Can GBR baselines be reasonably measured during construction? – Some case studies

Scott Peaker & Laifa Cao
WSP Canada Inc., Toronto, Ontario, Canada

ABSTRACT
Although the application of geotechnical baseline report (GBR)-based contracts is now fairly commonplace in most North American jurisdictions on tunneling projects, the jury is still out as to whether or not the setting of GBR baselines has resulted in equitable and satisfactory allocation of geo-risks between Owner and Contractor. One of the shortcomings of GBR contracts is the difficulty in reliably and practically measuring or tracking one or more baselined parameters during the normal course of construction. Since the focus of the contractor is in the safe execution of the work as efficiently as possible, the verification of GBR baselines is seldom a priority until the later stages of a project when the broader cascading impacts on schedule and production - attributable to in-ground issues - may become more apparent. Similarly, consultants may not have any mandate from Owners to take responsibility for the tracking and measurement of GBR baseline parameters during construction. In many cases, such as for in-tunnel work, safe access to the heading by the inspection agency may not be practical without a shut down in the work. In other cases, such as the case of microtunnels, access is impossible and only indirect evidence can be collected, potentially of dubious value. Moreover, many GBRs lack clear statements as to who is responsible for taking such 'measurements', how such measurements must be taken and how they need to be statistically interpreted. This paper presents a series of case studies of water and wastewater related projects in Southern Ontario (Canada) involving tunneling and microtunneling where claims were made against the GBR. The GBR baselines that were tested included the frequency and size distribution of cobbles and boulders and overburden undrained shear strength. The means of measuring the relevant GBR baseline parameter(s) under 'dispute' are described for each project and the logic applied to the assessment of merit of the claims is reviewed.

RÉSUMÉ
Bien que l'application de contrats basés sur la GBR soit maintenant assez courante dans la plupart des juridictions nord-américaines sur les projets de tunnels, le jury ne sait pas encore si l'établissement de paramètres de référence d'un GBR a déjà permis une répartition équitable et satisfaisante des risques géotechniques entre Propriétaire et Entrepreneur. L'une des faiblesses des paramètres de référence GBR est la difficulté à mesurer et à suivre de manière fiable et pratique un ou plusieurs paramètres de base lors de la construction du projet. Étant donné que l'entrepreneur se concentre sur l'exécution sécuritaire des travaux aussi efficacement que possible, la vérification des paramètres de référence GBR est rarement une priorité jusqu'aux étapes ultérieures d'un projet lorsque les répercussions en cascade sur le programme de construction – qui pourraient être attribuées aux paramètres du sol - peuvent devenir apparentes. De même, il se peut que les consultants ne soient pas mandatés par les propriétaires pour prendre la responsabilité du suivi et de la mesure des paramètres de référence GBR pendant la construction. Dans de nombreux cas, comme dans un tunnel, l'accès sécuritaire à la face d'excavation par l'organisme d'inspection peut ne pas être pratique sans un arrêt des travaux. Dans d'autres cas, tels que les micro tunnels, l'accès est impossible et seules des preuves indirectes peuvent être collectées. De plus, de nombreux GBR manquent d'énoncés clairs quant à savoir qui est responsable de ces «mesures», comment ces mesures doivent être prises et interprétées statistiquement. Cet article présente une série d'études de cas de projets liés à l'eau et aux eaux usées dans le sud de l'Ontario (Canada) impliquant des tunnels et des micro tunnels où des réclamations ont été faites contre le GBR.

1 INTRODUCTION

The Geotechnical Baseline Report (GBR) came about in the United States in the late 1990’s (ASCE, 1997). Early acceptance of the GBR, in the province of Ontario, and almost exclusively for tunneling projects, emerged about a decade later. Early adopters in Ontario included the Toronto Transit Commission and the Regional Municipality of Halton. Adoption of the GBR as a risk allocation tool in tunnel and major microtunnel contracts would now be considered by most geo-practitioners and public agencies to be the norm. Similarly, the North American contracting community now has an expectation that tunnel contracts will be tendered and administered using GBRs (ASCE, 2007). It ought to follow that the widespread adoption and apparent maturation of the GBR have led to advancements and efficiencies in the manner in which GBR contracts are administered as well as in the efficient and equitable adjudication of changed ground condition claims. In the author’s opinion, such advancement has seemingly stalled.

2 IS THE ADJUDICATION OF GBR CONTRACTS EVOLVING OR STALLED?

The delayed progression from ‘adolescence’ into ‘adulthood’ appears to be partly related to an excessive reliance on individual GBR-baselined parameters to rule on the merit of changed ground condition claims, when in certain cases the claims ought to be more straightforward to assess by the contracting parties and their geo-professionals. This may, in part, be related to poor linkage between the Contract or Special Provisions in the Contact and the GBR, where details explaining how measurement against GBR baselines should unfold, by whom and when. Even when field measurements against baselines are conducted, most contracts fall silent in terms of how to establish a method of establishing or negotiating quantum.

This paper does not purport to supply the answers as to how to advance the GBR to its next phase of maturation. It does, however, present case studies on Contracts where GBRs were applied and where some of the claims were resolved during or shortly after construction without the need to litigate.

3 WATERMAIN TUNNEL CONTRACT – NORTHEAST OF TORONTO

Claims related to boulders and cobbles, particularly in glacial and fluvial outwash geologic terrain are commonplace. The prevalence of these types of claims may be related to the difficulty in both the accurate quantification of the boulder/cobble content by means of traditional geotechnical investigation methods, combined with the significant impact these obstructions can have on equipment and loss of productivity. The most common measures utilized in GBRs to baseline boulders and cobbles are the Boulder Volume Ratio (BVR) and Cobble Volume Ratio (CVR), generally combined with additional details on the variability/distribution of lithology, hardness and abrasivity of these inclusions. Another baseline approach is to quantify a precise number of boulders to be expected in shaft or in tunnel, in a given geologic formation.

The BVR is simply defined as the ratio of the total combined volume of all boulder sized rock particles to the excavated soil volume. A statistically valid determination of BVR (or CVR) on the basis of field investigation is exceptionally costly (and may be impossible) since this requires advancement of large diameter test shafts or caissons. These are generally put down at proposed shaft locations since boulders and cobbles could potentially have an impact on both the shaft excavation as well as tunneling. Shaft locations are also often vacant, open sites which could facilitate such operations. Deep test pits have also been used to this end, but their application is obviously limited to stable ground where the tunnel horizon is shallow enough to be within reach of conventional excavators. The advancement of such trial bores / pits could be considered unto itself a small construction project, rife with permitting, coordination, logistical, safety and restoration issues.

Seminal work on this topic is described by Boone et al. (Boone et al. 1998). The work by Boone et al. (1998) is a statistical evaluation of boulder sizes recovered from the support of excavation (SOE) drilled shafts along the Sheppard Ave. Toronto Transit Commission (TTC) alignment, completed during an advance contract involving utility relocations prior to the twin tunnel contract. The field work involved the manual logging of boulders recovered from the drilled shaft spoils. This data was then statistically extrapolated. Given the comprehensive nature of this work and lack of comparable well-document comparable case studies, the ‘Boone’ boulder content values are often adopted by engineers preparing GBR’s in the Greater Toronto area despite the fact that their projects may not lie within the same geologic formation prevailing along the Sheppard Ave. subway.

A soft ground watermain tunnel, 2.4m in diameter, advanced over approximately 3km in a large Regional Municipality to the northeast of Toronto was mined using a TBM. The tunnel passed through variable geologic terrain including over-consolidated Wisconsinan age glacial tills of primarily sandy silt texture with some gravel. Saturated interglacial sands and silts are prevalent between glacial till sheets. A few kilometers into the drive, the tunneling contractor noted dramatic rise in thrust and a corresponding reduction in advance rate. This condition persisted over a distance of a few hundred meters at which time the contractor elected to rescue the TBM and assess what he correctly predicted was cutter/tooling damage/wear. The TBM was intentionally halted within a section of roadway where construction of a rescue shaft would be feasible owing to local absence of overhead hazards and buried utilities. An elliptical secant piled rescue shaft was put down with long axis 5.9m by 3.7m across the short internal axis. The crown of the TBM lay 8m below grade at the shaft location (Figure 1).

Figure 1. View of TBM within rescue shaft

In light of the fact that the TBM had travelled a relatively short distance on a set of new cutters and on the basis of previous successful performance of the machine, the contractor suspected that the stone content of the glacial till was the reason for the poor performance. With that in mind, the contractor put the Regional Municipality on notice and retained a geotechnical consultant to carefully log all cobble and boulder sizes removed from the rescue shaft spoils as it was dug down, with particular emphasis on the 8m to 10.5m depth range, representing the tunnel horizon. Significant laydown area was required to facilitate the cobble and boulder removal process and this required the excavated material from a given depth interval to be loaded onto triaxle trucks to an offsite compound where the material could be dumped, bladed to a thin lift using an excavator and each cobble/boulder individually removed. The removed stone inclusions were then sorted by size range (Figure 2). The Owner was informed that this procedure would be followed and was encouraged to have their own consulting engineer present to witness this work firsthand.

Figure 2. Segregation and depth-sorting of cobbles and boulders recovered from TBM rescue shaft, prior to sorting by size range

The GBR definition of boulders on this project made reference to an “equivalent spherical size”. This was interpreted (reasonably) by the contractor to mean an intact rock particle with displaced volume (using Archimedes principle) exceeding that of a sphere 300mm in diameter.

A summary of the logged boulder and cobble sizes recovered from the rescue shaft excavated soil is provided in Table 1.

Table 1. Summary of boulder and cobble sizes logged from rescue shaft spoils in silty sand till

Depth Range (m)	Number of Cobbles (> 75mm)	Number of Boulders	Largest Dimension (mm)
8.0 to 8.5	123	0	260x230x160
8.5 to 8.9	226	0	410x290x160
8.9 to 9.6	220	3	460x300x100
9.6 to 10.5	97	0	330x270x160
Total	666	3	

Soils within the tunnel horizon as found within the rescue shaft consisted of Silty Sand Glacial Till. As indicated in Table 1, there were a total of 666 cobble sizes (>75mm) and 3 boulders logged in the excavated material taken from the rescue shaft within the tunnel depth range.

The GBR stated the following with respect to boulders: **“**within the tunnelling zone, in glacial tills of silty sand texture, the GBR-predicted number of boulders is: 20 boulders derived from an excavated in-place volume of 2381m^3.” This equates to a predicted baseline of 0.0084 boulders in a cubic metre of soil (or 0.84 in 100 cubic metres). The rescue shaft volume in the tunnel horizon is approximately 42 cubic metres. Within that excavated volume of silty sand till soils, 3 boulders were uncovered. This equates to 0.0714 boulders in a cubic metre of soil (or 7 in 100 cubic metres). The ratio of the as-encountered boulders to the baseline was therefore 8.5 to 1.

The GBR stated the following with respect to cobble content: **“**within the tunnelling zone, in glacial tills of silty sand texture, the GBR-predicted number of cobbles is: 95 cobbles derived from an excavated in-place volume of 2381m^3**.”** This equates to a predicted baseline of 0.04 cobbles in a cubic metre of soil (or 4 in 100 cubic metres). The rescue shaft volume in the tunnel horizon is approximately 42 cubic metres. Within that excavated volume of silty sand till soils, 666 cobbles were uncovered. This equates to 15.89 cobbles in a cubic metre of soil (or 1,589 in 100 cubic metres). The ratio of the as-encountered cobbles to the baseline was therefore 397 to 1.

Despite the rather extraordinary measures taken by the contractor to document and ultimately prove the preponderance of cobbles in the till formation relative to the baseline, there was still prolonged resistance on the part of the Owner and their geotechnical consultant to resolve this claim. Part of their initial rationale for rejection included the argument that the shaft location was not necessarily representative of the average conditions within the glacial till formation despite the indirect evidence of anomalous wear on the TBM cutters and head. They also asserted (incorrectly) that irrespective of the baseline cobble content, the TBM ought to have been able to mine and digest any number of cobble sizes without sustaining ill effects and they were critical of the contractor's selected cutter types and machine head design. Many months of negotiations were required to settle this claim, despite the obvious magnitude of cobble content over and above baseline. Although the claim was settled in favour of the contractor, both sides walked away unhappy. While the GBR proved to be effective in establishing a baseline for this parameter which was directly measurable (albeit by means of a costly procedure initially borne by the contractor), the contract provisions proved wholly ineffective in resolving the claim. The fact that the GBR in this instance had been prepared by the same consultant who prepared the Geotechnical Data Report (GDR) may have impeded the prompt and reasonable resolution of this claim due to issues of pride and the misplaced notion that their role was to protect the interests of the Owner rather than to fairly adjudicate the claim under the GBR.

Would the cobble claim against the GBR have been successful had the claim been put forward on the sole basis of indirect evidence – i.e. wear and loss of cutters and tool holders coupled with unusually slow production? We surmise that such claim would have been extremely difficult to resolve without litigation and in that respect, the physical counting of obstructions proved meritorious.

4 SANITARY SEWER MICROTUNNEL, WEST OF TORONTO

A Regional Municipality located west of Toronto tendered a wastewater project involving construction of 5.3km of 1500mm to 1800mm inside diameter reinforced concrete pipe. The delivery model was design-bid-build and the project was awarded to a microtunneling contractor of international repute, who also acted as general contractor. The project includes four sets of microtunnel launching and receiving shafts.

The project site is located within the Peel Plain physiographic region. Ground conditions found within the shaft and tunnel horizons consist of glacial till ranging in texture from cohesive clayey silt to non-plastic sandy silt. Shale and limestone bedrock of the Georgian Bay Formation underlies overburden. There is a zone locally referred to as 'shale/till' complex sandwiched between the overburden and bedrock contact. This is a zone of till intermixed with rock fragments, resembling highly weathered shale/limestone but with evidence of transport during deposition.

The contract included a GDR and GBR which baselined the soil properties including their textural gradation bands and layer thicknesses, as well as boulder content. Baseline soil parameters for the cohesive glacial till deposit are spelled out in Table 2, including standard penetration test (SPT) N value, soil unit weight, γ, effective friction angle, ϕ', effective cohesion, c', and undrained shear strength, s_u.

Table 2. Baseline parameters for cohesive glacial till

	SPT N	γ (kN/m^3)	ϕ'	c'	s_u (kN/m^3)
10th percentile	10	20	28	5	50
50th percentile	24	21	30	5	100
90th percentile	>50	22.5	34	10	300

The contractor constructed all shafts using the sunken caisson method. Cast-in-place concrete shaft rings were formed on surface and sunk down sequentially as the interior of the shafts were excavated. A steel cutting shoe was cast into the lead segment. Bentonite lubricant was pumped into the overcut annular space. Soil removals were effected using a conventional excavator to a depth of about 5m and then reverting to use of mini-excavator positioned in the shaft base for the remainder. Shaft depths ranged from 7 to 15m below grade.

In one of the shafts, which doubled as a future valve chamber, extremely laboured excavation by the mini-hoe was experienced which was brought to the attention of the on-site contract administrator while the work was underway. The layer in question comprised clayey silt till, approximately 1.5m thick. The contractor felt that the till above and below this horizon was substantively weaker as far as excavation progress was concerned. The contractor submitted a claim for delayed production in shaft excavation owing to the 'hard layer'. An initial claim was submitted which included the result of unconfined compressive strength testing. The test specimen had been cut from a chunk sample of till removed by the excavator and delivered to a third party laboratory. The unconfined compressive strength (UCS) test result for the cube samples ranged from 1900 to 2000 kPa (s_u = 950 to 1000 kPa). The Owner's consultant reviewed the third party lab test results and rejected the data on the basis that the length to width ratio of the sample tested was close to 1:1, falling well short of ASTM requirements. The Owner's consultant did state that they would be open to reviewing better quality data, in light of the anecdotal field reports from inspection personnel which corroborated the contractor's account of laboured excavation. The contractor commissioned a second set of soil cores, this time taken from within the shaft, bored horizontally. The cores had L/D meeting ASTM standards and the as-tested water content was within the expected range. The second sample UCS result was 845 kPa (s_u = 423 kPa).

On the basis of the revised laboratory test result which indicated that that s_u values of the 1.5m thick till layer in the shaft exceeded the 90th percentile baseline, the Owner's consultant and the Contract Administrator agreed on the merit of the claim. The amount claimed (less than $15,000 CAD) covered only the labour and equipment time increment for excavation over and above the average rate of shaft sinking using the mini-excavator. No cascading delay claim was submitted involving other aspects of the operation.

This is a relatively straightforward claim, readily measured and resolved against the GBR baseline. A subsequent claim, related to cobbles and boulders impeding microtunneling, was not as cut and dried.

During the crossing of a major expressway on the same project, the contractor's slurry return lines and pump became clogged by rock fragments (Figure 3). The rock fragments were of a shape and size that indicated they had been cut or broken down by the TBM's disc cutters. This blockage occurred on several occasions over the course of a four week period. The tunnel horizon over this portion of the alignment changes from sandy silt/silty sand glacial till to shale/till 'complex'. The geological contact is inferred to lie near the centre median of the expressway. The contractor's Herrenknecht AVN 1800 was fitted with disc cutters, as commonly used in the Toronto area to negotiate dense stony glacial tills and moderately strong shale.

Figure 3. View of cut rock fragments removed from MTBM slurry return lines

In addition to the baselining of soil and bedrock parameters, the GBR spelled out a number of basic operational requirements for the tunneling. These included the requirement for: direct jacking of microtunnel pipe by slurry shield MTBM; discs plus pick cutters, hard facing; back/loaded cutter tools; high pressure water jets in the head to cut cohesive soils; slurry separation plant capable of dealing with a full range of soil and rock flour particle sizes as well as cohesive clods of clay; and the launching of an intermediate jacking station (IJS) every 80 to 100 m.

Cobbles were defined in the GBR as: "rock fragments that cannot pass through a screen with 75mm square openings and are less than 300mm in maximum dimension". Boulders were defined as "rock fragments with maximum dimension being equal to or greater than 300mm". Removal of cobbles during shaft excavation and construction was baselined to be part of routine construction and such materials would not be considered as obstructions. Baselined cumulative boulder volume by total volume of excavated soils were as follows:

BVR - Cohesive glacial tills and till/shale complex – 3%;
BVR - Sandy silt to silty sand glacial tills – 5%;
BVR - Till/shale complex – 5%.

For baseline purposes, 99% of the boulders were baselined to not exceed 1m in maximum dimension and 1% of the boulders were baselined to range from 1m to 3m in maximum dimension. For baseline purposes, cobbles and boulders were to be assumed to be comprised of Canadian Shield-derived igneous or metamorphic rock of "extremely high" Cerchar abrasiveness and "very strong to extremely strong" unconfined strength (100 MPa to 250 MPa), as defined by the International Society for Rock Mechanics.

This claim involving the blockage of slurry pumps and return lines by rock fragments has not been assessed at the time of preparation of this paper. The assessment will be difficult since the claim relates to the selection of equipment, the operating settings and functionality of that equipment, i.e. cutter tooling selection, opening sizes in the head, cone crusher settings. These are contractor-specified 'means and methods' issues.

5 CONCLUSIONS

Where problems exist in the adjudication of claims on GBR contracts, we see common trends in the Contracts, some of which may be holdovers from older, more traditional language which Owners were reluctant to part with. These issues have included:

- A lack of clearly defined contractual allocation of responsibility as to who measures against baselines during construction – the Owner's engineer, the Contractor or both parties;
- Lack of contract statement or payment line item clarifying who pays for the field data collection as well as any lost production time associated with the collection of data required to measure against baseline parameters;
- Use of several baseline parameters in the GBR which are not fundamental soil, bedrock or groundwater properties can be problematic – for example, many baselines are index parameters or borehole indices. For example, rock quality designation (RQD) is a borehole index with directional bias which is not directly quantifiable in a tunnel or trench;
- In such instances where baselines are based on borehole indices, Contracts often do not clarify whether a claim against the baseline must be made solely on the basis of new borings or whether an alternative indirect measure can be applied (for example can conversion of rockmass scanline mapping data obtained in-tunnel be measured against borehole-derived baselines such as fracture frequency and how will directionality and directional bias be worked out?);
- Can a claim against a borehole be based on indirect evidence rather than soil or rock properties? (for example in a microtunnel project would anomalous wear of hard facing, cutters and tool holders be sufficient to justify a claim against the GBR without specialized abrasion testing of samples of the soil/rock media ?);
- In situations where multiple ground parameters have synergistic effects which together impede construction, will consideration be given to evaluating their combined effects (for example if mechanical excavation is used to remove rock and the UCS is marginally above baseline and true fracture spacing is marginally less than baselined, how will these combined effects be considered and relief granted?).

Many of the foregoing issues that have proven problematic on previous GBR contracts in Ontario could have been avoided through the baselining of anticipated soil or rock behavior in trench/in tunnel/within Support of Excavation (SOE) as opposed to the baselining of specific individual parameters or properties. The obvious difficulty with this approach is that ground behaviour is intimately linked with contractor's means, methods, and standard of care. Most Owners and Consultants are not willing to move the GBR needle in this direction.

The primary impetus for Owners to tender tunnel contracts using GBRs is to force contractors to make quantitative factual claims against baselined parameters as opposed to presenting claims on the basis of reduced productivity or means and methods. It is no longer adequate, in the context of a GBR contract, for the contractor to simply state that their equipment was designed to accommodate the baselined conditions; they must go further and demonstrate that there is a material difference in the as-encountered soil, bedrock or groundwater conditions relative to baselines. This is particularly problematic in a microtunneling scenario since there is no possibility of examining the tunnel heading and all of the soil and rock material through which the tunnel passes is reconstituted into a slurry and digested through the MTBM. Shafts remain practically the only 'windows' into the subsurface where the contractor and Owner can visually examine the conditions firsthand and assess relative to baselines. Contract language should acknowledge this reality and should formalize the required procedures for logging of soil/bedrock materials as the shafts are put down, including clear allocation of responsibility for this work, how it needs to be documented, who should be present to witness this work and how lost time associated with such logging will be compensated.

It would seem that the GBR has advanced to the point where it well serves its primary intended purpose of forcing the contracting community to base claims on quantitative soil, bedrock and groundwater parameters rather than on expected productivity. There is still some work to be done in reaching consensus as to whether geo-parameters that are not fundamental, intrinsic properties ought to be baselined or not. If the method of measurement of a parameter affects the outcome of the measurement, then the property is probably not a fundamental one.

Where more hard work needs to be done, in the opinions of the writers, is in the crafting of the linkage documents in the Contract (or Special Provisions) which reference the GBR and explain:

- how claims against the GBR will be assessed;
- what the statistical test(s) will be to determine whether a baselined parameter is exceeded;
- who is responsible for collecting field data used to compare against the GBR;
- who pays for the latter field data collection and associated lost time when work needs to be interrupted to facilitate its collection;
- how will synergistic effects of multiple geo-parameters be considered if more than one geo-parameter is deemed to play a part in impeding construction;
- how quickly will claims be assessed during construction and will interim assessment be made before the end of construction;
- set a value on relatively small value claims that should be rapidly adjudicated between the Owner and contractor versus those that ought to be escalated to the Dispute Resolution Board.

6 REFERENCES

ASCE, 1997. *Geotechnical Baseline Reports for Underground Construction, Guidelines and Practices*, R.J. Essex ed.

ASCE, 2007. *Geotechnical Baseline Reports for Underground Construction, Suggested Guidelines.*

Boon, S.J., Westland, J., and Garrod, B., 1998. Prediction of Boulder Obstructions, *Proc. World Tunnel Congress*, Sao Paulo, Brazil, 817-882.

Hunt, S.W., and Del Nero, D.E., 2013, Microtunneling in Gravel, Cobbles & Boulders, *RETC*.

RETC, 2005, *Geotechnical Baseline Reports – A State of the Practice Review*, Ed. Randall Essex and Bart Bartholomew.

Westland, J., Busbridge, J.R., and Ball, J.G., Managing Subsurface Risk for Toronto's Rapid Transit Expansion Program, *Proc. Of North American Tunneling '98*, Balkema.