

Excavations in the Atlantic Piedmont

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Abstract

During a period of over 24 years practicing in the Mid-Atlantic region, the writer was involved with dozens of construction differing site condition claims. By far the largest single group of these disputes was over what constituted "rock" and how it could be excavated. Inherent in these disputes was the relationships between the test data for the subsurface materials and the excavatability of these materials. Typically the test data available are sparse and the relationships between the data and excavation characteristics are very crude, at best. This situation clearly points to the need for more reliable constructability information for all projects involving excavations into these materials. This need is for both: (1) research to develop more reliable test methods and excavatability relationships, and (2) a commitment to conduct site investigations that provide sufficient types and amounts of data from which reliable excavatability conclusions can be drawn.

Introduction

Excavations are a part of virtually every civil engineering facility. They include such processes as general site grading, basements, footings, utilities, drilled shaft foundations, and tunnels. Yet experience indicates that very little effort goes into subsurface investigations to directly aid the designer or the builder to address the constructability and costs of these processes. Even if more data were obtained there would still be a significant problem, i.e., a lack of reliable predictive relationships between the measured physical properties of the hard materials and the ease/difficulty of their excavation.

Subsurface investigations are largely focused on developing design information. The attitude seems to be that constructability is the builder's problem. The fact that excavations are so often the source of construction disputes and claims in the Piedmont attest to the importance of these excavation issues and why more attention should be paid to them during subsurface characterization. This paper

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examine these issues and makes recommendations intended to minimize future problems.

Background

The Atlantic Piedmont geologic province provides a good example of an area of weak and weathered rocks that pose significant uncertainties relative to the cost of many types of excavations. Two problems arise from these uncertainties in the Piedmont. First is the technical issue of whether there was necessary and sufficient subsurface information to facilitate rational decisions as to the methods and costs of such excavations. Second is the non-technical issue of how the risk should be shared for excavation costs. Disputes over these two issues have resulted in numerous construction claims.

From the technical perspective, this paper examines what is known or what can be known about the excavation of a project site based on current, routine subsurface investigations. In general the author believes that the current state of the practice for evaluating excavability is severely lacking, and that the design and building professions should join together and insist that this issue be addressed for the good of all parties involved in such construction. For those who might raise the question as to why this issue is important to the designers, we can look to the words of John Turner (1992) for an explanation, "Even though it is best to allow the contractor to choose the construction methods and tools (to obtain the best bid prices), the design engineer must be familiar with them so he can: (1) make accurate cost estimates; (2) assess the influence of construction procedures on design assumptions; and (3) develop appropriate construction specifications and inspection procedures." In short, it is not reasonable for a designer to ignore constructability issues, because understanding them is necessary for a sound design.

The non-technical issue involves defining the roles and responsibilities of the three participants in the construction process, i.e., the owner of the site and the project, the designer and the builder. For purposes of this paper all participants directly involved in development of a project belong to one of these three groups. While parts of the tunnel and highway construction industries have successfully addressed the roles and responsibilities associated with such geotechnical construction issues, most of the rest of the construction industry has not made much progress in dealing rationally with these issues.

Piedmont Geology

The Piedmont province roughly parallels the East Coast of the US and extends from Alabama to New York. The bedrock in this area is predominately Precambrian metamorphic schist and gneiss. These rocks have been extensively deformed and faulted and have been subsequently intruded by igneous rocks that are typically more resistant to weathering than the host bedrock.

For hundreds of million of years the surface exposures of these rocks have been subjected to weathering that has lead to their progressive decomposition. While this decomposition generally decreases with depth, the pattern of decomposition has been significantly influenced by fractures in and variable compositions of the parent rock. It has been further influenced by the igneous intrusions into these masses. While erosion has removed some of the surficial materials, most of the Piedmont was beyond the limits of the continental glaciers, and therefore the amounts of removal of surficial decomposed rock has been limited. As a result the zone of weathered and decomposed (weakened) rock in the Piedmont averages approximately 15m (50 ft) below ground surface with variation in thickness from a few meters, or fractions of meters, to well over 30m (100 ft) deep, and even deeper in some portions of the Piedmont. (Gardner, 1987; White & Richardson, 1987)

The surface materials have so thoroughly decomposed that they have been transformed into residual soil, often called saprolite, that shows virtually no evidence of the parent rock. Below the residual soil, decomposition generally decreases with depth with more rock-like features evident, especially strength. While the general trend is for decreasing decomposition with depth, it must be remembered that at any given location in the subsurface zone the actual conditions are quite variable, both laterally and with depth.

At some depth, say at 15m to 45m (50 to 150 ft), the overlying mass has shielded the parent rock from the effect of weathering and the bedrock can be found in a competent, relatively unweathered condition. From the perspective of excavation, it is the thick, variable decomposed transition zone, overlying the unweathered parent rock that poses the greatest uncertainties relative to the cost of excavations.

In the text that follows, the author has attempted to avoid, as much as possible, use of the term rock and instead has referred to the subsurface profile as earth materials, transitional materials, or simply materials. The reason for this is that the term "rock" is often perceived to convey the message of a material that will require blasting for excavation. Furthermore the absence of this term is claimed by some as a warrantee to imply that the cited materials will not be difficult to excavate.

Excavations

This paper examines Piedmont excavations from a broad perspective that includes drilled shafts, large open excavations, utility trenches and tunnels. This approach was adopted because it helps to emphasize that excavatability is not a unique property of a specific earth material. It is typically different for each of the above types of excavations because excavatability depends on the geometry of excavation relative to rock features, the size of the excavation and the type of excavating equipment used. Even for a specific type of excavation, in the same earth material, and being constructed with the same general type of equipment, the size/power of the equipment determines excavatability. For example there is a measurable difference

between the excavatability characteristics of a Caterpillar D-7 and a D-9 in open excavations. (Caterpillar, 1988)

Categories. Excavatability is generally characterized into three categories (NAVFAC, 1982; Wyllie, 1992). These categories are described below.

- * Dig- This category relates to the removal of fragmented or weakly bonded earth materials, such as soils, that can be routinely excavated using equipment such as earth augers, tractor mounted backhoes, and scrapers
- Rip (and Remove)- This category is for moderately coherent earth masses, such as weathered and decomposed rock, that require some additional force to separate the mass into pieces small enough to be removed in the subsequent digging process. The ripping category involves such equipment as rock augers, roadheaders, rippers and trenchers
- * Break (or Blast) (and Remove)- This category relates to strong, coherent earth masses, such as sound, unweathered gneiss, that require strong forces to break the mass into pieces of a size manageable by a removal system. Equipment/processes used to accomplish these breaking tasks are blasting, disk cutters on TBMs, and down-the-hole hammers

Costs. The major factor that separates these categories is cost. Based on various sources over a 24+ year period of practice, it is the author's experience that the ratio of these costs, Dig: Rip: Break, is on the order of 1:2to5: 5to25 (Wyllie, 1992; Personal experience). This ratio points out the large cost differences for various types of excavations. Furthermore they indicate the reason for hard fought disputes where the category of excavation was underestimated during bidding of the contract.

Material Property Related to Excavatability. Separating or breaking the mass into removable-sized pieces is required to excavate coherent earth materials. Therefore the controlling material property is the strength of the bond between particles that makeup the mass. The strength of Piedmont rocks, especially rocks in a stage of decomposition, has two components. They are (1) the strength of individual pieces of the material and (2) the strength of the mass, as a whole, including the effects of discontinuities such as joints.

The most widely used measure of the strength of the individual blocks of rock is the unconfined compressive strength (UCS). The Standard Penetration Test (SPT) driving resistance, N value², is often used as a crude index or indicator parameter for the UCS.

² Standard Penetration Test N-values are presented either: (1) as integers which indicate the number of blows required to drive the sampler one foot or (2) as fractions in which case the numerator indicates the number of blows and the denominator indicates the number of inches of penetration that were achieved.

Quantification of naturally occurring fractures is typically accomplished by logging the rock and fractures in core borings. From core data one can calculate the Rock Quality Designation (RQD) and/or the Fracture Frequency (FF).

Seismic wave velocity (SWV) is a commonly used measure of excavatability. The Caterpillar Company developed, and continues to upgrade, charts relating excavatability of their equipment to SWV (Caterpillar, 1988). SWV has proven successful for this task because it provides a measurement of the combined effects of strengths of individual blocks of the material together with the effect of joints within the mass.

Unclassified Excavations. When all is said and done, it is the individual excavation contractor (as part of the builder's team) who should establish the means, methods and costs of excavating the subsurface materials. These decisions will be based on what the excavator interprets from the subsurface data as viewed from the perspective of that contractor's own experience, personnel, equipment, and in many cases the schedule constraints. In this context, it does not make sense for the designer to impose their interpretation of excavatability on the contractor. The designer should see that the contractor gets adequate data to exercise their entrepreneurial skills and make their own decisions regarding the excavation process. (It is the issue of what constitutes adequate data that needs further research.) Therefore this writer believes that all specifications for Piedmont excavations should be unclassified.

Site Characterization for Excavation Evaluation

Current Practice. Site investigations in the Piedmont typically consist of SPT borings with N-values and samples. In some cases the boreholes will be extended by NX core drilling, and in some cases rock core samples will be tested in the laboratory for UCS. If rock core samples are taken, it is typical to calculate the RQD. Another piece of information that is of value in an excavatability evaluation is the recorded level of auger refusal, typically a 30cm (12in.) diameter hollow-stem auger through which the SPT sampler and rock core sampler are advanced. There are situations where probes are conducted using small 10cm (typically 4in.) diameter solid-stem augers with carbide cutting teeth to determine auger refusal. From these types of data, excavatability assessments are typically made. In addition to borehole data, seismic velocity surveys are sometimes made to delineate the depth to materials requiring different types of excavation efforts. Given below are some of the commonly used criteria for these assessments.

The Dig/Rip Boundary. The boundary between Dig and Rip for large, open excavations using scrapers assisted by dozers typically is estimated to occur when the Piedmont material has N-values up to the range of 50 to 70 (Personal experience). For trench excavations, Obermeier and Langer (1986) concluded that material up to the range of 750-1200m/sec (2500-3900 ft./sec) could be excavated using a tractor-mounted backhoe. Experience with open excavations in the Piedmont

indicates that the Dig/Rip boundary produces far fewer disputes than the Rip/Break boundary.

The same cannot be said for the comparable Dig/Rip boundary for drill shaft foundations. Unlike basements where the depth of excavation is set by the geometry of the facility, drilled shaft foundations depths are established by the designer based on estimates of side friction and end bearing values of the material to be excavated. This means that the designer must understand the excavation process and the associated costs, necessary to achieve the foundations they will specify. Without this knowledge, the designer can not adequately assess design alternatives comparing different configurations of drill shafts and other types of deep foundation units.

In the Piedmont, drill shaft contractors typically price their work based on the type of auger that must be used to advance the shaft. Beginning with an earth auger, the shaft is advanced until the progress of augering is slowed by the strength of the material to some minimum rate of advancement, and then the earth auger is replaced by a rock auger. (This replacement level is the equivalent of the Dig-Rip boundary.) The reduced advancement rate that is often used to define this change in the Piedmont is 15cm (6in.) or less of penetration in a 5-minute period. This rate occurs at about $N=100/3$ for sites in the northern Piedmont (Personal experience). While advancement rates are a function of the earth material and the cutting mechanism of the auger, they are also dependent on the available torque of the drill rig.

In tunneling, the Dig/Rip interface is the material strength where backhoes mounted inside tunnel shields must give way to roadheaders utilizing drag pick cutters. These cutters are very similar to the rock auger teeth used for drilled shafts. Limited experience indicates that this change occurs when the materials encountered have UCS on the order of 14Mpa (200psi) (Personal experience)

The Rip/Break Boundary. For large, open excavations the boundary between Rip and Break is frequently defined in terms of high N-Values. For such excavations using a Caterpillar D-9, or equivalent dozer, with a ripper, N-values in the range of 10018 to 10012 have been typically cited by contractors (Personal experience) as the indicators of the transition into materials requiring blasting. White and Richardson (1987) in their survey cited the typical response to be 10014 with a range of 10012 to refusal (presumed to be 10010). Working with one contractor in a dispute involving Piedmont materials, it was determined that a Caterpillar 235 excavator with rock teeth could not be stopped by materials with an N-value of 10012, but it was likely to be stopped by materials with RQDs in excess of 50% (Smith, Gabr, & Kula, 1991)

The point of this discussion is twofold, namely: (1) that different contractors have different criteria for the same excavation operations and (2) that the N-values being used to make these critical decisions are at the extreme end of the range of this test, i.e., 10018 to 100/0. Therefore this acknowledged crude test, SPT, is being used at, and probably beyond, the limit of its ability to provide meaningful data.

The other testing method often used for open excavation evaluations is seismic velocity. The work to establish criteria in this area has been carried out by the Caterpillar Company (1988). Of these Caterpillar charts, it should be noted that each size/class of dozer has its own chart emphasizing the point that excavatability is not a unique material property. The Rip-Break interface in large Piedmont excavations is in the range of 1850-2750m/sec (6000-9000ft/sec) (Obermeier & Langer, 1986). Abramson (1983) indicated that the Rip-Break boundary for large excavations in the Atlanta area was 2150m/sec (7000ft/sec) based on the subway work there. Seismic velocity surveys are most often used where the Rip-Break interface is relatively shallow, say less than 8m (25ft), particularly in long trench type excavations. As noted by H.J. Smith (1997) seismic velocity is "a good indication of excavatability in highly fractured rock masses with high intact strength whereas unconfined compression strength is suitable "in more massive and/or weaker materials".

The comparable boundary for drilled shafts is the where the strength or the material causes the drilling to shift from rock augers to either down-the-hole hammers or the Calyx drilling system. The UCS at which this transition occurs is on the order of 28MPa (4000psi) (Wyllie, 1992). In a paper relating SWV to drill shaft excavatability, Wight and Shug (Ref. 14) found rock auger refusal to occur at SWV in excess of 1500m/sec (5000fps) for granite and metavolcanics drilled with a Watson 3000 rig.

The Rip/Break boundary in tunnel excavations is when the reduced efficiency of excavation calls for changing from roadheaders with drag pick cutters to drill and blast construction or Tunnel Boring Machines (TBM) with disk cutters. The upper limit for most currently operating roadheaders is for material with UCS in the range of 70-80Mpa (10,000-12,000psi) (Franklin & Dusseault, 1989, Personal experience)

Obtaining More Effective Excavatability Data. Typically site investigations are directed toward providing information for design and do not appropriately develop data for construction. Wise owners with continuing construction, such as modern subway agencies, have learned that this practice is not in their best interest and more typically conduct their subsurface investigations to include important constructability data. This information is used to establish a geotechnical data set for the site that is a baseline for builders' bids. Such owners have learned that if construction disputes develop where the builder lost money and can rightfully point to a lack of or ambiguous subsurface data, more often than not the arbitrator/judge/mediator will find some justification to compensate the damaged builder. Therefore these owners have found that it is cost effective to provide builders with relevant and sufficient subsurface baseline information, and then have all bidders compete from this common baseline.

When it is more widely accepted that builders need and owner benefit from better excavatability data, the following ideas could be researched as ways of

improving the reliability of site investigation data for correlation with excavation equipment performance.

- Using a 1335N (3001bf) Hammer for SPT in hard materials ($N < 80$) This will require new correlation, but it should improve the sensitivity of the data.
- Decrease the spacing on SPT to every .76m (2.5ft).
- Begin coring in weaker materials (say at $N=100$) and use Point Load Tests on the core to correlate with excavation characteristics such as given in NAVFAC DM-7.2 Figure 9 (1982).
- Develop a tricone drilling index test based on the rate of penetration.
- Use down hole geophysical methods

Potentially more useful than the list of single parameters cited above is the concept of correlation of excavatability with rock mass classifications. As noted by Franklin and Dusseault (1989), the British have made efforts to adapt the RMR (Bieniawski, 1984) classification to use for classifying excavatability in open excavations. Likewise Barton (1999) has recently modified the Q classification to address the excavatability of TBMs. Both the Q and the RMR consider 5 to 6 relevant factors to develop a reliable, yet empirical, predictor of earth mass behavior during construction.

Piedmont Earth Classification

Some owners with large projects in the Piedmont, particularly subway agencies, have developed soil/rock classification systems to serve their projects, for example Atlanta, Baltimore, and Washington. For general use in the piedmont, the author has found a three-part classification system is most effective in conveying the critical concepts of this geology. The three major divisions are Residual Soil, Transition Zone, and Rock. The most important point is to refrain from calling the middle zone either soil or rock. The purpose is to draw attention to this material as a highly variable transition between the completely decomposed rock at the surface to the virtually unaltered parent rock at depth. Each of these three zones can be subdivided. But we must clearly alert the users of this information, many of who are not geologists or geotechnical engineers, to the fact that the transition zone is a variable combination of both soil and rock.

These geologic descriptors should not be allowed to be inferred as excavatability boundaries. These are fixed boundaries that are based solely on material properties, and excavatability boundaries depend on both equipment performance as well as material properties. Excavatability boundaries are something that builders have to establish for themselves based on the material property values provided by the owner and the builder's assessment of their own experience, equipment, staff and schedule.

Case Study #1. This project involved excavation of a 3.7m (12ft) diameter tunnel, 41m (135ft) long tunnel beneath an inactive ramp (for planned future development)

of an Interstate highway interchange. The distance from the crown of the tunnel to the road surface was about 37 m (12ft). There were two test borings within the tunnel alignment. They indicated the following profile within the tunnel:

- **Top:** 1.5m (5ft) of sand and gravel in the crown; N=10 to 20
- **Middle** 1.5m (5ft) of "silty, fine medium, coarse sand and fine, medium coarse gravel"; N-values = 10015, 100/3, 100/1.5, 10015, 100/1
- **Bottom or Invert:** 0.6m (2ft) of "gness(sic)-hard bedded. RQD= 45%, 66%

Presumably because of the thin cover beneath the highway ramps, the State Highway permit, which was part of the contract, prohibited blasting in the tunnel. This critical restriction was conveyed as a one-sentence statement in the permit. It was not called out or featured in the tunneling specifications. The contract specifically notified the contractor that it was responsible for any rock removal at no increase in price. As revealed during the arbitration testimony, the contractor's project manager, who prepared the tunnel bid, did not realize until the post-award conference that blasting was not allowed in the tunnel.

Progress in the tunnel averaged 1.2m (4ft) per week, and a differing site condition claim followed. The claim alleged that the only rock indicated in the tunnel by the test borings was the 0.6m (2ft) of gneiss in the invert. Furthermore the project manager stated during testimony that based on the test boring information, he had assumed that 0.6-0.9m (2-3ft) of the invert rock (Bottom zone) could be removed by air spades and therefore would not require blasting. In effect, the blasting restriction didn't matter because the data indicated to him that the tunnel could be excavated without blasting.

The owner's expert argued that the boring logs and experience with the local geology, which the contractor's project manager had, clearly indicated both the Middle and Bottom zones were part of the Piedmont transition zone and would require special excavation techniques. Specifically he pointed out that the material descriptions and the high N-values indicated that the Middle zone was partially decomposed Piedmont rock and would be very difficult to excavate in the confines of a tunnel without the aid of blasting. Likewise based on the core samples and RQD values, the gneiss in the Bottom zone indicated very difficult excavation problems in the invert of the tunnel.

To the contrary, the contractor's expert argued that the Middle zone was investigated using soil boring techniques, was sampled using soil sampling techniques, and described on the boring logs as a soil. (See description above.) Therefore the contractor was entitled to expect that it was a soil and could be excavated as a soil. When cross-examined about the high N-values, the contractor's expert said it was possible to have high N-values in materials similar to those described on the boring logs and not necessarily have difficulty excavating them.

The arbiter awarded the contractor 65% of what had been requested in the claim, and the contractor seemed quite pleased with the outcome.

There are several lessons that can be learned from this case. They are:

- Unless you can strongly defend a specification provision that significantly restricts the contractor's work, don't put it in the contract. If such a provision must be included, it must be brought to everyone's attention, in no uncertain terms.
- If you observe that a contractor is in trouble and losing money, you had better alert all the parties to the contract and aggressively start a campaign to minimize the losses and rectify the problem. This may not be a very popular position with the owner's on-site representative. However, you need to be aware that in the end the owner organization will likely be unhappy with you if you were not proactive. They often take the position that, since this problem was in the area of expertise they hired you to cover, you should have alerted them, regardless of their on-site representative's position; noting that their representative was not an expert in this area.
- Be very careful in preparing geotechnical reports not to set the stage for a non-expert (foreseeable) users of that report to use the geological terminology to support their position of an implied warranty of construction behavior.

Case Study # 2. This project involved excavating a school parking lot to design grades. The contract classified all excavation in terms of earth and rock and provided detailed, equipment-based definitions for the difference between earth and rock. Earth and rock excavations had separate unit prices, with the unit price for rock being about ten times the price for earth. Furthermore the contract required that rock excavations be quantified and approved for payment before the contractor could proceed with excavation.

When hard materials were encountered, the contractor brought in the equipment cited in the rock definition specification and proceeded to excavate the soil down to the top of rock in preparation for cross-sectioning and quantification. For some reason (possibly an unexpectedly large amount of rock and a high contract unit price for its excavation), the owner decided to determine the top of rock by a drilling method. The area was drilled on a grid pattern at 131 locations using a solid stem auger with carbide teeth. This led to a considerable difference in quantity from that of the contractor (about 50% less) and a resulting large difference in cost.

However, after having the site auger probed to establish the top of rock, the owner and designer took one month to convert the survey data (131 survey points) into a quantity takeoff. During this period the owner criticized the contractor for not proceeding with the excavation prior to an owner approved quantity takeoff. The contractor did not show great restraint and began a war of letters and eventually walked off the job.

A third party asked this author to examine the facts in this case and express an opinion as to the possible outcome of legal proceedings. While I did not learn of the final outcome, there are some Lessons to be learned from what we do know.

- The time to do subsurface exploration is before the work is bid. The cost for such exploration is much less than the costs for claims, attorneys and experts.
- You can't change the rules/definitions after you're written them and had a contractor agree to abide by them. This is true even though it may be obvious that those rules are being used to your significant disadvantage.
- During a construction dispute, all parties must act in a timely manner to resolve the issues.
- Successful use of equipment-based specifications requires a lot of knowledge: (1) about the subsurface conditions prior to construction and (2) about the performance of the specified equipment. Yet many people who use this type of specification lack both sets of this knowledge. The origin of this type of specification is generally attributed to the U.S. Army Corps of Engineers who knew how to use it wisely. Using this kind of specification is putting one's fate and the owner's resources in hands of the contractor.

Summary - Lessons Learned

An evaluation of excavatability problems in the Piedmont has lead to the conclusion that much of the root cause for these disputes resides in a contracting system that allocates all the risks for site subsurface conditions to the builder. Until and unless this situation is equitably resolved the problems of claims, inflated excavation costs and litigation will continue. Furthermore having assigned the subsurface risk to the builder, the owner is not likely to allow their geotechnical consultant to make subsurface investigations that directly address constructability issues such as excavatability or groundwater control during construction. As a result there is little incentive to improve the technology that could lead to better constructability assessments and lower overall construction costs.

In an effort to contribute to the solution of the Piedmont excavatability problem, the following lessons learned are offered for consideration.

No.1. The site and the project belong to the owner. The owner should be responsible for providing the site geotechnical investigation(s) that obtains necessary and sufficient data to serve as a basis for the designer and the builder to perform their respective functions.

- A geotechnical baseline report should be included in the contract as the common basis for all bidders.
- The construction contract should include the Federal Differing Site Conditions clause.

In the Piedmont, a geological classification system should be used that minimizes the possibility that some party might confuse geological boundaries with excavatability boundaries. Use of the "Transition Zone" is recommended.

No.2. All Piedmont excavations should be bid as unclassified.

- Each bidder should make their own assessment of excavatability based on: (1) the geotechnical baseline information and (2) their own experience, equipment, personnel and schedule.

No.3. It is far better to have a construction dispute heard at the time it arises and by a panel familiar with the type of construction under dispute.

- The Disputes Review Board concept is the best available form of construction dispute resolution involving geotechnical issues.
- When you observe that a project has a construction problem related to geotechnical conditions, you should get actively involved in resolving the matter as soon as possible. If you aren't a part of the solution, you're a part of the problem.

No.4. The current state of the practice for excavatability assessments is crude at best, and needs to be improved both for the designers and the builders.

- Advancing the state of the practice should not be difficult once the construction industry; owners, designers, and builders; recognize that it is in their common best interest to have soundly based constructability assessment techniques.
- In materials that are too soft to core, some improvement in the SPT is needed, such as increasing the sensitivity of the test results by using a heavier drop hammer.
- When coring is feasible (and it often is for far softer materials than it is typically applied to), the most productive approach to improvement is likely to be in the use of either the Q or RMR classification system as correlated with field performance.

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