The
GROUT
LINE

The Grout Line

Paolo Gazzarrini

Overture

Here it is, the fourth appointment with the Grout Line. It seems that I finally succeeded in scaring my (twenty) readers into providing some feedback rather than enduring another of my complete articles. For this issue: 1 article and 1 comment on John Dunnicliff's contribution of June '06.

The first article is from Marcelo Chaqui, General Manager of MONIR-Precision Monitoring Inc. Mississauga, ON. Marcelo caught perfectly the intent of this section and his article can be the basis of further discussions and your comments. As I have the privilege of being the first to read Marcelo's paper, I have expressed my initial comments at the end of Marcelo's article.

Discussion Paper: How Many Components in a Grout Mix?

Marcelo Chaqui

Abstract

This article is presented to stimulate thought and discussion on how many additives should be included in high-mobility cement based grouts (HMG). The number of components used varies from just two (cement and water) to as many as ten. The ideal number will depend on many factors. The goal of this article is not to provide an ideal number nor to provide a recipe for formulating grouts, but rather to provide some relevant information and discussion on the subject of grout components.

Additives range from chemicals specifically designed to affect cement hydration and the rheology of suspensions, to naturally occurring minerals, clays and sands. A description of some of the more common additives, the characteristics they modify and typical dosages is provided. A table describing the most common quality control test is also included.

Both fluid and set characteristics of grouts are briefly described, including bleed, segregation, resistance to pressure filtration, control of particle agglomeration, anti-washout characteristics, evolution of rheology and cohesion with time, set time, matrix porosity, ultimate strength, resistance to chemical attack, and durability.

A range for the water/cement ratio and the proposed components for a base formulation for an uncomplicated HMG are identified. Discussion on modification of the base formulation to adjust to application specific challenges is then provided.

Introduction

The term HMG refers to cement-based suspension grouts that have a relatively low viscosity, high mobility and a rheology which is best measured by either a Marsh cone or flow cone.

This article focuses on additives as they relate to HMG with water cement ratios between 1.5 and 0.45. These grouts are typically used for fissure grouting of rock or permeation grouting of soils with low silt or clay content.

In the past, typical North American practice had been to use unstable HMG's comprised of only cement and water (Albritton, 1982). The last twenty years have seen major changes in grout mix formulation. Routinely, projects are now employing suites of balanced, stable particulate grouts whose fluid and set properties are achieved by the use of multiple additives, as well as variations in the water content and cement characteristics (Littlejohn, 2003). Such HMGs are characterized by low bleed, superior resistance to pressure filtration, and controlled rheology.

How many additives allow for maximum benefit while still being practical?

Many practitioners have strong and divergent opinions with respect to this question for the same project/application. This paper provides a discussion of some of the considerations required to address these questions for different applications.

Properties of a HMG

In this section, a brief discussion of some of the characteristics and properties of HMG is provided. These properties will be referred to when discussing the grout additives in section 3. Table 1 provides a summary of typical field quality control tests (Chuaqui and Bruce, 2003).

Rheology and the Evolution of Apparent Viscosity and Cohesion with Time

Water and true solutions behave as Newtonian fluids, while stable HMGs behave like Binghamian fluids. The rheology of an HMG is characterized by apparent viscosity, cohesion, and internal friction. A detailed discussion on apparent viscosity, yield stress and internal friction can be found in "Fundamental Observations on Cement Based Grouts (1): Microfine Cements and the Cemill Process" (De Paoli et al., 1992).

The cohesion (c) corresponds to the yield stress (Lombardi, 2003). The cohesion controls how far a grout will penetrate an aperture of given radius at a specific pressure, while the viscosity determines the flow rate and therefore, the grouting time for an aperture of given radius at a specific pressure (Lombardi, 1985):

L=(p x r)/(2 x C), where: L = length of the channel, p = the applied pressure, r = radius of the channel, C = cohesion of the grout.

In order to allow for proper control and analysis of the injection process, the fluid properties of grout must remain constant during injection. Therefore, it is typically desirable for a grout to maintain a constant viscosity for a period of time equal to the injection time and then for its viscosity to increase rapidly until initial set is reached.

Resistance to Pressure Filtration

Injecting grouts into small apertures is similar to pressing the grout against a filter material. Depending on the formulation of the grout, the water can be forced out, creating a filter cake at the borehole wall. HMG resistance to pressure filtration is typically measured with an API filter press (De Paoli et al., 1992). These tests are described in Table 1.

The relationship between cohesion and pressure filtration coefficient is shown in Figure 1.

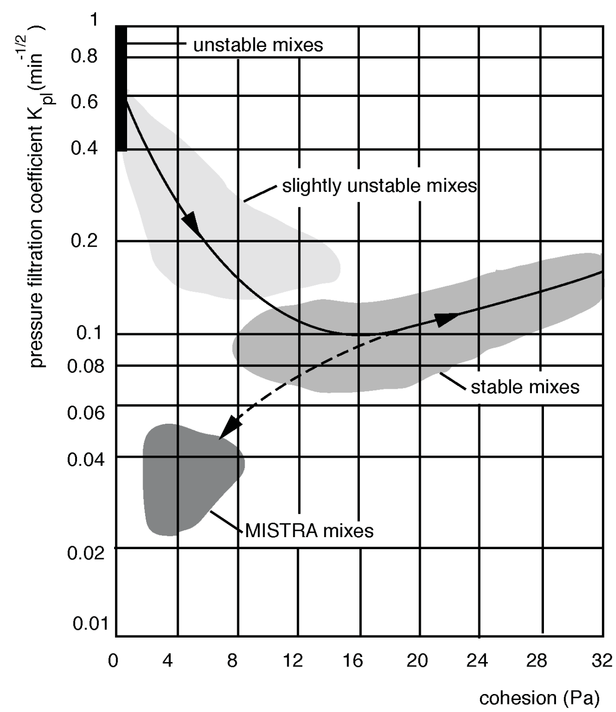

Figure 1. Relationship between resistance to pressure filtration and cohesion for different types of mixes (De Paoli et al., 1992). (Note "MISTRA" refers to a Modified Stabilized Cement Grout.")

By utilizing combinations of cement additives and water/solids ratios pressure filtration coefficients below 0.01 min$^{-1/2}$ can be achieved, while maintaining the apparent viscosity under a 60 second Marsh time; this significantly enhances the penetrability potential of HMGs.

Bleed

Bleed develops as the cement particles settle due to the effects of gravity and allow free water to bleed from the suspension. If a grout has high bleed capacity, it will not fully fill the pore space within the soil or fractures in a rock due to the bleed water which forms as it sets (Lombardi, 2003). Such effects have been demonstrated when using unstable microfine cement grouts in fine sands (Helal and Krizek, 1992). For stable HMGs, bleed should be as low as possible (preferably less than 2%), but in no case should be more than 5%.

Prevention of Particle Agglomeration

The maximum particle size of the hydrated solids in a grout is a key factor that determines the dimensions of soils pores or fractures that can be penetrated. In principle this can be resolved by reducing the particle sizes of the cement, especially the coarse portion. However, if the particles within the suspension are agglomerating during mixing and pumping then the effective maximum particle size is increased and thus, certain soils or fractures simply become inaccessible.

Table 1. Standard Field Quality Control Tests for HMGs

Equipment	Test	Description
Marsh Funnel	Apparent Viscosity	The Marsh time of the grout can be measured in accordance with the method described in API Recommended Practice 13B-1 with a Marsh funnel and a calibrated container. The test is performed by filling the Marsh cone to the bottom of the dump screen and then measuring the time for 0.26 gallons (l liter) of grout to flow through the funnel.
Penetrometer or Shear Vane or Lombardi plate	Cohesion and Time to Initial/Final Gelation	Either a penetrometer or shear vane type test will be used to measure the amount of time required for the grout to reach initial gelation (cohesion of 100 Pa) and final gelation (cohesion of 1000 Pa). Cohesion can be measured with a Lombardi plate (Lombardi, 2003).
API Filter Press	Pressure Filtration Coefficient	The pressure coefficient can be measured with an API filter press. The test is performed by pouring a 0.42 quart (400 ml) grout sample into the top of the filter press. The sample is then pressurized to 0.7 MPa. The test is run until all the water is expelled from the sample. The value of the pressure filtration coefficient is then calculated with the following equation: $K_{pf} = \frac{\text{volume of filtrate}}{\text{volume of sample x (time in minutes)}^{(1/2)}}$
250-ml Graduated Cylinder - Glass	Bleed	The bleed capacity of the grout can be measured in accordance with the method ASTM C940 with a 0.26 quart (250 ml) graduate cylinder. The test is performed by pouring grout into the cylinder to the 0.21 quart (200 ml) level. The sample is then left undisturbed for two hours before the amount of bleed water is measured.
Baroid Mud Balance	Specific Gravity	The specific gravity of a grout can be measured in accordance with the method described in API Recommended Practice 13B-1 with a Baroid Mud Balance. The Baroid Mud Balance is a calibrated scale that is used to measure the specific gravity. Micromotion flow/density meters and hydrometers are also used in practice.
Vicat Needle	Initial and Final Set Times	The initial and final set times can be determined with the Vicat needle testing apparatus. The Vicat needle is set at the surface of the grout sample and released. Initial set is reached when the needle only penetrates 1 inch (25 mm). Final set is reached when the needle does not penetrate the surface of the grout sample.

Water-Repellant/Anti-Washout Characteristics

If a grout is being placed below the water table, it is undesirable for the grout to disassociate. This characteristic becomes especially important when there is the potential of HMG encountering moving water: it will be diluted, thereby reducing its effectiveness and potentially posing an environmental threat.

Hydration Control

The ability to accelerate or retard the set of grout is critical for certain grouting applications.

Prevention of Filler Segregation

For sanded HMG, it is important that the sand within the grout remains suspended and evenly distributed. If the sand falls out of suspension, it does not become part of the grout matrix and furthermore it becomes very difficult to pump the grout.

Matrix Porosity of Cured Grout

Set grouts with low matrix porosity are more durable since water penetration potential is correspondingly reduced. This property is very important for environmental cut-off applications were very low permeabilities are required or when durability and resistance to chemical attack are important. The permeability can be reduced by lowering the water:cement ratio and/or adding materials with a very small particle size such as silica fume. Further details are provided by Littlejohn (1982).

HMG Components

Cements

There are several different types of cements available for specific purposes. These include cements with different particle size gradations, and cements chemically formulated to be resistant to specific chemical attack or to provide high early strength. Table 2 lists the different cements types and properties.

Additives

Formulating a suitable HMG involves balancing the potential positive and negative impacts of different additives

Table 2. Types of Cement Available in North America	
Cement	**Description**
Type I Portland	Accepted as the general-purpose cement for the majority of grouting projects when the special properties of the other types are not required.
Type II Portland	Manufactured to resist moderate sulfate attack and to generate a slower rate of heat of hydration than Type I.
Type III Portland	Used when high early strength is required. It is considered for applications were fast sets are required. Also because it consists of finer particles it can be used to grout slightly smaller apertures than can be penetrated with Type I.
Type IV Portland	Generates less heat during hydration than Type II and develops strength at a slower rate than Type I. It can be used for applications were a large mass of grout will be placed and high hydration temperatures are unacceptable.
Type V Portland	Manufactured for use in grout exposed to severe sulfate action.
Microfine Cement	Has been ground finer to allow penetration of finer fissures or soil pores. These cements are available with a variety of different properties and may contain blast furnace slag as well as Portland cement.

against each other. It is important to note that the interactions between different additives can sometimes be unpredictable. Even though the composition of cements and additives is typically standardized, there is sufficient variance within the standards for unforeseen reactions to take place. For most applications, it is critical that a laboratory testing program and/or a field trial mixing program be performed prior to production work.

Table 3 lists some of the most commonly used additives, the properties they impact and typical dosages By Weight Of Cement (BWOC):

Discussion

Water/Cement Ratio

Fluids with high internal friction are not optimal for injection, as high pressures are required to pump them over significant distances. Unstable grouts behave unpredictably, acting alternatively as a Newtonian fluid and then as a Binghamian fluid with internal friction (Gause and Bruce, 1997). Therefore, an HMG must have enough solids to be stable and reach an acceptable strength and durability.

The use of grouts with high water/cement ratios (i.e. greater than 1.5 by weight) is typically disadvantageous due to the resultant reduced injectability, reduced stability, increased bleed, increased matrix porosity and reduced durability. The use of grouts for ground treatment with a water/cement ratio of lower then 0.45 by weight is not common due to the high costs and the limitations of mixing and pumping equipment.

A Base Formulation

An HMG consisting of just cement and water with a water/cement ratio of between on 0.45 to 1.5 has limited applicability. If it is to be utilized for permeation grouting, the size of aperture than can be penetrated will be reduced due both to pressure filtration and particle agglomeration. For the higher end of water/cement ratio, bleed also becomes a concern.

The addition of bentonite and super-plasticizer will enhance the resistance to pressure filtration, reduce the amount of particle agglomeration and reduce bleed without significantly increasing the viscosity of the grout. Therefore, for uncomplicated permeation grouting applications, a four-component base formulation of cement, water, bentonite and super-plasticizer is a reasonable starting point.

More Complicated Applications

As applications present more specific challenges, this base formulation can be modified to address the specific challenges. A few examples are provided within this section to illustrate how the base formulation can be modified for application specific challenges. The list of examples is intended to be illustrative and not comprehensive.

Active Flow

When grouting in active flow conditions, in apertures or conditions that do not allow the use of Low Mobility Grout (LMG) (Byle, 1997), it is desirable for the grouts to have high viscosity and cohesion that enhance anti-washout characteristics. The high cohesion is not disadvantageous in such circumstances, since penetration of very small apertures is not required in this application. An accelerated set time is also highly desirable and when inline mixing at the bottom of the hole is conducted, set times lower than 1 minute can be achieved.

The use of anti-washout agents and/or accelerators is usually warranted in active flow conditions.

Soil Grouting With Low Residual Permeability Requirements

Achieving low residual permeability in soils typically requires multiple injections with different formulations into the same soil horizon. During multiple-pass soil grouting, a retarded initial set can be highly desirable, since retarded set times allow multiple passes to be conducted without having to attempt to hydrofracture cured grouts. It is therefore possible to re-inject certain horizons several times with different formulations, so permitting further penetration and/or densification.

Table 3: Summary of Additives, Properties Impacted and Typical Dosages.

Additive	Description	Affects	Typical Dosage
Super-Plasticizer	naphthalene sulphonate, lingo sulphonate, and melamine-based materials	Reduce the viscosity of the grout by inhibiting particle agglomeration. Enhanced strength and durability (Gause and Bruce, 1997). Typically retard the initial set of the grout.	0.5% to 2%
Bentonite[1]	sodium montmorillonite	Stabilizes the grout, increases its resistance to pressure filtration and increases its viscosity. Will reduce the ultimate strength (Deere, 1982) and (Littlejohn, 1982).	Less than 5%
Flyash[2]	Type C and Type F Flyash are pozzolanic materials.	Enhance resistance against pressure filtration and increase the durability of the cured grout.	Variable
Silica Fume (Micro Silica)	microfine powder (< 1 micron)	Enhances resistance against pressure filtration, and increases durability and strength of cured grout by reducing its matrix porosity.	Less than 10% cement replacement
Thixotropic Agents/Gums[3]	Kelco-Crete/Welan Gum - high molecular weight biopolymers	Significantly enhance resistance to pressure filtration and make grouts thixotropic.	0.1% to 0.2%
Anti-Washout Agents[4]	Master Builder's Rheomac UW450	Enhances resistance to washout, reduces the pressure filtration coefficient, and makes the grout thixotropic.	0.2% to 1.0%
Hydration Controls[5]	Accelerators, Retarders and Hydration Inhibitors	Allow control of hydration process and manipulation of onset of initial set.	Variable

[1]Bentonite - There is a wide variety of grades and types of bentonite. However, for most grouting operations, pure, chemically unaltered Wyoming sodium montmorillonite is optimal. The sequence and quality of mixing is critical (Jefferis, 1982). Bentonite should be hydrated for 12 hours prior to being used unless tests show that equivalent hydration can be achieved with a high shear mixer. Grouts with bentonite that has not been hydrated can be subject to durability problems due to cracking.

[2]Flyash – It is important to note that Type C Flyash expands and when used in dosages over 20% can cause durability problems in grouts.

[3]Thixotropic materials are characterized by viscosity which increases and decreases virtually instantaneously in response to the removal and application of shear. This property results in fluids which readily flow but are capable of suspending or stabilizing components.

[4]Anti-Washout Agents – This additive is not compatible with naphthalene sulphonate plasticizer and moderately compatible with Whelan gum and bentonite due to the sharp increase in the HMG viscosity. Typical proportioning is 0.2% to 1.0% by weight of cement.

[5]Hydration Controls – There are three distinct concepts:

a) Accelerators: There are several different kinds of accelerators the most common of which are sodium silicate and calcium chloride.

b) Retarders: Extend the gel and set times of grouts in a controllable fashion. Set times of several days are achievable with some of the more recent products.

c) Hydration Inhibitors: These are two-component systems involving the use of a stabilizer and an activator. The stabilizer forms a protective coating around the cement particles that stops the hydration process. When the activator is introduced to the grout dissolution of the protective barrier occurs, allowing the commencement of hydration and so normal crystal growth (Gause and Bruce, 1997).

For certain soil grouting applications, the use of hydration controls is warranted depending on soil conditions and residual permeability requirements.

Environmental Cut-Off

For some environmental applications, the durability, matrix porosity and resistance to chemical attack of the grout becomes critical. The use of additives such as flyash, silica fume and ground pumice becomes warranted in such applications.

Void Filling

Thixotropic grouts have a low viscosity while being in turbulent motion (being sheared during injection) and much higher viscosity when no shear is applied. This property is beneficial when injecting grouts into open voids because the grout can be placed where it is desired without it flowing away after pumping ceases.

Final Remarks

When formulating a HMG, we are trying to achieve both superior technical performance and cost effectiveness. Improving the properties of a HMG typically allows for a more cost effective grouting program. The unit cost of the grout likely will increase, but less grout will be required to achieve the targeted performance criteria. Cost savings are realized from reduced project duration. Often the project goals cannot be achieved without the optimization of the HMG formulation. This remains true as long as the performance requirements for the HMG are matched to the application. For example, it would not make sense to reduce the viscosity and pressure filtration coefficient of a basic void-filling HMG.

It also important to keep in mind the practical aspects: having too many formulations to select from on the same project can lead to excessive waste and switching of mixes. Making a process more complicated than is required will unnecessarily increase project costs.

The goal should be to use the simplest formulation that will allow the project objectives to be met efficiently.

For uncomplicated permeation grouting applications, a four-component base formulation of cement, water, bentonite and super-plasticizer is a reasonable starting point. As the application becomes more complicated, additional enhancement to the HMGs properties becomes practical and a more complicated HMG formulation is then warranted.

References

Albritton J.A., (1982). "Cement Grouting Practices US Army Corps of Engineers." Proceedings of the ASCE Specialty Conference in Grouting in Geotechnical Engineering, New Orleans, LA, pp. 264-278.

Byle, M.J. (1997). "Limited Mobility Displacement Grouting: When "Compaction Grout" is NOT Compaction Grout", *Grouting – Compaction, Remediation, and Testing*, Proc. of Sessions Sponsored by the Grouting Committee of the Geo-Institute of the American Society of Civil Engineers, Logan UT, Ed. by C. Vipulanandan, Geotechnical Special Publication No. 66, July 16-18, pp. 32-42.

Chuaqui, M.H and D.A. Bruce, 2003) "Mix Design and Quality Control Procedures for High Mobility Cement Based Grouts," Proceedings of the ASCE Specialty Conference in Grouting in Geotechnical Engineering, New Orleans, LA, pp. 1153-1168.

Deere, D.U. (1982), "Cement-Bentonite Grouting For Dams," Proceedings of the ASCE Specialty Conference in Grouting in Geotechnical Engineering, New Orleans, LA, pp. 279-300.

De Paoli, B., Bosco, B., Granata, R. and Bruce, D.A. (1992). "Fundamental Observations on Cement Based Grouts (1): Microfine Cements and the Cemill Process." Proc. ASCE Conference, "Grouting, Soil Improvement and Geosynthetics", New Orleans, LA,. Feb. 25-28, 2 Volumes, pp. 474-485.

Gause, C.C. and D.A. Bruce. (1997). "Control of Fluid Properties of Particulate Grouts: Part 1 – General Concepts." *Grouting – Compaction, Remediation, and Testing*, Proc. of Sessions Sponsored by the Grouting Committee of the Geo-Institute of the American Society of Civil Engineers, Logan, UT, Ed. by C. Vipulanandan, Geotechnical Special Publication No. 66, July 16-18, pp. 212-229.

Helal, A.M and Krizek, (1992), "Preferred Orientation of Pore Structure In Cement-Grouted Sand," Proceedings of the ASCE Specialty Conference in Grouting in Geotechnical Engineering, New Orleans, LA, pp 526-540.

Jefferis, S.A., (1982), "Effects of Mixing On Bentonite Slurries and Grouts," Specialty Conference in Grouting in Geotechnical Engineering, New Orleans, LA, Feb. 10 to 12, pp. 62-77.

Littlejohn, G.S. (2003), "The Development of Practice in Permeation and Compensation Grouting: A Historical Review (1802-2002) Part 1: Premeation Grouting" Proceedings of the ASCE Specialty Conference in Grouting in Geotechnical Engineering, New Orleans, LA, pp. 50-99.

Littlejohn, G.S. (1982), "Design of Cement Based Grouts," Proceedings of the ASCE Specialty Conference in Grouting in Geotechnical Engineering, New Orleans, LA, Feb.10 to 12, pp.55-48.

Lombardi, G., (2003) "Grouting of Rock Masses," Proceedings of the ASCE Specialty Conference in Grouting in Geotechnical Engineering, New Orleans, LA, pp. 164-197.

Lombardi, G., (1985), "The Role of Cohesion in Cement Grouting of Rock," 15th ICOLD Congress. Lausanne, Switzerland, Q58, p.13.

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Discussion of "How Many Components in a Grout Mix?"

Marcelo Chaqui

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Paolo Gazzarrini

Here are my comments with the hope to inspire more discussion on the topic.

- The first comment is regarding the use of bentonite in grout mixes. The bentonite, as it is well known, reduces the compressive strength of the grout mixes and consequently its long terms characteristics. Additionally bentonite increases the cohesion with consequent reduction in penetrability. These two negative aspects of the use of bentonite are, marginally balanced, by its ability to reduce the bleeding and to keep the grout mixes stable. For these reasons, personally and generally, I tend to avoid completely the use of bentonite in grout mixes. The technical aspect of not using bentonite is also helpful on site because it reduces the procedures for preparing the grout mix. If using bentonite, it must be hydrated and consequently the procedure is a slightly more complicated operation for the grout mix preparation.
- Regarding the use of additives. How many? What kind? I have the following comments and personal principle. I tend to use as few components as possible, and usually 3 components are more than enough (I am a Lombardi supporter). The grout mix must be, in my opinion, the simplest possible for several reasons:
  a) The first reason is that we are working in the field, usually under difficult conditions. The grouting is carried out in the field and not in the lab. If we are using more than one additive there are more complex procedures for the preparation of the grout and more possibility of mistakes. Life is already difficult, why complicate it any more?
  b) Secondly, fewer components mean, as already mentioned, less possibility of mistakes and more constancy in the quality of the grout grouted.
  c) Thirdly fewer additives result in savings for the project, in both material costs and Q/C from the Contractor and Owner/Engineer's point of view.
- From the 2 previous points my simple recipe is W/C ratio as low as possible in order to have a stable mix, with the highest characteristics in terms of UCS, and addition of a superplasticizer to reduce the cohesion and viscosity (again Lombardi supporter).
- Some marginal comments regarding the tests for QC.
  a) API Filter press. I agree with the theory expressed in the article mentioned in Marcelo's references: Lombardi, G., (2003) "Grouting of Rock Masses," Proceedings of the ASCE Specialty Conference in Grouting in Geotechnical Engineering, New Orleans, LA, pp. 164-197, in which Dr. Lombardi considers the theory of presso-filtration obsolete, and consequently this test is not important, in my opinion.
  b) Bleed. I tend to use 1000 cc graduated cylinder, which makes it easier to evaluate the bleeding.
  c) Vicat test. Instead of using the needle (the time required is too long) I use a 10 mm diameter plunger. Consider that the Vicat test was created for concrete and mortar and not for grout mixes. We shortly discuss this point with Marcelo and there is another test that we can do .... a pencil immerged in the grout…effective but not standardized …we don't understand why it is not possible to have a standardization!
- Comments about the Additives:
  a) I used Welam Gum and UW450 both as anti-washout agents and with the same purpose.
  b) Regarding the Thixotropic Agents and more specifically concerning the definition of Thixotropy. Marcelo, in his article, says: "Thixotropics materials are characterized by viscosity which increases and decrease virtually instantaneously in response to the removal and application of shear." I am not a Thixotropic expert and I am not a Chemist but I remember that the perfect Thixotropy is observed in bentonite mud. It is gel when still, liquid when agitated. This characteristic is observed also after days of preparation of the mud. With the grout mix this perfection does not exist: after few hours the grout mix start setting and it is impossible to return to the liquid status. When we are taking about thixotropy in the grout mix, can be a good idea to define also a time when the thixotropic characteristics are still applicable? Any additive producer readers can give us their comments and opinion?

OK, I have started with my comments. We (Marcelo and me) will wait for yours to continue the discussion.

Discussion of "Listen to the Driller"

John Dunnicliff

Geotechnical News. Vol. 23, No. 3, September 2005

Ken Weaver

The second comment is from Ken Weaver. Ken Weaver is another North American Grouting "guru". In his first email he defined himself as "Grouting curmudgeon emeritus", in another "Grouting Poobah Emeritus, Fremont California Coven of the Ancient and Honorable Society of Grouting Witches and Warlocks". Wonderful positions…..

A*t the Grouting and Ground Treatment conference in New Orleans in 2003. Ken Weaver was awarded, along with Jim Warner, Ed Graf, Rube Karol, and Joe Welsh, with the title of Grouting G.R.E.A.T (Grouting Research Education and Training).*

He *is also the promoter and "father', along with other members, of the Grouting Glossary, edited by the Grouting Committee of the Geo-Institute (ASCE). Refer to my conclusion for additional comment about the Grouting Glossary.*

Comments

John Dunnicliff was quite right in stating - and emphasizing - that one must **Listen to the Driller!** However, whether or not the driller is listened to, it is **vitally important** the geological conditions at the site and in the reservoir area be well defined and understood when developing the design of the grouting program (and before the Driller sets foot on the site). Thus, my response to Dr. Dunnicliff's advice would be this: **Listen to the Geologist** at all stages of the project from preliminary design exploration through design and construction of the grout curtain.

More specifically with regard to Dokan Dam, I am left wondering what constitutes "an extremely comprehensive grout curtain" as defined by Dr. Dunnicliff. Was the curtain "comprehensive" by solely by dint of primary, secondary and tertiary holes having been drilled and Lugeon tests having been performed? Or, more importantly, did the curtain reach an impermeable stratum, did the curtain extend an appropriate distance beyond the crest of the dam (in order to prevent an "end run" of seepage/leakage), were the grout holes oriented and spaced so as to cross all of the steeply dipping joints, and was more than a single row of grout holes drilled? And, did the grouting program include drilling a sufficient number of verification holes at carefully selected locations and at appropriate orientations so as to enable a confident assessment to be made that the design objectives had been achieved? Or, was the grout curtain a single-row affair constructed to a depth determined by a formula and in a paint-by-the-numbers spacing reduction sequence that was arbitrarily stopped at tertiary holes?

Lugeon tests can, of course, provide much useful data about the bedrock foundation conditions and -in fractured insoluble rock - can be essential in ascertaining whether or not the design permeability criteria are being approached or met. However, classical (multi-pressure) Lugeon tests need not (and, indeed, should not) be made for that latter purpose; relatively short duration packer tests made at a single pressure appropriate for the stage being tested should be sufficient in most cases. And, yes, I am a strong believer in testing every stage of every hole in this manner. I would further state that the fact that Lugeon tests and the short tests that I prefer for general use are made with water is totally appropriate, and the fact that the characteristics of grout (no matter how formulated) are quite different than those of water to be irrelevant.

Regarding "control" of grouting by computers, suffice to say that computers can provide an efficient means of monitoring grouting operations performed in accordance with early twentieth century standards and procedures, without regard to whether or not those standards and procedures - or, in fact, the design - are technically adequate.

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My moral of the 2 stories: Listen to the Driller,…listen to the Geologist,…. and what about the Engineers, Owners etc? Is this not "team" work that we are talking about, where we listen to each other and we do the work together?

Conclusion

My friend Jim Warner asked me to remind everybody (grouting expert or not) about the upcoming Grouting Course scheduled for May 15-19 at the Colorado School of Mines. This will be the 27^{th} year it is held!

For more information:

www.mines.edu/outreach/cont_ed/grouting/grouting1.html

As I mentioned earlier a Grouting Glossary has been published in Volume 131, Issue 12 of the *Journal of Geotechnical and Geoenvironmental Engineering* (ASCE). I am in the process of obtaining the required authorization to have it published also in our section and to have a larger distribution in our industry.

Send me your grouting stuff, papers, article or simple comments to: *Paolo Gazzarrini, fax 604-913 0106 or paolo@paologaz.com or paologaz@shaw.ca*