**Overture**

Here we are again for the twelfth appointment with our Grout Line.

For this issue we have 2 articles, and a short comment related to one of the articles. Both articles are related to previous articles published in past editions of The Grout Line. I remind you here that all the past articles of the Grout Line can be downloaded at www.groutline.com/Articles.htm.

The first article is the answer of Dr. Lombardi (Lombardi SA Engineering Limited, Minusio, Switzerland, info@lombardi.ch) to the article published on the Grout Line - Geotechnical News Volume 25 Number 3- on September 2007 by Dr. Shuttle and others. This was consequent to a previous article of Dr. Lombardi published on the Grout Line - Geotechnical News Volume 25 Number 3- on September 2007.

Dr. Shuttle also sent me a short final comment that you can find at the end of Dr. Lombardi’s article.

The controversy about the GIN (Grouting Intensity Number) is continuing!

The second piece is Jim Warner’s clarification of the article published in the March ’08 issue related to the difference between Low Mobility Grout and Compaction Grout.

I wait for your grouting papers, articles or comments. Please send them to: Paolo Gazzarrini, fax 604-913-0106 or paolo@paologaz.com, paologaz@shaw.ca or paolo@groutline.com. Ciao!

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**Misunderstanding of GIN Confirmed**

**Giovanni Lombardi**

In a paper published by “Geotechnical News” “Grout line” [1] titled “GIN Again Misunderstood” the writer presented some comments to the paper “Penetrability Control of GIN Mixes during Fractured Rock Grouting” by Vafa Rombough, Grant Bonin and Dawn Shuttle [2]. In response to these comments the paper “GIN Distilled” by the same authors was published, also in Grout Line with date September 2007 [3].

As this last paper contains again some misunderstandings, the following considerations will refer to them, but will provide also some considerations of more general nature.

**GIN as Limit**

In the intent to show the presumed “limits of GIN”, figure 2 from the Antamina Dam, was presented in paper [3]. The same is reported hereafter with its original legend, as Figure 1.

Unfortunately, its meaning was again misunderstood and was the occasion to invent the amazing tale of “multiple GIN closures”. It was actually assumed that the so-called “closure” was reached 4 times at the points A, B, C and D, where the GIN-line was touched by the pressure path.

The question is thus: why only 4 times?

In fact the GIN line could have been easily reached and even crossed not only 4 but 40 or more times. Even more, if said GIN line would have been followed continuously from a point of “high pressure - low volume” to a point of “low pressure - high volume”, to some final value, then the two lines would have coincided an infinity of times.

Fortunately, the 4 mentioned points are not “closure points” at all, because the flow rate at these instants was about

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1 In fact the same grout path crosses easily 40 times a somewhat smaller GIN line as the one shown on figure 1.
The GROUT Line

Figure 1. As presented in “GIN distilled” [3] as figure 2; with its original legend.

a) Pressure vs. Volume curve
b) Measured flow rate vs. injected volume
Example gROUT injection data from Antamina Dams showing multiple GIN “closures” [2] (HP 27.6-32.6 m) adapted from Richie and others, 2003.

Figure 2. The real “closure” for the example shown on figure 1 takes place at the point E. In fact, the unique closure would have taken place at the point E or near of it, at a flow rate nil. The gROUTing was stopped before reaching the real closure.

20.12.90, and 6. L/min respectively.
As one should know - and this is repeated again - the flow rate at the “closure point” should and will be nil. Only then can talk of “closure.”
From the graph of Figure 2 one may, in extrapolating the flow-rate tendency, easily conclude that the nil flow rate would have been arrived at for a volume injected of about 400 l/m. Therefore the closure would have occurred at the point E (or nearby), which point was however not reached with the gROUTing works, and which is the unique real “closure” point in spite of the mentioned tale.
In the case of figure 1, the gROUTing was stopped too early, that is before reaching the point of “closure” E. This means simply that the concept of the GIN-method was not really understood, already at the time of gROUTing. Only 300 l/m were injected instead of the about 400 l/m, which should have been. The real closure point was missed by 33% of volume.

This point outlines again one of the significant aspects of the GIN value and doesn’t need many comments, except that it was overlooked both by the gROUTing engineer at site and the writers of the paper from which figure 1 was taken.
By the way, this point E could have been reached in following the GIN line (which task requires however some skill and an adequate equipment, but which could be considered to be the most logical one). The point E could also having been reached from below or from above the GIN line (provided, in this last case, that the volume taken would not overpass the corresponding estimated value, e.g. 400 l/m) (see Figure 3).

Indeed the GIN line is a target to be reached not a “wall” which could not be crossed. However, frequent cases are met where certain GIN values represent a physical limit, which can hardly be crossed. This happens when an important hydro-fracturing, hydro-splitting or hydro-jacking takes place.

One knows, from the theory and the gROUTing practice, that when the pressure suddenly decreases at an almost constant flow rate, a phenomenon of this kind does occur. Said decrease of pressure, often at a constant GIN value, may be of a limited extent. This means...
that the hydro-fracturing discontinuity itself is of a limited length because cut by other more stable fractures or by different rock layers.

During a grouting process a series of such "local" limited hydro-fracturings can therefore be observed on always higher intensities, that is on higher GIN values.

In some cases, however, a major hydro-fracturing along a main discontinuity can take place.

The meaning of the GIN line as a limit for hydro-fracturing was described in paper [7], from where Figure 4 is taken.

The fact that hydro-jacking takes place by increasing volume and decreasing pressure is easily explained, because the GIN value - that is the grouting intensity - represents roughly the energy pumped into the rock mass, and because - like many other instabilities - the hydro-jacking event takes place at a practically constant energy level (see [7]).

It may also be mentioned that, as shown in Figure 5, when the pressure path follows the GIN line two cases may happen:

Case 1: the flow rate tends to diminish with increasing volume injected. In this case a normal grouting takes place.

Case 2: the flow rate remains more or less constant, then an important hydro-splitting is likely to occur.

In this last case the corresponding GIN line represents a barrier, which cannot, or at least should not, be over-passed. Even more the continuation of the grouting can practically take place only along said GIN line. Increasing the power of the pump leads mainly to an increase of the flow rate, while the pressure still decreases.

Reducing that power leads to a reduction of the flow rate and soon to a stoppage of the injection. Consequently, the GIN value has an additional meaning when hydro-jacking or hydro-splitting takes place.

It should thus be evident that the conclusions drawn in paper [3] do not hold, and that an additional merit of the GIN concept has to be recognized, in the sense of a protection against excessive hydro-fracturing of the rock mass.
GIN "Closure"

It appears, further that in the background of many statements about the GIN-method, the opinion prevails that grouting by that method must take place in using a constant, possibly very low flow rate. It is thus stated in [3]: "hence in practice GIN becomes unreliable to control practical grouting". Fortunately, this is an additional confirmed misunderstanding.

It was not seen by many that figure 3 of paper [5] titled "Actual grouting path and grouting intensity (GIN)" as well as the concept of over-passing it by, for example 10%, have just the intent to explain the question. (Possibly, the explanation was not clear enough) (see Figure 6).

It is said also, by the authors of paper [3], that "in a typical GIN grouting project you pump at a constant rate".

For sure, there are worldwide a number of designers, who specify a constant and even a low flow rate, when referring to the so-called GIN grouting. (Hopefully, they know the reason of!). But, such a specification and similar ones are independent of the GIN principle and are by far not always optimal.

The right way to proceed is shown at the reverse in paper "Grouting design and control using the GIN principle" [5] published already in 1993. It consists to steer the grouting process in taking into account the "penetrability" defined by q/p (flow rate divided by grouting pressure), which value has obviously to be shown to the operator at real time on the display (see Figure 7).

In fact, the penetrability must be nil at the closure point, thus also the flow rate. As already shown, this principle was not understood in the case of Antamina shown (as well as in a number of other jobs).

The principle to follow consists simply in adapting progressively the pressure and thus the flow-rate, when the GIN value (at nil flow rate) accordingly to the flow path, approaches the desired value.

This way of doing allows a certain extrapolation in time of the decrease of the penetrability so there is no need to select an "extremely low flow rate" long before stopping the process (see again figures 2 and 3).

To avoid new misunderstandings some additional explanations appear to be necessary.

An example is shown on Figure 8 for the case the pressure is maintained constant, which means that it is changed only stepwise.

No matter how the grouting did proceed until the point A. At that instant, the pressure p1 and the flow rate q1 were arrived at and the volume V1 was already injected.

If the pressure were kept constant, its line would cross the GIN line at the point B with a value V_B for the take. However, a check shows that the decrease of the flow rate would take place quite earlier and the extrapolation of it would lead to a stop at the volume V_C, which is smaller than V_B. The two values V_B and V_C should obviously coincide.

The pressure must thus be increased at the point 2 so that the corresponding volume, V_A, will decrease while the expected one, V_C, would increase reducing the gap (V_A - V_C) between them.

If necessary, a further adjustment of the pressure can be done a while later.
Figure 8. Example of a way to steer the grouting process.

\[ p = \text{grouting pressure} \]
\[ q = \text{flow rate} \]
\[ VB = \text{volume theoretically taken at a pressure } p_1 \] (\( VB = \text{GIN}/p_1 \))
\[ VC = \text{volume taken estimated in extrapolating the decrease of the flow rate} \] (better the decrease of the penetrability = \( q/p \))
If \( VC > VB \) then increase the pressure, so \( VC \) increases and \( VB \) decreases, reducing the gap (\( VB-VC \)).

At the reverse, if \( VC \) appears to be greater than \( VB \), the pressure should be reduced.

The procedure can be improved in referring to the penetrability, \( q/p \), instead of the flow rate, \( q \), itself. In doing so, at least certain irregularities are smoothed and the process made more precise and easy to steer (refer to figure 7).

A way to speed up the procedure, as already presented in paper [7], consists to target a somewhat higher (10%) GIN and to stop when the flow rate falls below a certain small value.

It may be easily understood that the described procedure can be automatized in using an adequate software. Similar procedure can also be developed if different grouting methods were adopted.

By the way, the following consideration is due.

The GIN value will be decided on the basis of some grouting tests in a rock mass similar to the one, which has to be actually grouted; but, obviously not for any single borehole nor for any single grouting stage. Therefore it is not necessary to try to reach some theoretical absolute precision and therefore some tolerance has to be accepted. Other means, as for example additional boreholes series, are available to compensate for too important scatter in the rock mass properties.

This way of doing is by far not a “poor guidance” and the statement “in practice GIN becomes unreliable to control practical grouting” does not hold. In fact, the practical experience on many sites confirms the good, if not excellent, guidance it provides. GIN is actually a target, which can be missed as many times as one wishes. However, this is a problem of the shooter not of the target!

Also there are, for sure, many people who don’t know how to steer correctly the GIN grouting process.

At the end of the day, the actual physical penetration distance reached by the grout depends on the pattern of the discontinuities, on the grout volume absorbed, and on the cohesion-related term of the pressure at the moment the procedure is stopped. Indeed, when the pump is turned off the flow rate becomes nil and the viscosity related terms disappear.

This is exactly the definition of the GIN value.

In fact, the actual pressure path, the flow rate and their variations during the first part of the grouting process are of a quite secondary importance, except they may influence the duration of the procedure.

In fact, in accepting the GIN principle, higher grouting pressures, and thus higher flow-rates as usual can be used as long as some distance from the targeted GIN value is kept. This allows speeding up the grouting process. The second part of the grouting process was already discussed.

**Definition of the GIN Value**

It should be clear that due to the extremely high number of unknowns existing in the actual rock mass, as types of discontinuities, orientation, opening, deformability, ruggedness, frequency, interconnections, infill, etc., no possibility does exist to define a priori on a theoretical base the parameters to be selected for the grouting process.

The only realistic way is to carry out test fields for each zone of the rock mass, which may reasonably be considered to be homogeneous, as explained in paper [6].

The split-spacing method should be used in any case both for grout curtains and for foundation consolidation. The criteria to judge the results are the decrease of the take from series to series of boreholes while keeping a constant GIN value.

In matter of the grout reach it was not always clearly distinguished between the GIN value computed for a single joint of constant opening and the value obtained by a grout test in an actual rock mass.

Therefore the statement “GIN overestimates the grout reach” cannot have any meaning when referred to a grout test, in a real rock mass, nor when re-
the joints and fissures are filled by the grout in all directions. The model of a radial flow is thus a bit more realistic than the one of a strip flow.

The weak point of the strip model is that the "specific flow rate", that is the flow by unit width is assumed to be constant all along the discontinuities from the borehole to the border of the grouted zone, while it is obvious that this specific flow-rate decreases strongly with the distance from the borehole. (Approximately with 1/r in function of the actual reach.) As consequence of the strip-model the pressure gradient appears to be constant and thus the pressure to decrease linearly from the borehole, while in fact the pressure drops very strongly near the borehole and is very significantly reduced at distance.

The linear distribution is reached only when the process is stopped and the flow rate is nil everywhere.

For this reason, at this moment, the theoretical final reach and the pressure distribution are the same, whether computed with the strip or with the 2-D model.

In the reality, the grouting process is sometimes more a 3-D than a 2-D problem, but for sure not a 1-D one.

In any case the statement "the GIN method does overestimate the reach of the grouting" is the consequence of the wrong assumption that the method implies a low, near nil flow rate, that is a low grouting pressure and thus a long grouting time. The contrary is true because in keeping a sufficient distance from the "dangerous-zone", accordingly to figure 4, higher grouting pressures can be used at the beginning of the process, which will be successively reduced, as already explained.

One of the consequences of the assumption made in using the strip model is that the splitting force produced by the grout is wrongly computed, that is overestimated until the end of the grouting, where the flow rate nil corresponds.
Figure 10. Pressure distribution along the joint at different time intervals during grouting.

To the value obtained by the radial flow-model.

The strip model is thus misleading in evaluating the risk of hydro-fracturing the rock. See [1].

Flow Rate Computation

In the paper by Dawn Shuttle and others, it is claimed that the analytical formula for a radial flow does not exist. It could at the best be developed under very restrictive assumptions (e.g., constant pressure or flow rate). In fact, such a formula is not necessary at all because the following steps can be easily carried out:

- at a given grouting flow rate the "specific flow" slows down from the borehole with the ratio (1/R), provided the possible opening of the discontinuity due to the pressure itself is disregarded (no hydro-jacking considered);
- consequently, the gradient of the pressure drop can be computed at any point using the properties of the grout that are cohesion and viscosity of the Bingham body;
- in integrating that gradient from the momentaneous border reached by the grout towards the borehole the corresponding grout pressure can be obtained;
- the flow rate can then be changed as required, for example in order to respect the characteristics of the grouting pump or any other required steering procedure, in particular when the grouting process is stopped;
- as the integration is carried out numerically, any kind of grouting procedure can be considered, in contrast to any analytical formula, which could, at the best, take into account only a predefined one.

It is agreed, that the procedure is less simple than an analytical formula, but has a much more general meaning and is significantly more flexible.

So, the example shown in paper [4], 1985 and represented in Figure 10 was computed accordingly.

It is thus quite difficult to imagine how "to give Bingham a try" as paper [3] proposes in its conclusion, because in any case the computation of the pressures and of the flow rate is based on the properties of the Bingham body.

Of course, there is nothing against any proposal in order to improve the GIN procedure. However a realistic way to do so has not been suggested yet.

For sure, the improvement can not consist to come back to historical criteria as, for example, to reach any a priori, arbitrarily specified constant pressure in ignoring the risk of hydro-fracturing the rock mass and thus to waste any amount of grout if such a phenomenon does occur.

Also, any arbitrarily given maximum take can not be of any help if not put in relation with the pressure required to reach it, that is to the grouting intensity.

Conclusions

It is well known, that there are worldwide quite a number of people who do not like and do not use the GIN method of grouting. They have, of course, the right to do so, even if this is not in the interest of the job, nor in that of the owner. The reasons of this fact are indeed numerous.

A first one is that GIN disturbs certain, sometimes century old, habits and ways of thinking.

Very interesting historical cases are also referred to, without taking into account how normal or exceptional they were.

Procedures and ways of thinking developed for unstable mixes continue to be applied when using stable ones.

Some operator prefers indeed to follow the principle "don’t think, just click" or introduces new rules so to get a "simplified procedure", as for example to define a GIN value on the design board instead of carrying out the necessary grouting tests on the site.

A list of frequent mistakes can be found in paper [7].

It is also quite usual to make any kind of errors during the grouting operation and then to criticise the GIN method instead of recognising the mistakes made.

The case of Antamina is clearly one of them.

Often also, the GIN method is used to grout karstic or similar formations for which it is not intended nor applicable. It should be used only at a second stage, when the karstic cavities have already been filled, e.g. with mortar.
On a given dam the lack of communication between the pumping station and the borehole mouth led to frequent excessive grouting in over-passing the GIN line because the pump was turned off too late. As usual, not the malfunctioning of the communications but the GIN method itself was considered responsible for the mishaps and this wrong conclusion was largely published.

Finally, people, even very specialized in some particular field, try to lead a grouting campaign in spite of a lack of an overall knowledge of this kind of work in the theoretical field or in the practical operation.

Indeed, grouting is a quite special activity, which requires both theory and practice, as well as some thinking.

The overall conclusion is thus the counsel to try to apply seriously GIN; one will finally like it. Indeed, the only problem with GIN is that it requires to be understood.

Bibliography

Dr. Lombardi’s article references several articles published on the Grout Line and from himself. You can download these articles (of course for free) from: www.groutline.com/Articles.htm (article published). www.lombardi.ch (publications).

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