Paolo Gazzarrini

Overture

Welcome to the 27th edition of the Grout Line, after a short "spring break" (March issue) due to a very busy start to 2012. The grouting industry has been very lively, mainly for the organization and participation in the 4th International Conference on Grouting and Soil Mixing held in New Orleans during the month of February.

The following article has been re-printed from "Deep Foundation", the magazine of DFI (Deep Foundation Institute) and my personal comment about the conference is that: IT WAS A BLAST! For several reasons: number of participants, quality of the papers, quality of key note lectures, quality of the exhibitors and, dulcis in fundo, the Mardi Gras events during the conference.

New Orleans.

For this issue we have also a very interesting article prepared by Jim Warner, and a lot of the top people of the grouting industry as co-authors. The topic of the article is the discussion of continuous monitoring/ recording of parameters in our drilling & grouting industry, further to an animated discussion held in New Orleans.

4th International Conference on Grouting and Soil Mixing

reprinted from Deep Foundations, The Magazine of the Deep Foundations Institute

ICOG –explosive growth, exponential growth

The Fourth International Conference on Grouting and Deep Mixing (ICOG) met in February in New Orleans, La., in record-breaking numbers. The group began in 1982 with 419 attendees, and the 2012 attendees numbered over 700. ICOG, which stands for the International Conference Organization for Grouting, has become he informal name for the geotechnical subset specialty professionals. The chairs were Michael Byle, Donald Bruce and Larry Johnsen, who were helped by a committee of 13. DFI managed the entire international event. The core group's original plan was to reconvene every ten years, and that plan has been realized, except for a year's slippage in 2003.

Superlatives abounded at ICOG. Of the 700-plus attendees, the number of non-North American participants rose to 240, who came from Asia, South America, Europe, Australia and Africa highlighting the importance of and the interest in the deep foundations industry's expertise worldwide. There were about 30 concurrent sessions, and roughly 150 separate presentations. These covered state-of-the art in several areas, current research findings, the evolution of the several technologies, and included innovations in grouting, soil mixing and associated equipment. Six keynote speakers drew large audiences even those starting at 7:30 am, notwithstanding the previous evenings Mardi Gras festivities.

The three ICOG chairs, Johnsen, Byle and Bruce, opened the meeting with comments about Hurricane Katrina and its devastation of the New Orleans levee system and the deep mixing techniques used to repair and rehabilitate the post-hurricane damage in a dauntingly short time frame of 14 months. Bruce noted that the work was the largest use of DM outside of Japan. In one of the sessions, Peter Cali, of the U.S. Army Corps of Engineers (USACE) said that the project was undertaken with an "Alternative Evaluation Process," where the production rate was key. This concern led to the selection choice of Deep Soil Mixing. Cali also noted that the high price of steel was a factor in the process. If the work were done the following year, when steel prices were lower, T-walls might have been chosen.

The opening guest lecturer, Eric Halpin, the U.S. Corps of Engineers special assistant for Dam and Levee Safety, said the Corps estimates safety needs at $26 billion for the 2100 levees and 694 dams they oversee and maintain. That assumed expenditure over the coming years bespeaks an impressive need and a market for those in the deep foundations field. Halpin also said 77% of the US levees exhibit seepage and piping. He also mentioned regional challenges posed by Karst formations, the subject of many presentations at ICOG.

More strikingly, Halpin said the Corps is "rethinking failure mode analysis." Some staff thinks it possible that overly conservative design requirements might have been a factor in a reported $2 billion in "avoidable" costs. Cost-effectiveness and risk management are important issues currently. The organization, according to Halpin, is aiming at "Three Rs," resilience, robustness and redundancy in its projects.

ICOG honorees

The "G.R.E.A.T.S." luncheon was a highlight of the meeting, at which ICOG honored "Grouters (dedicated to) Research, Education, Advancement of Technology and Service." This year, all five recipients were from outside the U.S. Organizing committee members, Allen Cadden of Schnabel Engineering, LLC and James Warner, Consultant, presided over the ceremony that honored G. Stuart Littlejohn, U.K.; Freidrich-Karl Ewert, Germany; Giovanni Lombardi, Switzerland; and Mitssuhiro Shibazaki, Japan. The latter two were unable to attend. Sadly, the fifth honoree, A. Clive Houlsby, Australia, died shortly after he was singled out for this honor. A presentation on the life of each of the G.R.E.A.T.S. was made and those present offered acceptance speeches and the two others accepted via video.

The six keynote speakers were also honored by being chosen for exceptional performance and knowledge in their conference subject area. Their names and topics follow:

Stephan Jefferis, Environmental Geotechnics, Ltd, *Cement-Bentonite Slurry Systems*

David Wilson, Gannett Fleming, *Practice, Perspectives & Trends in U.S. Rock Grouting*

George Burke, Hayward Baker, *State of the Practice of Jet Grouting*

George Filz, Virginia Tech, *Design of Deep Mixing for Support of Levees and Floodwalls*

Clif Kettle, Bachy Soletanche, *Compensation Grouting, Evolution, Field of Application and Current State of Art in UK Practice*

Michael Byle, Tetratech EC, Inc., and James Warner, Consulting Engineer, *Limited Mobility Grouting-Past, Present and Future*

Encylopedic subject range

The conference tracks were Grouting and Deep Mixing for Tunneling, Highways and Transportation, Structural Support and Dams, Speakers also addressed performance, analysis and design, grouting applications and new equipment and technologies.

Advances in instrumentation and data acquisition were noted frequently as speakers looked back over the years since 2003, the last ICOG meeting. Many papers also focused on progress and research on dealing with Karst formations. Burke, in his keynote address on jet grouting, said there had been a "dramatic" change in data acquisition, noting the electric cylinder method as one new method. Speaker Richard Hanke of Malcolm Drilling spoke of a "full suite" of electronic data collection in real time at a Seattle site. Burke also mentioned data collection was used in the demonstration project at Tuttle Creek by the Corps of Engineers. Other speakers alluded

Theresa Rappaport and Organizing Committee – left to right: Theresa Rappaport, Justice Maswoswe, Jim Warner, Paolo Gazzarrini, Larry Johnsen, Mike Byle, Donald Bruce, Allen Cadden and Steve Maranowski.

to Wolf Creek Dam as a workshop for information on jet grouting and other cutoff wall techniques. Ground modification and grouting applications were described for mitigation of liquefaction, nuclear waste containment and seismic remediation. Compensation grouting, Clif Kettle's keynote subject, is "not easy and not cheap," typically used as a last resort for historic structures or emergency situations. Stephan Jefferis traced his work using blast furnace slag-fly ash in grouts over the years, while Helen Robinson, Schnabel Engineering, spoke about her research in polyethurene grouts.

Other addresses were diverse and included case histories from around the globe. One example from Norway was the use of accelerated cement to stop inflow under hydrostatic pressure of 540 psi in almost freezing temperatures. Another was a tunnel in Modena, Italy, at which 75% of the tunnel lining was repaired under water repair using bentonite panels. An unusual Hot Bitumen grouting in USA was one of the many presentations focusing on karst formations.

Devon Mothersille from the U.K., spoke about a tunnel in Australia at which all 5,200 grouted anchors were corroded and had to be remediated. The testing and remediation, led to a 9-year multi million dollar (AUD) settlement. From Finland, the case history of grouting in crystalline fractured bedrock to nuclear waste containment was presented and from Portugal, a jet grouting application for load transfer at a resort on the Tagus River to allow for cruise ships. New and smaller equipment for deep soil mixing from Italy was described by professors from the University of Naples. Daniele Vanni, Cesena-Italy, talked about deep soil mixing solution used to restore the listing campanile in Venice's San Marco Piazza. Similarly, cutter soil mixing applications all over the world, were presented by Franz Werner Gerresen, of Bauer Maschinen.

The presentations mentioned here are a small fraction of the total ICOG papers, which will be published in August 2012 by ASCE. ICOG attracted over 20 cooperating organization, over 70 exhibitors and 10 Poster presentations. DFI's management of the vast event was an enormous and successful undertaking.

A Monitoring Ruckus

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Background

A heated discussion occurred during a question period at the 4th International Conference on Grouting and Deep Mixing (ICOG) in New Orleans. The author (Ref. 1) had summarized the investigation and design of a grouting program to arrest settlement of a nearly 100 year old Amtrak bridge pier, located in deep water, and crossing the mouth of the Thames River in Connecticut. While installing piles for a bridge retrofit, one end of the pier supporting the lift span began to settle, threatening a disruption in continued rail service. Initiation of rapid corrective action was imperative, but little was known about either the foundation, structure, or the soils. An exploratory boring program and instrumentation of the pier were immediately initiated, as were consideration of remedial approaches. Although little was known about the underlying foundation, it was concluded that some sort of pressure grouting would be required. Early on the team members considered it important to include a grouting contractor in the planning, and several were interviewed.

There were few absolute requirements other than experience with, and ability to mobilize for, both compaction and permeation grouting, and real time computer monitoring with the original data provided in non-proprietary software such as Microsoft Excel. The latter requirement was negatively received by many, and was refused by some of the prospective contractors. It was this requirement that resulted in the heated discussion at ICOG. The paramount objection was basically that some contractors have developed expensive proprietary monitoring programs which allow all to observe the parameters on a monitor during grout injection, and it is unreasonable to require anything further.

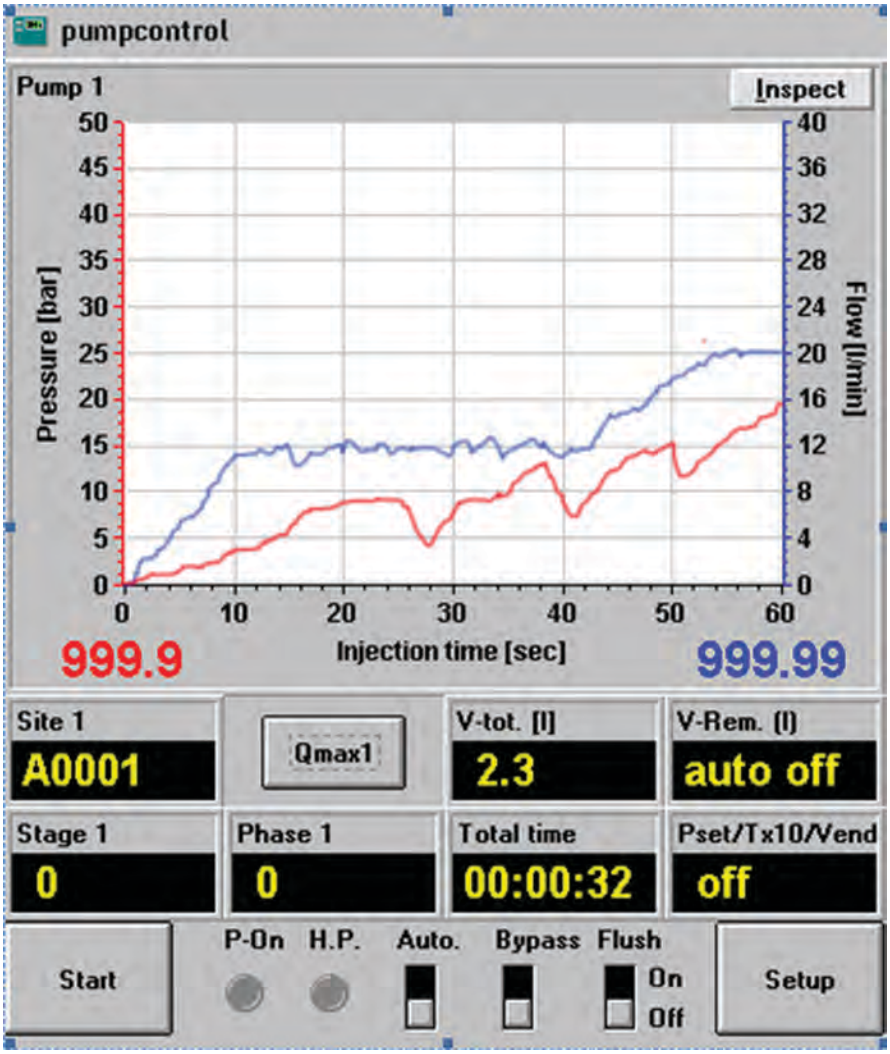
Although it did not arise at ICOG, this 'unreasonable to do more' attitude is actually a much wider issue. There are commercial grouting data acquisition systems with proprietary processing software that allows no more than the limited plot types embedded in the software. And, perhaps even more surprisingly, on larger projects with Owner appointed 'Review Boards', it is not uncommon to encounter reviewers with a 'we have always done it this way and nothing more is needed' viewpoint.

So, what drives these attitudes, and are they reasonable?

Purpose of monitoring

Real time computer monitoring of grouting serves three functions:

1. Display of grouting parameters during injection to allow control of the work, a) to ensure the best possible effectiveness (the result the Owner is paying for) b) to maintain cost-effectiveness (operational efficiency)
2. Providing original data for further analysis and thereby enabling optimization of subsequent work, particularly if any unusual events occurred during injection (in effect allowing validation of the grouting design/protocol/procedures)
3. Providing a record of the grouting
   a) For pay-items
   b) For project archives (used to



Grouting Sample.

resolve claims, and for future reference on large projects that will likely be subject to further grouting).

The authors believe that the listed applications of the data have the status of "Principles" that we all agree apply to grouting works. And these Principles have improved grouting – taking rock fracture grouting as an example, adding electronic monitoring systems enables the industry to routinely grout to a ~ 0.5 Lugeon standard today versus something like ~ 2 Lugeons thirty years ago, while using no more than Type 3 cement, and at ~ 30% less cost. So why the ruckus? We suggest the cause is that while all grouting engineers might agree on the above three principles, there is no common or accepted methodology to set about meeting these principles, and further, there exists a notion that being "proprietary" provides both risk aversion and competitive advantage. None of the above, however, provides best performance for the owner. And none of the above is in the long term interest of our industry.

Background to computer monitoring

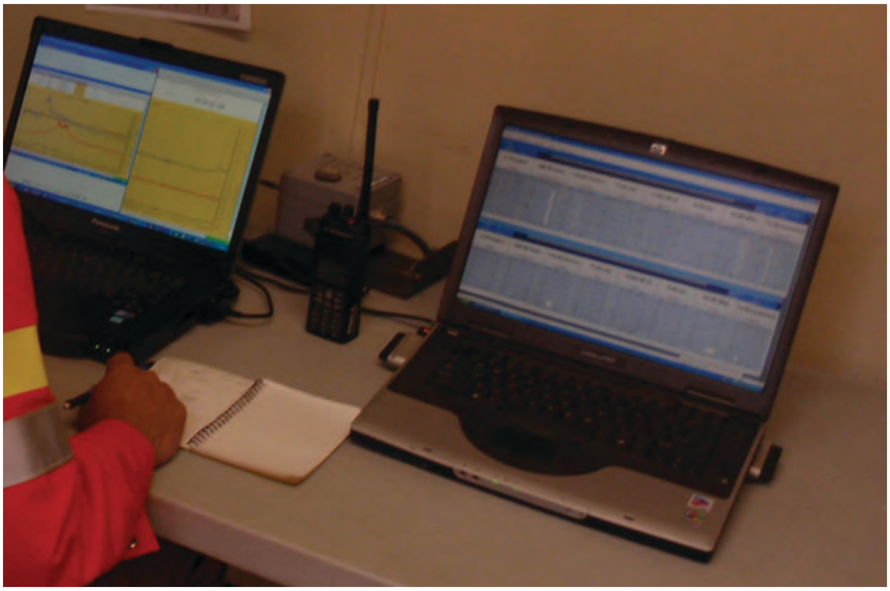
A reasonable starting point is to ask: what are the standards/procedures in the industry for monitoring of grouting using computer-based digital data acquisition? For the answer to this question, let us accept that the four New Orleans specialty conferences indicate the state of the industry.

Using fractured rock as an example, these conference proceedings show that although electronic monitoring started thirty years ago (e.g. Ref. 2) there is still no consensus on what needs to be measured or how those measurements should be plotted/displayed. These differences stem from different underlying idealizations and so forth on how grout behaves. The "GIN-sufficient" group (working from Ref. 3 as updated in Ref. 4) are likely happy with a single plot of pressure versus volume injected. The "GIN-misleading" group (e.g. Ref. 5, 6) require pressure versus flow rate, penetrability versus time, and penetrability versus volume injected. Yet others (following Ref. 7) might ask for 'Grout Lugeon' plotted against time. What we should all ask for, but remains absent, is to add real-time measurement of grout rheology (although a good start at this was discussed at the Conference, Ref. 8).

Perhaps surprisingly, the issues and computer systems for monitoring of compaction grouting are similar to those of fractured rock grouting. Largely driven by one extreme application (Bennett Dam; Refs. 9, 10), it is now accepted that compaction grouting should be monitored for injection pressure, grout flow rate, and total grout injected (Ref. 11).

Sorting out unusual occurrences

The evolution of monitoring, from the perspective of these New Orleans conferences, shows good appreciation of the role of computers around Principle 1. But the issues surrounding applying monitoring data to sort out unusual ground response or grout behavior – Principle 2 - has seemingly not been discussed (or at least, we did not find a single paper in our readings of that literature). Here we offer some examples where the ability to retrieve data after grouting for further evaluation has been important (if not crucial)



Computer contol room.

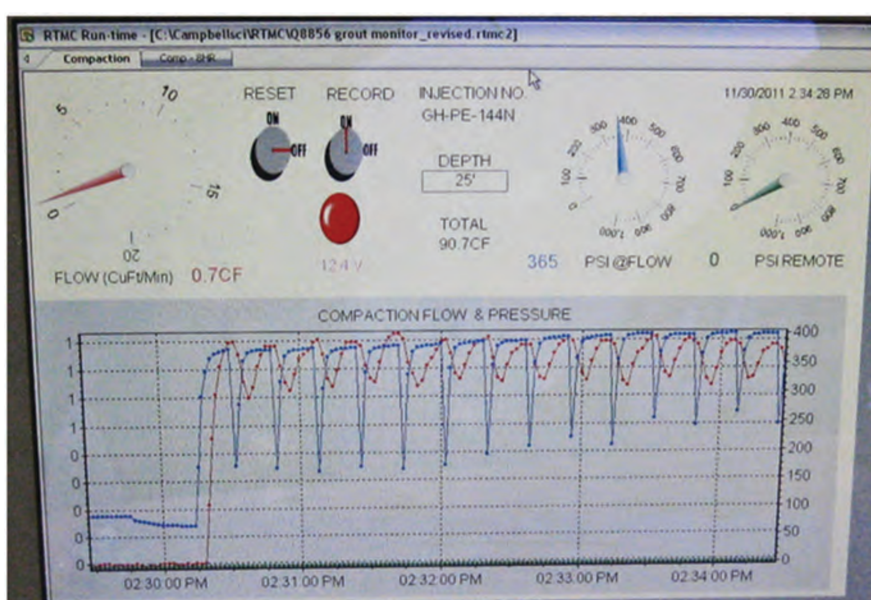
to the work's success.

Bennett Dam: An extensive array of piezometers had been installed adjacent to the area to be grouted. Maximum allowable pore pressure increase had been established for each piezometer, dictating the maximum grout injection rate and resulting pore pressure. Initial injection rate was established based upon analysis and experience, and should have been sufficiently slow to not exceed the allowable pore pressure rise. The reality was, excessive pore pressure rises occurred on several occasions requiring cessation of all operations until they were resolved. The recorded digital record was uploaded into Excel and viewed at an expanded scale, to show what was going on within a single pump stroke. Substantial variation in the rate at which the piston moved was observed, even though the average rate was as intended. The grout pumps were then replaced with higher quality pumps capable of uniform operation, and the excess pore pressure problems disappeared.

California Aqueduct: Internal erosion and piping leakage of an embankment on the California Aqueduct resulted in an emergency grouting operation. Time constraint limited the soils investigation to CPT probes, with this data supplemented through close monitoring of the injection behavior during grouting. Each day's computer monitoring data, again uploaded into Excel, was analyzed overnight, distributed to team members over the internet, and injection parameters adjusted for the following day's work. Upon completion of the emergency work, the data was used to better understand the existing conditions, facilitating future action consideration.

Colorado Oil Shale: A perimeter grout curtain was intended as a component for environmental isolation of in situ recovery of hydrocarbons from the shale. However, initial operations viewed the ground as ungroutable with reported observations that grout "ran away into the formation". This project involved greater than usual depths (more than 400 m working from surface). Grout data was recovered from the data acquisition system and uploaded into Excel for detailed analysis. The following situation was revealed. Grouting started with water-filled tubing, and as grout travelled down the tubing the collar pressure dropped dramatically because of the weight of the grout, until the water in the grout cavitated with consequent loss of flow control – the reported "run away" into the formation. The situation became controlled once sufficient grout had penetrated the formation to build enough hydraulic drag to return the collar pressure to less than that allowing cavitation of the grout. Excel analysis of the data determined low density, high viscosity grouts were needed for the project.

Amtrak Bridge: This project involved



Compaction recording.

emergency remediation of a bridge pier in deep water, subject to tidal variation, founded on a concrete filled timber caisson of unknown strength, condition, or exact dimension. The suspected "faulty" soil was at a depth of 160 to 170 feet, underlying a deposit of organic clay and silt mud approximately 100 feet thick. The soil was variable, consisting of a range of sands, some silt, and even some minor clay. Sampling and sample retrieval were time consuming and very difficult to accomplish, and the soils were not well understood when the grout injection began. Because of the emergency conditions, grouting was actually started boring and installation of instrumentation systems progressed, such that primary guidance for the work was through analysis of the ongoing injection as it progressed. Similar to the California Aqueduct, monitoring data was uploaded into Excel for analysis to guide the ongoing injections. Further, the remediation team members were literally scattered across the country. Many teleconferences were held during which the team members could observe and discuss the original data, transmitted via an FTP site.

The above examples illustrate that "unusual events" can be investigated by exporting data to Excel for cross-plotting (correlating), expanding scales and so forth – data processing features omitted in current "proprietary" software. However, once the data is in Excel we can go one step further to understand what is happening in the ground.

Understanding through analysis

Excel has a programming language "VBA" that is readily accessed from the worksheets (see the 'Macro' menu). Grouting data can be imported and plotted in Excel, with all the plots found in the real-time monitoring systems easily replicated, but with now the possibility of adding formal analysis through VBA. This is easiest appreciated by example.

For remediation of Bennett Dam by compaction grouting, grout injection was simulated in finite element software to develop a set of response 'type curves' that were transferred to a VBA routine. These curves could then be called up from within a worksheet to overlay a simulation on the measured data in an "image matching" process, with the ground parameters adjusted to get the best-fit; those best-fit parameters show the current state of the ground. In effect, each compaction grout injection was treated as if it were a pressuremeter test with the evolution of the estimated ground parameters directly showing how the effectiveness of the work was developing.

The process of modeling grouting has now been extended to fractured rock grouting. The Bingham equations for flow in rough fractures can be solved directly in VBA. Just like compaction grouting, fracture roughness properties estimated from for example televiewer data,and then adjusted to best-fit the Bingham solution on the measured penetrability versus injected volume curve – giving a measure of how far the grout penetrated into the formation in that stage.

These two examples show the potential power of getting computer-acquired grouting data into Excel. They also illustrate two independent functions for grouting data: i) job-control in real-time situation – that is, activities around Principle 1; and, ii) protocol-assessment within hours of an injection – that is, activity in support of Principle 2. Whether this Principle 2 assessment is done by an onsite grouting engineer, an offsite support engineer, or by the Owner's appointed review engineer, does not matter – it is a distinct function with different purpose from day to day job control. And, today, Principle 2 needs data that can be loaded into analytical software such as Excel.

Of course these two cases of analysis-guided grouting do not represent the current state of practice. But, they do show where the industry might go, and how we can further improve and expand our technology.

Required computer-based data acquisition

Data in support of grouting covers a wide range of drilling and grouting activities, and all the data is needed to guide the work. However, the 'ruckus'

Grout Computers.

was focused on that portion of the data measured by the computer systems monitoring the grout injections. So, let us turn our attention to how we make these measurements.

Computer data acquisition and monitoring is a rather well-established technology (Ref. 12 is a convenient briefing for grouters). The discussion between various grouting groups on "what" to measure is irrelevant as modern computing systems can measure many more parameters than any grouter will ever need. It is trivial to have eight channels of data. The minimum data suite only uses five: time, pressure, flowrate, volume injected, grout rheology (or mix indicator).

However, the appropriate data acquisition strategy in terms of scanning rate, filtering procedures etc. has been neglected with no industry consensus on "how" to monitor. A computer systems engineer might be horrified with what we are all doing. From a grouting perspective, the most challenging measurement issue is reliably detecting hydrojacking, a process that can initiate in seconds because of the pressure-storage within the grout delivery system. And, this need suggests a minimum standard of filtering at 1 Hz for noise, with a matching 4 Hz scan rate; higher frequencies are fine, but also result in larger files than needed to understand what is going on (inconvenient, but not a "deal breaker").

Data storage format is open to choices, and a proprietary (i.e. binary) format could be used. But, a binary format would be a poor choice as file size is small for grouting records, and the gain from reduced storage in binary format is completely offset because the data can no longer be inspected with a text editor. By far the best choice is a text format complying with the American Standard Code for Information Interchange (i.e. ASCII files). ASCII files are readily imported into Excel for analysis, and are a basic format in any high-level programming language if writing proprietary (custom) software. There is no reason to not use an ASCII format, ideally "comma separated values" (csv), and every reason to so do.

Where proprietary software becomes more of a consideration is with the real-time display. With some systems, a high-level "building block" language is used (e.g. National Instrument's DASYlab) and it is not difficult to add or change the display used on the monitoring computer. Conversely, if the display has been programmed in C++ language changing the display format may be challenging. This points to the need for grouting industry standards, but standards won't develop until we have a consensus on the appropriate plots to be used – and, as an industry, we are some way off from that realization as discussed earlier. Practically, this may not matter in the short term provided the engineering team can bring up the data in Excel for further processing and display.

Final comments and a question

This essay was triggered by a ruckus over proprietary monitoring of grouting. But if we accept that the New Orleans conferences represent the Industry's view of what is appropriate, then the companies offering proprietary systems must address the question: Why should aspects others grouters in the industry consider important be excluded by their "proprietary" system? Or as one of the participants at the Conference inquired "What do they want to hide?"

In reality, "proprietary" systems seem focused on 'job-control' rather than 'engineering-of-adequacy', and owners could live with such proprietary systems provided data can be exported for Principle 2 assessment. However, there is a caution too for such proprietary systems – it is not for the proponents of proprietary systems to determine what is adequate. That is the task of the owners engineers and consultants, and industry-consensus. And if that consensus requires aspects not in proprietary systems, then those systems must be modified to comply with industry standards.

And a final request; open discussion is the way we all learn. Real time computer monitoring has proven advantageous in managing and controlling grouting work, and its use will only increase over time. Original data is often provided in standard format by quality contractors. It is essential that all grouting professionals are aware of its advantages, disadvantages, limitations, and all things related. The authors strongly hope this essay will be the beginning of ample and thoughtful discussion (pro and con) of the subject. Be it a few sentence opinion, or a comprehensive article, send your comments to the Grout Line!

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Editor's comments

Jim asked me to add my name to the list of the co-authors but my first thought was, being the editor of the Grout Line, to be "super-partes" and my original intention was not to take any position in this controversy. But, I have reconsidered and decided to share my thoughts. It is a topic in which I am very passionate considering that I started using computers and continuous monitoring/recording of data in drilling & grouting in 1989 (23 years ago). Since then I have become quite obsessed/addicted with the use of this (at that time, very new) technology. It is a delicate matter and sometimes controversies can happen. For example, battles about the use of computers have been held during the preparation of the "Jet Grouting – ASCE - Guideline Specification".

I agree completely with the content of the article and my first comment/reminder is that the same concepts can be applicable also to the drilling, with the automatic monitoring/ recording in real time of all the drilling parameters such as speed, torque, pressure on the tool and rotation. Don't forget the drilling!

I concur that it is not acceptable and not admissible to withhold the "raw data". The simple concept is that these "raw data" are a couple of recorded numbers as (in grouting): flow, pressure (and if we want to add rheology) recorded every defined time (1 or 2 or 3 seconds or…). One value for the time and one for the parameter we want to control/record. It can be discussed what shall be the "best" timing interval, but these concepts are quite simple.

Other parameters such as volume or energy (GIN) or penetrability or equivalent Lugeon etc, are usually function of the basic parameters monitored and recorded vs. time. Consequently for these parameters, no additional sensors are required but only simple formulas.

Each manufacturer of recording systems or Contractors have, of course, their own graphical representation and evaluation (and here I agree that their software can be proprietary) but the "raw data" must always be made available to the Owner/Engineer for their exclusive use, and that is not necessarily compatible with the "proprietary" software provided.

Another aspect to analyze is related to what the article says about stage termination criteria or grouting design; GIN or Equivalent Lugeon or "misleading GIN", or…. Of course, the software used for a grouting job shall be adapted/modified depending on the grouting criteria/design specified and also in this case can be proprietary. But again the "raw data" shall always be provided.

In my personal experience, I have used several recording systems available on the market, and all of them were capable of providing "raw data" (ASCII format) readable later in a simple Excel sheet (or equivalent – a lot of spreadsheet programs are available now) or a simple database. So I have never had any discussions about this problem.

Unfortunately I was not present at the "heated discussion" in New Orleans (too many interesting papers to follow) and maybe I missed some other concepts in the discussion. I reiterate, I consider it to be completely acceptable that every manufacturer/contractor has their own "proprietary software," compatible with the needs of the grouting job to be done, but in my opinion it is a lost war for those who argue that the raw data does not need to be made available to the owner/engineer.

If you have additional comments about this interesting topic, or grouting stories or case histories, you can write to me: Paolo Gazzarrini, fax 604-913 0106 or paolo@paologaz.com, paologaz@shaw.ca or paolo@groutline.com.

Ciao!