across this UCS range, with about 20 percent of the samples having a strength of less than 2 kips per square inch (ksi) and about 25 percent with an UCS higher than 10 ksi. There are valid reasons for this type of distribution, such as variations in the mineralogy or texture of the rock, differences in cementation, healed joints, or other small scale defects in the samples. The key point is that for Sandstone A, over 60 percent of the data is within 2 ksi (+/-) of the mean strength, whereas for Sandstone B, only about 20 percent of the data is within 2 ksi (+/-) of the mean value. Baselining the average UCS value for Sandstone A appears to be a reasonable way to represent the mean strength of this rock. However, for Sandstone B it would be better to baseline a strength distribution by histogram or a distribution similar to its histogram (i.e., baselining the percentage of the rock greater than 10 ksi and less than 2 ksi as well as some intermediate values).

Another approach might be to determine the average rock strength from each boring in the formation and either use a weighted average approach or have the baseline average rock strength vary along the tunnel alignment similar to the borings, provided this is a valid trend based on the data and the data are not adversely influenced by features such as fault zones. Setting the baseline using an approach other than the strict arithmetic mean of the test data, which may or may not be representative, should be acceptable as long as the basis is logical and clearly explained.

Baselines Not Consistent with Test Data

Care must be used to assign baselines that are reasonably consistent with the statistical database. For example, Gould (1995) describes a project where the engineer increased the baseline rock strength to account for the difference between laboratory rock strength tests and in situ rock strength resulting from sample disturbance. However, the reason for this adjustment was not fully explained in the GBR, and the DRB ruled for the contractor, indicating that this adjustment appeared to be a strategy to protect the owner and not a proper baseline for bidding. When the baseline deviates from the test data, it may be important to explain the basis or justification for the adjustment in the GBR so it is clear that the baseline is not being established arbitrarily or unfairly. However, in the authors' opinion, a baseline is a baseline, even without such a justification.

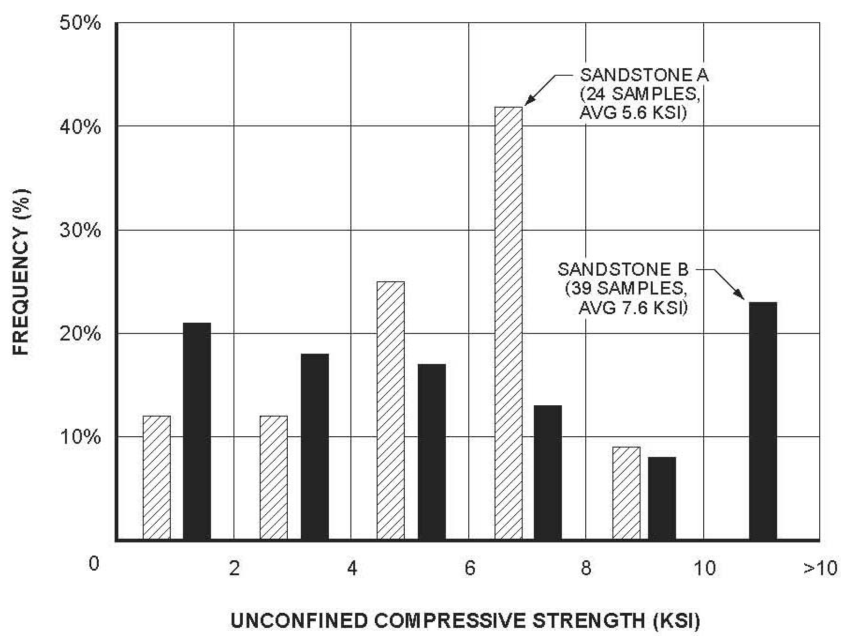

Figure 1 - Comparison of UCS Data from Two Sandstones.

Groundwater Control

More recently, the issue of tighter control of groundwater inflows has been coming up more frequently for a variety of reasons, including potential third-party impacts. This issue becomes most challenging in complex geological environments, particularly in hard rock with high groundwater levels, where the seemingly unpredictable nature of rock mass discontinuities controls the inflow into the tunnel. To define the range of conditions expected, two baselines are often employed: one for flush flows and steady-state inflows from untreated ground to define in situ conditions, and a second for flush and steady-state inflows from grouted ground. Sophisticated numerical groundwater models are useful tools that can be used to help quantify the inflows. However, extreme care is necessary in setting the baseline for treated ground as the amount and type of grouting needed to achieve this condition will be difficult to determine in advance of construction, and will also be highly dependent on the contractor's grouting means and methods.

In cases where the ground or groundwater conditions are poorly defined and have the potential to adversely impact the work, the owner often elects to direct pre-excavation grouting measures to achieve desired reduction in groundwater inflows and to control costs. However, this approach can impact the contractor in several ways that complicate the work. Contractors typically want to be free to do the grouting they feel is necessary and to be paid for this grouting. With these competing interests, whether it is better for the owner or contractor to control such grouting remains an unresolved issue in the tunneling industry. The best way to handle this issue will vary by project depending on the technical requirements of the work; the risk or uncertainties involved; the contracting/delivery method being utilized; and the relationships between the owner, contractor, and any third parties. From a GBR perspective, it is important to recognize that the baselines that are ultimately established need to be consistent with the contracting approach and specified requirements.

Conflicting Baselines

Conflicting baselines result when more than one soil/rock property with the same general purpose are baselined. For example, with regard to TBM boreability and disc cutter wear, the abrasiveness of hard rock can be evaluated by using the Cutter Life Index (CLI) of the SINTEF method, or by using the Cerchar Index (Johannessen, 1988). If both parameters are baselined and they do not result in the same predicted cutter life, the GBR has provided two baselines for the same purpose that do not agree. While in this instance the contractor would be free to select either baseline, it is clearly not an ideal situation and one that can easily be avoided by providing, in this case, only one baseline for cutter wear.

Similar problems arise in determining the completeness of the baseline. The CLI requires information on mineralogy (rock type) and quartz content to evaluate cutter wear. If only the CLI is baselined, but not quartz content, the baseline is incomplete.

Conservative Baselines

Some GBRs seem to be written to protect the owner from any risk, attempting to put all of the risk on the contractor. There is little advantage, either to the owner or to the contactor, in artificially making baselines too conservative. Although technically the owner has the right to do so, it serves no purpose to make the baseline so conservative that the owner pays for conditions that are unlikely to occur. Also, when baselines are made overly conservative it can backfire when the "law of unintended consequences" comes into play. In general, baselines should be realistic and, as close as possible, reflect the actual expected ground conditions. It should be recognized that there is a natural tendency to be conservative due to the uncertainties involved with a limited database and our imprecise knowledge of geologic variability. This underscores the importance of completing adequate geotechnical investigations in the first place.

Ground Classification

In classifying the ground, the GBR commonly employs terms and definitions that are standard to the industry. Occasionally, however, it is advantageous to develop new definitions or modify existing ones. For example, many tunnel projects in Atlanta, Georgia, have employed a weathering classification system solely developed for the region and with terminology familiar to local contractors. In other situations, established classification systems, such as the Terzaghi's rock classification system (Proctor and White, 1968), have been found to be too narrow. For example, Terzaghi's definition of "crushed" rock indicates it is comprised of "chemically intact rock" with the "character of a crusher run." If, however, the crushed material is weathered or altered, resulting in a clay fraction, the clay can act as a weak cohesive binder. Therefore, to include this material in the crushed rock category, a modification to the definition is required. Contrary to some recent DRB decisions, the authors believe such modifications or project-specific definitions are acceptable as long as the definitions are clear and unambiguous and the reasons for making these changes are also explained in the GBR.

Terzaghi also uses the phrase “chemically intact” in his description of blocky and seamy rock (Proctor and White, 1968). Some GBRs have used Terzaghi’s rock classification system and baselined the weathering condition of the rock mass separately. This has been criticized by some as being inconsistent because the term “chemically intact” does not appear to be consistent with a weathered rock mass. However, Terzaghi did not intend to limit the term “blocky and seamy rock” to only “chemically intact” rock, as he also indicates:

> *This condition is encountered in both closely jointed and badly broken rock. The joints may be narrow or wide, empty or filled with the products of rock weathering.*

In dealing with this apparent contradiction, the engineer has two options: (1) modify the standard Terzaghi definition, as discussed above; or (2) develop a project-specific classification system. Using a project-specific ground classification system avoids the contradiction by defining each ground class in terms selected to specifically communicate the unique aspects of the ground conditions to the contractor.

GROUND BEHAVIOR/PERFORMANCE

Predicting ground behavior in the tunnel excavation is one area of the GBR where engineers and geologists often have difficulty in making an accurate assessment. This is because ground behavior ultimately depends on both the in situ properties of the soil or rock mass and the contractor’s applied means and methods. Ideally, a discussion of potential ground behavior in the GBR should only reflect the unmodified, in situ ground conditions and not relate to effects of the applied construction means and methods. While selected means and methods will modify the behavior of the ground, this is the contractor’s domain and, as has been demonstrated on many projects, the engineer is rarely correct when making assumptions about the contractor's means and methods or workmanship, unless the methods are specified.

For example, subhorizontal foliation combined with high angle intersecting joints can result in overbreak within the crown area. In TBM excavations, fallout could occur some distance behind the cutterhead only in response to displacements due to stress redistribution around the excavation opening. However, if drill and blast methods are used, all of the overbreak can occur simultaneously with excavation of each round. Should the GBR explain this? While in our opinion the answer is yes (as discussed below), the magnitude of the effects are primarily related to the contractor's particular means and methods, and thus the specific amount of overbreak should not be baselined.

In ground with short standup time, if the contractor delays the installation of adequate initial support, more overbreak can occur than if installed in a timely manner; the key words being "adequate" and "timely." In this regard, great care is necessary in preparing the GBR by limiting the discussions to the relevant facts, mainly unmodified ground conditions. Baselines regarding ground behavior that are heavily influenced by the applied means and methods may not be appropriate.

CONSTRUCTION CONSIDERATIONS

Some have argued it is not appropriate for GBRs to address construction considerations and the report should focus entirely on baselining the anticipated ground conditions. This may have to do with concerns regarding the level of detail provided when the contractor's means and methods are unknown and there is a potential of introducing extraneous or possibly misleading material. On the other hand, the GBR is the only interpretive geotechnical report provided to the contractor and the consequences of the anticipated ground conditions on the construction work should be explained, *but not be baselined*, to enhance the contractor's understanding of the project requirements.

Many claims deal with the relationship between the ground conditions and the construction process. Examples include slaking or softening of the ground, overbreak, timeliness of ground support, TBM gripper problems, face stability, abrasive rock conditions, and the need for pre-support, to name a few. The value of discussing construction considerations (or potential construction problems) is that this provides the contractor with key information in planning the work and may help avoid claims and delays during construction (Waggoner et al., 1969; USNCTT, 1984). Unless the specifications require the contractor to specifically address the issue, the contractor may not have a contractual requirement to provide a solution but at least they are alerted to the situation and have the opportunity to take appropriate action.

Another advantage of discussing construction considerations in the GBR from a legal perspective involves the differing site conditions clause. This clause recognizes two types of DSCs: Type 1 where conditions differ materially from those indicated in the Contract; and Type 2 which involves unusual physical conditions that differ from those ordinarily encountered or generally recognized as being inherent in the work (UTRC, 1997, 2007). Violating a GBR baseline usually would be considered a Type 1 DSC. If the GBR were silent on a certain construction problem/difficulty (i.e., no discussion of construction considerations involved with the anticipated ground conditions) then the contractor could possibly allege a Type 2 DSC.

After the engineer identifies a potential construction problem or issue, there are three general approaches that can be adopted in the GBR (and design documents):

1. Be silent on solving the problem/issue and let the contractor decide how to address it.
2. Provide a recommended solution(s) and allow the contractor to select the solution.
3. Specify a solution that will work and require the contractor to implement that approach.

It is difficult to identify which approach is best. This depends on the issue, the potential consequences in terms of risk and cost, and in some cases, the owner’s preference. When the problem/issue is left entirely up to the contractor to solve (No. 1 above), then it must be assumed that the low bidder will probably try to implement the least expensive solution. No claims should result as long as this solution works. This approach may offer the owner potential cost savings because the contractor is free to select the approach that is most economical, but it could involve some significant risk for the owner if this approach does not work.

The second approach is to not specify means and methods, but instead to discuss concerns and appropriate solutions through recommendations provided in the GBR. Presenting relevant discussions, recommendations, and/or suggestions in the GBR as to appropriate means and methods (such as the need for certain features on a TBM) provides the contractor with an assessment of how ground conditions could impact the work and would indicate intent, but would not be binding. In that case, the contractor is free to accept the recommendations or ignore them. However, if they are ignored and this issue becomes a factor in a dispute, the DRB has been provided with specific indications for consideration.

The last approach often is used when there are difficult or risky ground conditions and also when construction could impact third parties. Rather than try to define or baseline conditions that are too complex to convey accurately in words, an approach that is believed to be the appropriate (and usually somewhat conservative) is specified. In response, contractors often indicate that the resulting specifications are overly prescriptive. Design engineers argue that it is important to define requirements they perceive as important for success; however, this results in a potential for conflicts as the contractor wants to be able to select the means and methods of construction. Again, discussions of construction considerations in the GBR can be useful in explaining the designer’s logic for prescriptive requirements.

USE OF THE GBR DURING CONSTRUCTION

Contractors need to carefully study the GBR and understand the implications of the baselines before preparing their bid. Some contractors retain an engineering geologist or geotechnical engineer to assist them in assessing the GBR during their bid preparation. Others only review the GBR well into the construction and then retain engineering geology or geotechnical engineering support when they want to pursue a DSC claim. Possibly this has to do with the limited time frame for preparing the bid. Whatever the reason, this later approach is counterproductive and is not in keeping with the intent of the GBR.

Likewise, the owner's construction management (CM) team also should study the GBR at the outset and not wait until the contractor submits a DSC claim to get familiar with the document. Extra care should be exercised during the review of the contractor's submittals to ensure that the construction considerations discussed in the GBR have been addressed and incorporated into the contractor's selected means and methods. Recommendations and/or warnings in the GBR, not addressed by the contractor, should be pointed out in the CM team review comments.

During construction, when reviewing DSCs it is most important that DRBs render their decisions based on entire contents of the GBR, not just on a narrow interpretation of the report. For example, if the condition of the ground (strength, joint frequency or characteristics, weathering, etc.) varies from the GBR descriptions but the behavior is the same as indicated in the report, does this constitute a valid DSC? The only way to find a DSC in this situation is for the impact on the contractor to be due to the ground characteristics that varied from the GBR, not the behavior.

The authors recently experienced a case where the GBR warned the contractor of raveling ground conditions in "highly altered" rock; however, a DSC was awarded by the DRB for more highly altered ground even though the actual behavior of the ground was consistent with the baseline. This questionable decision was not accepted by the owner.

It is important for DRBs to recognize that a DSC claim is not automatically valid just because a baseline has been violated. There must also be some impact to the contractor, and the impact must be "solely" due to the property or characteristic that has differed from the baseline (Cibinic et al., 1995). Failure to evaluate and determine if this connection exists is inappropriate. Where the contractor was warned of potential problems in discussions of construction considerations and these warnings were ignored, even if certain baselines were violated, the contractor may have some responsibility to address the condition.

RECOMMENDATIONS

In a relatively short time, only about ten years, GBRs have become an accepted practice in the tunneling industry. Therefore, it is important to make these reports as effective as possible. The following recommendations should be considered:

- Reasonable baselines need to be incorporated into the GBR. Avoid unnecessary or superfluous baselines. Overly conservative baselines or attempts to place unreasonable risk on the contractor may not be successful and are not recommended. Other approaches for incorporating contingency measures in the contract to deal with adverse conditions should be utilized.
- It must be recognized that geotechnical investigation needs for construction often exceed the needs strictly for design (Gould, 1995). Preparing realistic baselines starts with having a statistically adequate geologic database.
- Quantification of the baselines should consider how the properties will be measured in the tunnel, and in general, the baselined values should be consistent with the geologic database or explain any deviations.
- Ground performance or baselines related to ground behavior should be avoided to the extent they are affected by the contractor's selected means and methods. However, discussions of construction considerations/difficulties should be included in the GBR to communicate to the contractor the potential consequences of the baselined ground conditions. Whether recommendations are provided for

handling these issues or specific contract requirements are included in the specifications depends on the potential impact, the risk in leaving it up to the contractor (and the marketplace), and the potential for third-party impacts.

- Contractors should give attention to discussions of construction difficulties/ problems described in the GBR and consider these issues in the selection of their means and methods.
- Owners should actively review the GBR while it is in the developmental stage and make sure they understand the cost/risk ramifications. For major projects, an independent opinion from a consultant board/panel is recommended. The implications of the baselined conditions should be fully addressed by the CM team in reviewing the contractor's submittals during construction.
- DRBs should respect the baselines indicated in the GBR and consider the GBR in its entirety in deciding the merit of DSC claims. It is not reasonable for the contractor to base a claim solely on one word, phrase, or sentence in the GBR, especially where the potential construction difficulties/problems are correctly recognized and discussed in the GBR but ignored by the contractor.
- GBRs are not a panacea and do not by themselves guarantee a successful project. Difficult and complex ground conditions require an experienced, qualified, and conscientious contractor, whose selected means and methods are appropriate and compatible with the anticipated ground conditions. Such challenging projects also require a contracting and CM approach that encourages all parties to work together to solve the challenges they face. A GBR can identify the challenges but will not solve all of the problems.

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