SPECIFICATIONS FOR ROCK MASS GROUTING

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Abstract

Background is provided on the evolution of specifications for dam grouting projects, and on the different types of specifications. Guidance is provided on the various general items which must be addressed in such specifications. Thereafter the paper provides particular guidance regarding specific issues which the authors have observed to be points of current attention. These include issues relating to drilling and standpipe installation; flushing and water testing; and grouting means, methods and materials.

1. Perspective

Technical specifications for grouting operations should be closely tailored to the project at hand and to the objectives to be accomplished. Therefore, great caution should be exercised when attempting to use a preexisting standard specification as a guideline. It is common practice to lift sections from specifications from other projects and to use them as boilerplate to piece together a new specification. This practice is reasonable if the person doing so has verified that the meaning and the significance of requirements or provisions contained in lifted sections of existing specifications are clear, that such sections functioned satisfactorily on the previous project, and that they are equally applicable to the proposed project. Conversely, if not used judiciously, the use of boilerplate specifications can cause problems and can help perpetuate the use of outmoded and inappropriate philosophies, methodologies, and materials.

During the years in which hundreds of dams were being built concurrently in the United States, grouting operations typically were performed by specialty contractors who had submitted the lowest bids for the work and had not been disqualified by taking exception to certain requirements of the specification. Depending on the type of owner involved, this low-bid specialty contractor may have contracted directly with the owner, or with a prime contractor, also typically selected by the low-bid process. By far the greatest number of projects were conducted under very "prescriptive" specifications, discussed in Section 2, below.

Regarding contemporary practice, the authors support the statement by Kutzner (1996), who asserted that the owner:

> " … is entitled to have the work done according to the state of the art. Details of this state of the art may be debatable or even unknown to potential bidders. Other details are directly related to the particular project."

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This statement is particularly relevant at a time when construction technology is evolving ever more rapidly and when the applications for this technology are becoming increasingly challenging, especially in remedial grouting projects. It is becoming more common to find projects awarded on the basis of "best value," not necessarily or at all equivalent to "low bid." In this regard the practices and policies of the U.S. Army Corps of Engineers are setting the contemporary standard, and the quality of the work executed is undoubtedly improving.

2. Types of Specifications

There is a large variety in actual types of specifications, which often reflect the "practices and preferences" (Houlsby 1990) of particular countries, regions, or owners. Such traits will have developed historically over many years, reflecting the relative and respective levels of competence and experience of owners, engineers, and contractors, the size and intensity of the market, union or other governing regulations, and the complexity of the technical challenges. However, there are fundamentally two extremes of specification types: prescriptive and performance.

Prescriptive specifications describe specific detailed means, methods, and materials that must be used or followed by the contractor and do not necessarily describe the strategic goals of the work. The owner therefore assumes responsibility for the satisfactory performance and functioning of the as-built project, whereas the contractor must execute the work in strict conformance with the specifications, unless otherwise directed. In extreme examples, the contractor simply becomes a broker of labor, materials, and equipment and is directed in every detail by the owner via the specifications wielded by the supervisory staff. To a greater or lesser extent, low-bid situations are classic examples illustrating the ramifications of such an approach. This approach typically discouraged innovation, but it was understandable during the heydays of dam construction in the United States. Owners' field resources were rarely adequate in number or experience, so common rules had to be established and followed to ensure a certain acceptable level of construction quality. For example, the Bureau of Reclamation rules were often of exceptional thoroughness, as their "one inspector per grout pump" philosophy indicated (Smoak 2003).

Performance specifications require the contractor to exercise control over certain fundamental design, performance, and construction elements of the project, but must allow for a consistent and progressive demonstration to the owner that the final product or result meets the specified performance criteria. This method allows and encourages the contractor to provide a competitive and innovative scheme within the framework of the project vision. The responsibilities for the effectiveness of the work are shared, in some predetermined proportion, between the owner and the contractor. At its furthest extreme, the scope and design can be left entirely to the contractor (who therefore accepts full responsibility for successful performance). This method may initially complicate the selection of the successful bidder, but it subsequently strengthens the owner's contractual position to minimize change orders and cost escalations.

The performance approach is often inaccurately referred to as the European method; the implications are that, on that continent, contractors rule and that in some mysterious way competition is neither as intense nor as clean-cut as in North America. These are wrong suppositions. European contractors innovated out of economic necessity, because they long ago recognized the mortal threat of the "dinosaur syndrome" to their viability. In the United States, Dr. Wally Baker first introduced the concept of performance contracting (or design-build, as it was widely known in the mid-1970s). His foresight created a new atmosphere of “best value, not just low bid,” and established an approach imitated by other grouting specialists and by leaders in other related fields, such as anchoring, micropiling, and soil nailing, from the early 1980s onward. This philosophy brought the awareness that the ability to calculate the lowest price at bid time was not synonymous with the ability to provide the appropriate level of quality during sophisticated construction or the ability to provide the ultimate lowest cost at project completion.

In recent years, the innovative specification and contracting processes used by the U.S. Army Corps of Engineers, the Bureau of Reclamation, and others, have represented the logical and favorable evolution of Baker’s vision. Contractors for especially challenging remedial works on dams are routinely selected based more on their technical ability than on price, provided they are within the competitive range of costs pre-established by the owner. Procurement processes include the submittal of separate technical and cost proposals to be evaluated by the owner via independent teams and “best and final” resubmittals before the negotiation of the contract. Such sophisticated processes are required with larger and more-complex projects.

It must be noted that few if any specifications now lie at the extreme ends of the prescriptive-performance spectrum. Specifications now include elements of each, a fact that often confounds our legal colleagues when a dispute arises over the type of a particular specification and the role of that specification in (allegedly) creating the dispute. A simple illustration is provided in Figure 1, which makes it clear that the owner and the contractor will be jointly responsible to varying degrees on any project, in well-defined proportions.

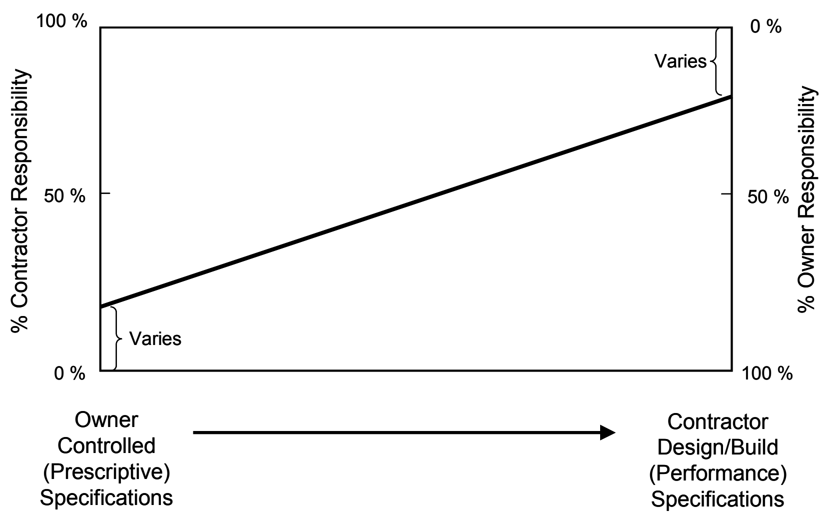

Figure 1. Allocation of responsibility depending on the type of specification method (Weaver and Bruce, 2007).

3. Items To Be Addressed in Specifications

Grouting requires specialized equipment, techniques, materials, methods, and personnel, and not every detail of the work can be specified in advance. Therefore, not every potential problem can be anticipated, further emphasizing the need for a thoroughly experienced contractor and an efficient line of communication with an informed owner.

A list of the major groups of tasks to be performed during the life of any grouting project is shown in Table 1. The party who performs each task will be dictated by the type of specification and the procurement system. The party responsible for each task must be clearly identified and mutually agreed on at the earliest point in the design process and the delegation of tasks must be clearly conveyed in the contract documents. Regardless, the owner (or his or her engineer) must always assume the responsibility for preparing the specifications and other contract documents.

Table 1. Tasks and responsibilities to be allocated prior to drafting the plans and specifications (Weaver and Bruce, 2007).

No.	Tasks
1	Decision to use grouting and of which type; type of specification and procurement method; prequalification process.
2	Full Investigation, appraisal, and analysis of all relevant geological, geotechnical, hydrological, and other technical characteristics and challenges (historical and future).
3	Identification of all project restraints of the logistical, environmental, scheduling, administrative, and financial nature, or any other non-technical source.
4	Determination of the standard required for the grouting and clear definition of the project goals, i.e., the "measures of success".
5	Obtaining easements, permissions, licenses, etc.
6	Scope of work.
7	Execution of the work.
8	Supervision of the work, and implementation of the QA/QC, and verification program.
9	Record keeping
10	Control over scheduling, sequencing, and coordination.
11	Maintenance and long term monitoring.
12	Requirements for standby equipment.
13	Method of Measurement and Payment

With particular regard to the technical aspects of the specifications, the details of Table 2 are to be considered when drafting the specifications and the associated contract estimate of quantities and payment items. All data known or inferred about the site conditions, above and below ground, must be made available to prospective bidders. This is an issue of mutual risk management, as well as common sense and professional integrity. Such relevant data need not all be included with every set of bid documents, but all sources must be reasonably accessible to prospective bidders. Thus, although copies of summary site investigation reports and

Table 2. Items to be addressed and defined in the Technical Specifications (Weaver & Bruce 2007).

ITEM	TASKS
Mobilization/ Demobilization/ General	• Number of project phases (i.e., interim moves) • Project duration restraints • Site location • Scope and purpose of the project • Facilities to be provided on site upon arrival • Facilities to be provided for use by other parties. • Site preparation (e.g., grout caps; access roads; scaffolding)
Drilling and Redrilling	• Hole quantities, location, length, orientation, inclination, and number • Stage length and method (e.g., upstage vs. downstage) • Hole diameter (usually a minimum is given) • What is not acceptable during construction • Special drilling method requirements (e.g., coring – of a specified type – for investigatory and/or verification holes) • Deviation and straightness measurement and tolerances, and measuring method and frequency • What must be done in “extreme” or unforeseen conditions (e.g., major flush loss, rod drops) • Requirements for logging, presentation, and interpretation • Environmental restrictions (handling of spoils, dust) • Requirements for any standpipes or casing to be used • Routine hole washing requirements
Special Flushing	• Purpose, and measures of success • Duration and method of flushing • Minimum/maximum pressures, flow rates • Use of flushing aids • Handling of spoils
Water Pressure Testing	• Stage depths, lengths, and locations • Pressure and flow limits • Durations at each pressure • Upstage or downstage • Methods and accuracy of data recording, calculation, display, and analysis • Investigatory and Verification testing requirements • Definition of residual permeability target
Grouting	• Stage length and method • PST etc. sequencing to closure • Delays between grouting adjacent holes or phases • Pressures • Flow rates • Refusal criteria • Pre-construction laboratory or field testing requirements • Routine QA/QC procedures and frequencies

(continues)

ITEM	TASKS
Grouting	• Methods and accuracy of data recording, calculation, display and analysis • Properties of the various grout mixes (especially apparent viscosity; bleed; pressure filtration coefficient; setting times) • Procedures for unusual situation (runaway takes, zero takes, interconnections, surface leaks) • Equipment details (including ancillaries such as packers, lines, etc.) • What equipment types or principles which are acceptable (e.g., paddle mixers, water:cement ratio > 2 by weight) • Materials which can be used • Hole backfilling requirements • Relationship of drilling and permeability testing to grout takes • Communication means
Standby	• Circumstances under which Owner instructs • Definition of crew size and composition

geotechnical design reports can usually be provided with the bid documents, particularly voluminous reports, original as-built reports (in the case of remedial work), and any core samples should be made freely available by the owner for study. A prebid site visit, properly organized and facilitated by the owner, should be mandatory for all prospective bidders, and no bid should be accepted from a bidder who has not attended the site visit.

A lump-sum price may be appropriate for a project conducted under a predominantly performance specification, wherein the contractor has conducted the preponderance of the design. However, this specification may lead the bid price to be higher (to cover risks) and may force the subsequent construction quality down (in the drive to cut costs and maximize margin). The authors believe that the most equable method is to demand unit rates against the project's best estimate of final quantities. Such rates will apply throughout the project unless a certain quantity is substantially greater or lower than the bid estimate. As a guideline, the Federal Government standard for variation is 15%. The typical clause provides for extra compensation if an actual quantity is less than 85% of that foreseen, and a time extension (but no extra compensation) if a quantity exceeds 115% of that foreseen. Lump sums for payment on certain items, e.g., mobilization and demobilization or provision of computer monitoring systems over a finite period, remain valid in this scenario because the quantity is unity. If the finite period is exceeded due to the conditions encountered (at no fault of the Contractor), then compensation for extended site overhead and for operating and maintaining the monitoring system should be provided.

Similarly, "cost plus," though applicable in certain emergency situations, is also not wholly satisfactory in that the final cost is difficult for the owner to budget in advance and control properly, and it can reduce the financial incentive of the contractor to perform to maximum speed or efficiency. Long periods of post-construction negotiation are often required to resolve the final account.

Bid documents must emphasize that the quantities shown in the schedule are best estimates only and are provided principally to facilitate comparison of bids.

Regardless of the type of contract and specification, it is essential that the contractor prepare a detailed Method Statement (working plan) describing all phases of his or her work. This statement must be consistent with the details of the specification and the basis of his or her conforming bid. This method statement must be understood and approved by the owner before the work begins. Depending on the nature of the specification, the owner's supervision will either direct the work (prescriptive specification) or monitor it for compliance with the agreed method statement (performance specification); in either case, a full knowledge and understanding of the Method Statement is essential by these personnel.

4. Specific Issues for Consideration

4.1 Drilling, Redrilling and Standpipe Grouting

As noted in Table 2, the specifications should always clearly state which means and methods are not acceptable for the drilling-related activities. When drilling for fissure grouting operations, or for karstic treatment under existing structures, air flush should not be permitted. In the former case, it will obscure fissures with cuttings blocking access for grout, while in the second case it will have a very deleterious mechanical effect on clay infillings and can travel long and potentially dangerous distances in the foundation and in the embankment. This prohibition should apply to air-water "mists" often proposed by contractors to allow them to use conventional air-powered, down-the-hole hammers. (Conversely, water-powered, down-the-hole hammers are acceptable and indeed represent preferred state of practice.)

Further, when drilling through existing embankments, neither air nor water, under pressure, and at anything other than minimal amounts, is permissible for fear of pneumatic or hydraulic fracturing. In this regard, the USACE Guideline, "Engineering and Design Procedures for Drilling in Earth Embankments" (1997), should be observed. Acceptable methods include rotary sonic and double-head duplex (but with an internal auger to remove cuttings).

It has been typical that Exploratory holes, "Superprimaries" (i.e., a small proportion of all initial Primaries) and Verification holes are drilled by coring methods. In such cases, detailed specifications for the drilling, logging, testing and sampling of such holes must be provided. Alternatively, more recent practice has been to drill such holes by "production" methods, and to obtain "virtual core" by using an Optical Televiewer such as the Robertson Geologger or Colog System. Note that the use of this excellent tool may be practically impossible in very unstable formations.

Often times, holes may require redrilling. Unless this operation is required due to some type of negligence on the contractor's part, such work should be measured and paid for separately, at pre-agreed unit rates. It is not uncommon for such rates to be 25% to 50% of the equivalent rock drilling rate. All drilling operations must be accurately and continuously monitored and recorded in real time. This is the concept of "Measurement While Drilling" (MWD) in each production hole. MWD is to be conducted electronically or by manual monitoring of parameters to well-defined standards of care. Providing equipment with MWD capabilities for smaller projects might not be economically viable. In addition, obtaining meaningful electronic MWD data might not be possible for some drilling technologies including sonic and dual casing systems. In these cases, observation of the drilling through critical zones should be performed by a geologist or geotechnical engineer.

For remedial curtains under existing embankments, it will be necessary to first place and seal a standpipe (inaccurately referred to often as "casing") through the embankment and for some distance into rock. Such standpipes are placed within the previously installed, temporary drill casing which is withdrawn as, or before, the standpipe is sealed into the formation and embankment via annular grouting. The authors feel strongly that it is poor practice for contractors to be permitted to conduct simple "end of casing grouting" to provide this seal. The "rock socket" cannot be relied upon to not consume grout, and so the result may be incompletely filled annular spaces. This in turn can cause damage to the standpipe during subsequent rock drilling, and/or subsequent escape of water and/or grout up the annulus and into the embankment. In extreme cases, a completely open annulus can provide a direct connection from the developed phreatic surface through the embankment to a foundation defect or pipe where such a direct connection did not previous exist. The resulting open annulus is a synonymous condition to the rusted settlement plate standpipes that led to the sinkholes and subsequent major rehabilitation at the 600 foot high WAC Bennett Dam in British Columbia. These are significant dam safety considerations. Specifications should therefore require the contractor to install some type of inflatable barrier bag or swell seal around the standpipe, similar to the MPSP system (Bruce and Gallavresi, 1988) and develop a very clear Method Statement detailing how the standpipe sealing operation is to be conducted and verified. This is especially important in karstic terrains where the upper epikarst often contains zones which will readily accept considerable quantities of grouts of the type used for standpipe sealing and also contain persistent weathered joints or pipes that provide an open conduit for potential loss of embankment material.

A final point relates to grout hole spacing. It is common to find a specification requirement of the nature "Drilling, water pressure testing and grouting of Initial Primary holes shall not be performed within 140 feet of other open grout holes, or grout holes in the process of being drilled, water pressure tested, or grouted." The authors support this approach, while reminding that it can be re-examined in the light of actual field observations, and should not automatically apply to later Primary, Secondary or higher order holes if long grout travel distances are not occurring and hole to hole connections are infrequent.

4.2 Hole Flushing and Water Pressure Testing

Washing incidental to, and concurrent with, the drilling operation is not sufficient to adequately clean the hole prior to water testing and grouting. Other flushing measures must be employed to clearly defined measures of acceptability. Such work must be measured (e.g., per pump hour) and paid for, at pre-agreed unit rates. The purpose of this flushing or washing is to clear the entrance into fractures for water or grout. Removal of substantial clay infilling by washing is not possible and should not be the goal of a hole washing operation.

Water pressure testing of the multipressure "Houlsby" type should be specified for all stages in Exploratory holes, Superprimaries, and Verification holes. This may not be necessary if optical televiewers are deployed in these holes to provide information on the rock fissure aperture size, joint frequency, and the absences or existence of weathered materials or joint infilling. Despite the universal use of stable, High Mobility Grouts (HMG's) in contemporary practice (e.g., Bruce, Dreese and Heenan 2010) the tendency to eliminate the simple single-stage test on all (or most) other stages should be resisted in the Specifications or in the field. The authors feel that every stage should be water-pressure tested, in some fashion, as this is an invaluable contribution to quantifying the progress of a rock grouting program. To not do so is a disservice to the project and a false economy. With modern header systems or "grout carts" and computer monitoring systems, water testing can generally be completed in less than 10 minutes per stage.

Further, the target residual permeability of the program must be clearly specified, as this is the essence of a Quantitatively Engineered Grout Curtain (Wilson and Dreese, 2003). Further, this actual Lugeon value must be clearly differentiated from the Apparent Lugeon value, which is calculated during the grouting of any single stage, and is a grout refusal criterion, not a rock mass residual permeability.

4.3 Grouting

The effectiveness and quality of grouting is controlled by numerous factors. Many adverse factors have been neutralized by modern equipment and practices. However several factors not currently standardized in North American grouting practice can have a very substantial impact on the final quality or on the ultimate project cost to achieve an identified residual rock mass permeability. The major factors follow:

- Refusal Criterion: The injection rate at which grouting on a stage is stopped is one of the most important factors impacting the achieved residual rock mass permeability. The specified value for refusal varies widely in current North American grouting specifications and ranges from near zero (or absolute refusal) to a take of 1 cubic foot or less in 10 minutes (equivalent to 0.75 gpm). While specifying absolutely zero take is not recommended due to equipment accuracies, the authors recommend a very low stage refusal criterion such as less than 0.1 gpm. The premise is that a given fracture is only intercepted a finite number of times and that it is paramount to completely fill all intercepted or connected fractures when they are encountered. As an example, imagine a site with vertical fractures and holes drilled on 20 and 10 foot centers. For a hole angle of 15 degrees from vertical a vertical fracture will only be intercepted once every 75 feet vertically for holes at 20 foot spacing and once every 37 feet for a 10 foot hole spacing. This consideration also has implications to the final specified hole spacing where joints might not be persistent or beds are not massive. Another key consideration regarding refusal is the case where a relatively tight bedding plane fracture is intercepted that is connected to a large solutioned joint or pipe. A high refusal criterion might result in refusal being declared almost immediately and the pipe or lager opening will remain unfilled unless it is intersected directly by a future hole. Even final holes spacings of 5 feet being typical, a very large foundation defect could go untreated.
- Upstage vs. downstage: Downstage grouting is generally recognized as the technically superior grouting method, but is often only specified for difficult or problematic ground conditions due to the perceived cost savings associated with upstage grouting. Many notable authors have previously commented on the pros and cons associated with these methods, but the use of upstage grouting as the principal specified method remains common. Some excerpts from prior publications are provided below:
  - "This is the cheapest method on sites where all goes well but not where they don't. Its apparent lower cost is often an attraction to specification writers who are trying to minimize costs and are keeping their fingers crossed that all will go well and holes won't collapse too often." (Houlsby, 1990)

- "There are also substantial technical shortcomings to this progression….Obviously, a greater amount of drill cuttings will find their way into higher joints and defects. Significantly, this is usually the zone containing the largest number of defects and where the highest quality of work is needed because of contact with the dam body." (Warner, 2004)
- "It is generally applicable where minimal problems are encountered with seating packers, where the bore holes are mechanically stable, or with grout bypassing the packer through rock. A hole may collapse before or after the packer is introduced, leading to incomplete treatment." (Weaver and Bruce, 2007)

The authors recommend the use of "practical downstaging" where a project is always started utilizing downstage techniques if any question regarding hole stability exists. As always, exceptions should be made where a site or geology is known to be stable for upstage procedures. When performing practical downstage, downstage procedures are continued until the observed water losses and hole stability are such that upstage drilling and grouting is clearly possible. When performing remedial grouting through existing embankments, the top two stages should always be downstaged and the entire hole series on each stage completed to protect the embankment from erosion during deeper drilling and grouting activities. Consolidating the top two stages with holes on a maximum of 10-foot centers will ensure that no untreated vertical joint is in direct contact with the embankment.

- Measurement and payment for grout injection: One of the biggest unknowns is the rate at which grout can be injected into a formation. This is especially true in cases where minimal exploration work has been performed or in cases where the starting mix and the mix thickening procedures are not specified, but is as directed by the owner or engineer. Therefore, the only fair way to compensate for grout injection is on the basis of time and materials. Paying on the basis of the volume of material injected as the sole payment should be avoided as it is not only unfair, but also promotes actions not consistent with quality grouting such as over pressuring or achieving premature refusal by devious means.
- Construction Quality Control: Numerous standard specifications exist that rely on apparent viscosity measurements by Marsh funnel and specific gravity tests as the sole quality control tests for a grouting project. Quality control requirements in most specifications are deficient when it comes to the specified quality control procedures for all drilling and grouting operations. In addition, quality control checks should also be extended to automated material delivery systems and to flow and pressure measurement devices. Given the range of equipment used by various contractors, it is not necessary that the specifications be specific on the tests required. However, a submittal should be required from the contractor identifying how his equipment delivery and flow and pressure measuring equipment will be verified on a routine basis. A special consideration for projects that require "thicker" grouts is that the Marsh funnel has repeatability issues when the flow time exceeds 60 or 70 seconds. Therefore, the authors recommend that a flow cone be the required test for apparent viscosity for thicker grouts.
- Pressure Filtration Requirements: Grouts with zero bleed and high resistance to pressure filtration are required to provide a stable consistent grout formulation throughout the injection and post injection process. Grouts with zero bleed are easily formulated with the available admixtures and additives on the market. Creating grouts with resistance to pressure filtration is also easily achievable. The authors recommend that specifications require that bleed be zero for all mixes and that the pressure filtration resistance be less than 0.5 $min^{-1/2}$.

- Switching from HMG to MMG to LMG on any one hole, seamlessly is commonly specified but is not achievable. Having a second grout plant available and staffed for the purpose of adding sand to already prepared HMG is possible, but it does require that the owner be willing to pay for the equipment to be on standby when not being used and to pay for the labor to be available to operate the equipment when it is required. In this case, switching from HMG to MMG can be performed in a timely manner. However, it is not possible to easily change from grouting with HMG or MMG to LMG. The low mobility grouts require completely different equipment and delivery systems. This requirement should be ackowledged by specification writers. Recommended practice is to break out a LMG program as separate items where possible (such as a known cave feature) or to quarantine holes meeting the requirements for LMG and waiting to perform the LMG injection until a number of holes requiring such treatment are available.

5. Final Remarks

Grouting specifications — and especially those for large Federal projects — have evolved most positively over the last 15 years or so. They broadly reflect and embrace the best of contemporary U.S. dam grouting practice. However, issues relating to the execution, measurement and payment of certain operations do, in the opinion of the authors, merit reconsideration and clarification. No specification will, in all probability, ever be found to be totally comprehensive, but this should not impede the goal to be as effective as practically possible in such matters. Moreover, once a specification has been written and a contract awarded on its basis, the temptation to relax its requirements during the currency of the works should be strongly resisted. While it is laudable to look for ways to manage expenditures, such efforts should not be at the expense of our abilities to quantify and verify the work: what was deemed to be a project requirement during the specification preparation phase should be regarded as the minimum standard of care during the construction phase, and not a target to be chipped at and dissipated. Simultaneously, the owner, engineer, and contractor should be flexible to modify the grouting program and to treat unknown or differing site conditions encountered during the course of the work. A grouting program will usually be the most intense subsurface investigation ever performed at a site and some differing site conditions are bound to be encountered. Blindly following prescribed procedures found inappropriate during the conduct of the work is a disservice to all stakeholders including not only the project participants, but also taxpayers if a public project and the downstream population at risk.

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