6V

GIN principle revisited

In 1996, Water Power ran an article by Professor Friedrich-Karl Ewert[1] on the GIN principle, a grouting method proposed several years ago by Lombardi and Deere[4]. To provide more information on the subject, Giovanni Lombardi has followed up with a paper which sets out to clarify and enlarge on certain points of issue concerning the GIN grouting technique.

ROCK grouting, it seems, is an inexact science. It is almost impossible to achieve theoretically optimal results at any stage in the grouting process. So, for some time at least, the aim of GIN is to approach grouting in a simple, cost-effective way.

In its present form, the GIN technique attempts to steer clear of the most frequently encountered errors, but like any other grouting method, it has its limitations. For example, it is not directly applicable to karstic formations without the appropriate modifications.

GIN was never intended to make thinking superfluous, even if it did automate some of the grouting process. The temptation for schematic execution to reduce steady-state control should obviously be resisted by both the designer and the operator, just as the temptation to change the grouting parameters at any moment, merely to follow the fleeting thoughts of the on-duty geologist, should also be resisted.

It appears that a number of core principles of the GIN method are generally accepted. In his paper, published in *Water Power* in February and April 1996, Professor Ewert agrees with this thinking and considers these principles to be 'progressive components' of the technique (see table 1). However, two core aspects of Ewert's article, have apparently not been clearly understood and will be discussed in more detail in this article. These are:

- Abandoning the traditional water pressure tests.
- The concept of the GIN limiting curve, including the value of the corresponding parameters.

Water pressure tests

With the introduction of water pressure tests a few decades ago, Professor M Lugeon improved the evaluation of rock permeability, while, at the same time, gave a rough indication of where grouting may or may not be required. Unfortunately, frequent confusion surrounds Lugeon permeability and the groutability of a given rock mass.

In fact, Lugeon's - or, for that matter, any other type of water pressure test - may be useful in defining a certain type of rock mass permeability before and after grouting and thus estimating the limits of the zones to be grouted, as well as the results obtained. It does not, however, define the groutability of the rock itself. For this, one must consider that:

- Water is a Newtonian, but cement-based grout is a Bingham body.
- Water is molecular; grout is a suspension in water of cement grains of a given size.
- Water enters fine joints, grout will not.
- Water tests yield a flow rate, while grouting yields a grout take, ie, a volume.
- Water tests have a certain duration, grouting can extend beyond any time limit.
- Different pressures are used for water tests and for grouting.

Professor Ewert was correct in saying that 'Water pressure tests pose a dilemma,...often the results are doubtful.' So, no serious correlation can be expected between the groutability (the volume of grout to be absorbed by the rock mass) and the Lugeon test (which refers to a flow rate).

Indeed, the actual groutability can be defined only by grouting tests and not by any water pressure test. Additionally, grouting tests at the site are much easier and cheaper to carry out than water pressure tests, because they do not require additional equipment. Nor do they waste time since the boreholes drilled for water tests must be 'filled' later on (ie, grouted).

One of the basic ideas of the GIN method is to eliminate the usual water pressure tests and to define the actual groutability by carrying out grouting tests during construction. The grouting tests consist of simply analysing the graphs plotted by computer.

Professor Ewert seems to have misunderstood Lombardi and Deere. It was never meant that 'tight' or even 'very tight fissures' should be grouted by any means. The scope of grouting in such conditions is just to confirm (during the grouting process) that no grouting (or additional grouting) is necessary where at high pressure no significant grout take is required.

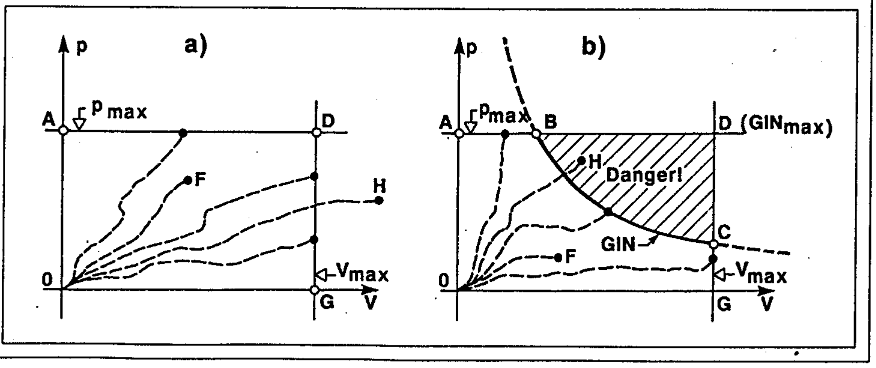
Generally, therefore, the nearby holes of the following series are not required, making an additional saving. In other words, the grouting process is directly managed by the grout takes and not by any inadequate, and at the end ineffectual, water pressure test at additional cost.

The GIN limiting curve

The question of the GIN limiting curve appears to be Professor Ewert's main concern. Firstly, one must consider that things, such as the 'refusal' by the rock mass during grouting, do not occur in nature. By increasing the grouting pressure, the grout take could always be increased beyond any given limit. Obviously, the grouting will generally stop at a given pressure and some unpredictable volume. Therefore it is unavoidable to define some criteria to stop the grouting process at a certain time and under certain conditions.

Traditionally, a pressure limit is set and grouting is stopped as soon as that threshold is reached. A limit is often set according to the volume taken per borehole meter, or stage, and again the

Figure 1: The limitations of grouting.



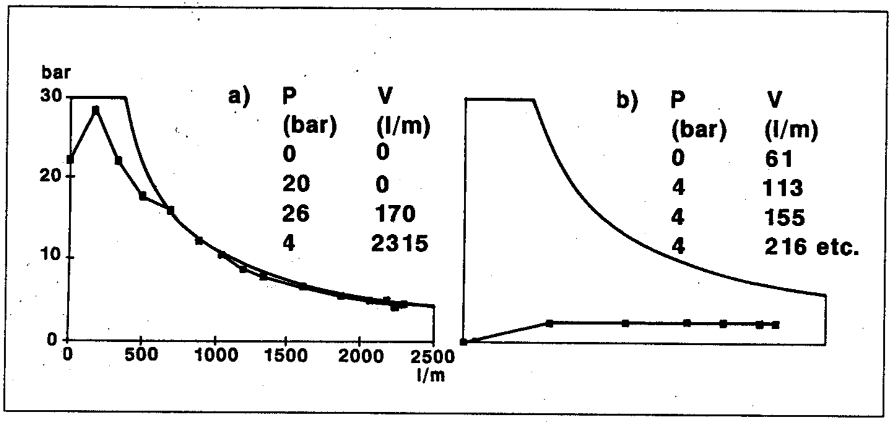


Figure 2: The GIN value is the governing factor of hydrojacking.

grouting process is stopped accordingly. No matter how scientifically or arbitrarily these two limits are defined, any point on the borders of the rectangle OADG (see figure 1a) can, and must, be reached by the grouting path of every grouting stage. No point of the grouting path is allowed outside the rectangle (point H), but also, no path can finish inside it (point F), except in the case of operator error. There is indeed no reason to stop the grouting before one of the two limits is reached, except by an arbitrary decision which would automatically imply that the limits selected were themselves designed incorrectly.

Given the concept of 'grouting intensity' is defined as:

$$GIN = pV \approx \text{grouting energy}$$

it is easily understood that this value is zero at the points A and G, and reaches its maximum at point D on figure 1a, where:

$$GIN_{max} = P_{max}V_{max}$$

The risk of hydrojacking or hydrofracturing is highest where the grouting intensity is the greatest. This fact was clearly shown by the theoretical analysis of the grouting process[3].

For this reason, a second principle of the GIN method consists of avoiding excessively high grouting intensities, which actually avoids the combination of high pressures with high volumes which have been taken, or as yet, not set. By introducing a GIN limiting curve, the shadowed area in figure 1b is not permissible any longer and the risks of hydrojacking are significantly reduced. In order to avoid such an occurrence, the designed GIN value, GIN_{des}, has to be significantly smaller than the critical value.

$$GIN_{des} < GIN_{crit}$$
and
$$GIN_{des} < P_{max}V_{max}$$

The critical GIN value is the value at which hydrofracturing takes place for any given set of geological and geomechanical conditions. The traditional case of figure 1a is just a special case of figure 1b, where the following conditions were assumed:

$$GIN_{des} > P_{max}V_{max}$$

There could have been no better experimental confirmation of the validity of the GIN principle, than the one shown by Professor Ewert in figure 10a of his paper, which is reproduced here in figure 2.

This figure shows the unique way in which the hydrofracturing process is like a hyperbola, ie. it takes place at a constant grouting intensity. (Apparently in this case, an extremely high one of GIN = 4 x 2315 = 9260 ~ 9000 bar.l/m was selected; except that the numbers on the figure of Professor Ewert's paper were incorrect and the volume shown does not refer to a 1m borehole but to a longer stage).

This example shows in an extremely convincing way that hydrojacking is controlled by the GIN value and not by the pressure itself. Here the GIN_{des} value was evidently chosen as more or less equal to the critical value. The hydrofracturing was finally arrested by an arbitrary, unknown decision. Obviously, a smaller, more adequate GIN value would have halted the grouting process well before this stage and would have avoided the recorded excessive consumption of grout. In that project the GIN value was chosen incorrectly, given that hydrojacking was not the intention of the designer.

It has to be recognised that rarely is nature kind enough to produce such perfect and clear grouting paths as the one carefully selected by Professor Ewert. This case apparently belongs to Project D where only a single well-defined set of extended discontinuities exists.

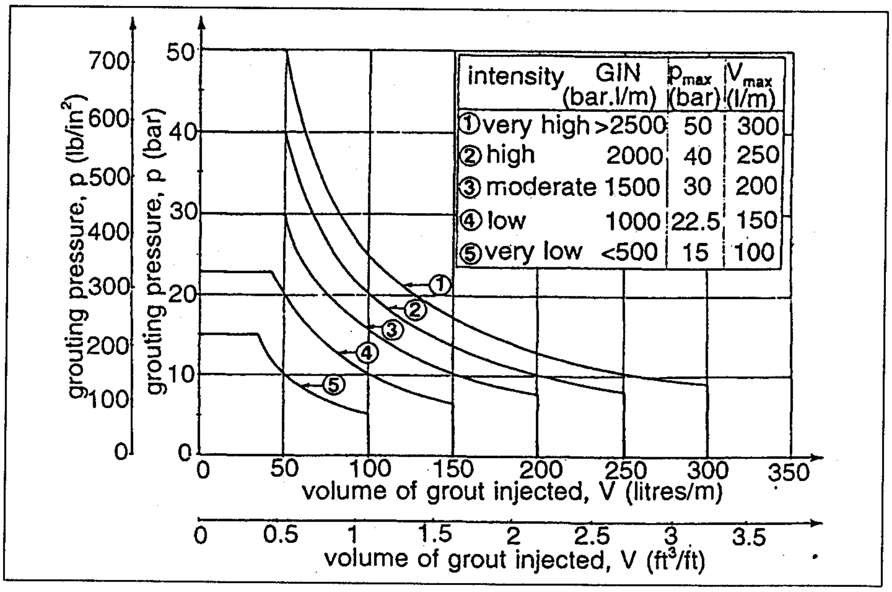
Generally, the plotted grouting paths are not clear, because different sets of joints which form a quite complex pattern are interested by the grouting. So the joints crossing the main one generally limit the extent of the hydrojacking. Therefore, very frequently only portions of similar curves are found and may also be seen in figure 8, case E of Professor Ewert's article (see figure 4).

While traditionally the limits for grouting are defined by two criteria, P_{max} and V_{max}, the GIN principle defines the limiting curve by three parameters - P_{max}, V_{max} and GIN. This fact reduces the risk of hydrofracturing and provides additional flexibility in favour of the designers. They can, for example, increase the pressure, or the take, or both limits, without increasing the risk of hydrofracturing as long as the GIN value is maintained. This is one great advantage of the procedure.

There is no doubt that these increased possibilities and such versatility open the way towards a significant improvement in the design of the grouting projects.

Introducing a GIN limit simply means that the limiting value for the grouting pressure is not constant, but is progressively decreasing in function compared to the volume of grout taken up to that point. It must be stated that the numerical definition of the three

Figure 3: Proposed limiting envelopes for grouting.



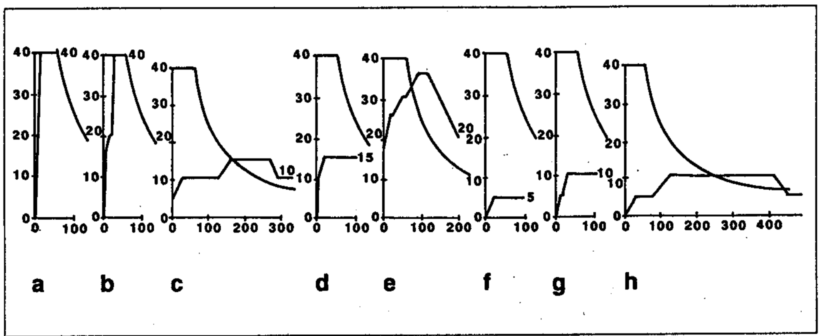


Figure 4: Grouting path curves which do not follow the GIN criteria accurately enough.

parameters must be made carefully, in accordance with the scope of the project as well as with the geological conditions prevailing in the zone of the rock to be treated.

Another point raised by Professor Ewert is the fact that in the GIN method the limiting pressure will usually be kept constant at the mouth of the borehole and will thus increase with depth in relation to the grout density (Yg). Despite the fact that the limiting pressure of the grout has to be selected by the designer for each zone being treated, the following considerations may be of some help to clarify this.

There are a number of crude rules which specify how to increase the grouting pressure with depth below ground. They generally start at zero (or close to zero) pressure at ground level. The situation is quite different in using the GIN method as at shallow depths the GIN value, and not the maximum pressure, is governing the grouting process; therefore the limiting pressure can be chosen at quite a high level, even at ground level.

There is no doubt that the optimal pressure for any grouting process depends, among other factors, on the compressive stresses in the rock mass as well as on the future water pressure. Under normal conditions, the stresses in the rock mass will increase with depth with its specific density (Yr) and the water pressure also with its own density (Yw).

It is thus felt, at least as a first approximation and as long as the other factors do not change, that it can not be too wrong when the limiting pressure at the grouting spot is also increasing in the same way in between the water pressure and the rock stresses. Therefore, the following inequality applies:

$$Y_w < Y_g < Y_r$$

Furthermore, provided a good stable mix is used, one of the two approximate relationships is valid, of course by pure coincidence:

$$Y_g \approx (Y_w + Y_r)/2; \; Y_g \approx \sqrt{Y_w . Y_r}$$

These last approximations should not be taken as mathematical rules, merely a sign that the choice of a constant grouting pressure at the borehole mouth is not entirely absurd.

Anyhow, should it be felt, that in particular cases increasing the limiting pressure with depth should be more adequate, there is obviously no difficulty in defining a new 'homogeneous zone' of the mass to be treated and redefining the three GIN parameters used elsewhere in the project. This is again the responsibility of the designer.

To avoid confusion, the following terminology should apply: hydrojacking should be used in the case of opening already existing joints (or any kind of discontinuities) in the rock mass, and hydrofracturing should be used in the case of creating new cracks.

The grouting of large, jointless rock is beyond the scope of this paper and, indeed, the GIN procedure. Grouting, as intended here, consists of the treatment of jointed rock masses. In such a mass - except in very rare conditions - existing cracks will open well before new ones form in the intact rock. Thus actual hydrofracturing will be a rare event and does not merit further discussion.

Grouting by pressure

Grouting is carried out by introducing a grout mix into the discontinuities through pressure. Pressure always opens (dilates) any fissure grout enters. So dilation of the discontinuities, and thus of the rock mass itself, is unavoidable. The question is not one of principle, but the extent of dilation. As long as the mathematical characteristics of the grouting path are positive (increasing take at increasing pressure and increasing GIN), a normal grouting procedure takes place by progressively opening the joints (dilation).

As soon as the characteristic becomes negative (increasing take by decreasing pressure at constant GIN) an instability (elastic or not) occurs and a hydrojacking event takes place, exactly as shown in figure 2.

It is, first of all, a question to be decided by the designer whether hydrojacking is acceptable or not, or whether it is even desired in order to obtain a certain result. It is wrong to believe that hydrojacking or 'claquage' should be avoided under any circumstance.

Accordingly, the critical GIN value has to be defined, or measured, and the design value decided upon in relation with that pre-requisite.

The three parameters of the limiting curve (P_{max}, V_{max} and GIN) must be 'designed' according to the problem to be solved by the planned grouting works. They should not be 'specified', as unfortunately this has occurred too often in the past by simply copying former tender documents without thinking. Certain criteria must be taken into consideration.

The grouting pressure has to be high enough in relation to the expected water pressure at any single point in the future. It is better to hydrojack the rock at the time of grouting, than to have this occurring due to the water pressure, after impounding.

The scope of the volume limits should, first of all, set a mark where thinking should begin. Are high takes due to leaks or to losses towards natural or excavated cavities? Is an excessively extended zone pointlessly grouted? Is there any other reason?

A decision should be taken accordingly. Should the grouting continue? Should it be resumed after the mix has set? Should a new hole be drilled? Or should the grouting be stopped?

The scope of the GIN limit is to avoid hydrojacking events, or at least to limit them to a given amount, according to the design of the grouting works. The scope also helps to achieve a more or less constant 'reach' of the grout independently of the initial aperture of the fissures. There is no need to state in more detail that in the frame of any single project, the set of the three GIN parameters must be defined for any zone which can be considered to be sufficiently homogeneous, from both the geomechanical and the project related engineering points of view.

As already stated, the GIN envelopes proposed by Lombardi and Deere in 1993 (figure 3) are considered to be the first estimates derived from a number of case histories; they are by no means fixed rules. Their three parameters are to be defined case by case by the engineer. This was done, for example, in Project B referred to by Professor Ewert, where the following parameters were selected: P_{max} = 30kg/cm^2, V_{max} = 400l/m and GIN 2000kg/cm^2.l/m. No such envelope is included in figure 3.

Whether this choice was an optimal one or not, can obviously not be decided without more information about the project and rock mass. It has to be considered that the three parameters are, more or less, independent of one another. Additionally, it must be emphasised that the selection of the GIN value is not only a matter of geology and technique, but also one of cost.

The main concern of Professor Ewert appears to be the numerical values of pressure, volume and grouting intensity, as schematically shown in figure 1b. His main remarks regarding the grouting pressures were that it was too high and could, in certain cases, have produced hydrofracturing (although hydrojacking is more likely). He may be right, provided however it was the designer's intention to avoid hydrojacking.This is a fundamental option which has to be decided upon before starting the works. Hydrojacking is governed by the GIN value and it is possible that in some cases an inadequate and too high a GIN value was selected.

A second set of Professor Ewert's remarks refer to the limiting volume which was considered to have been too low. There is no doubt that this parameter must take into account the geomechanical aspects of the rock mass as well as the scope of the project. It can evidently not be excluded that, in some projects, the designer did not consider this aspect in the correct way.

Some examples

Project A, as described by Ewert, is indeed quite 'informative' in that it abandons the flawed idea of 'using constant relationships between grouting pressure and grouting volumes'. GIN offers an opposite view in establishing a reciprocal, not constant, relationship between pressure and volume.

The question is obviously not to 'plot an hyperbolic envelope as postulated' around the results of the takes obtained by any other grouting criteria (or in arbitrarily stopping the procedure at any point), but to impose and respect a hyperbolic limiting curve for all the stages at the time of grouting.

In the case of Project B, a very tight rock was apparently grouted using a high grouting intensity of 2000bar.1/m (according to figure 6 in Professor Ewert's article), thus producing hydrofracturing. Indeed, it would have been better to discover - before rather than after grouting - that no grouting was actually required for this project.

Project C, identified as the Aguamilpa dam in Mexico, shows in figure 4 a number of typical grouting path curves. In fact it shows that the GIN principle was not respected. In paths d, f and g the grouting was stopped before reaching the GIN limit. Why? In paths c, e and h, on the contrary, the GIN curve was significantly exceeded. Again, begging the question, why?

Especially in case e, hydrojacking took place beyond the GIN hyperbola. No hydrofracturing would have occurred if the GIN criteria were enforced and the grouting stopped at the GIN limit. This again is a good example of how hydrofracturing can be avoided by using the GIN principle correctly. Only in cases a and b was the limiting pressure respected, but these stages are in fact two grouting tests with extremely low takes, not effective grouting stages.

The reason for this miss-match between actual grouting paths and limiting curve at this site is due to a problem of communication between the pumping station and the grouting spot. It has nothing to do with the use of the GIN principle.

Project D is a 39m high rockfill dam, apparently founded on weak layered sedimentary rock. If figure 2 is correct (originally figure 10 in Professor Ewert's article), an absurdly high GIN value of 9000 bar 1m was used. Even an inexperienced engineer should have noticed that according to figure 3 this value was beyond any reasonable range.

Conclusions

In a very comprehensive way, Professor Ewert has shown how mistakes can be made by people who claim to understand the GIN principle. It is also rather disappointing that in spite of the title of his paper - (The GIN principle - a helpful method for rock grouting?), no concrete criticism was formulated against the GIN principle, when criticism would have shown how the method can be improved.

Table 1: The generally accepted principles of the GIN method

- Use only a single mix, 'the best possible one', in order to ensure the quality of the results and to simplify the procedures. This will also avoid wasted grout.
- Define the 'best mix' for the project by laboratory tests both from a technical and an economical point of view. Only stable mixes, generally with super plasticiser, should be used[2]. Thick stable mixes have been favoured by European grouting experts for quite some time, but the use of GIN is not restricted to Europe.
- The split-spacing method for the bore holes is also not a new technique, but it is used in the GIN method as a self-adaptive and self-regulating procedure.
- The use of increasing stage lengths, with depth below ground, is also progressively recognised as a way of speeding up grouting and to make some, albeit small, savings.
- To inject water in dry and in absorbing rock formations above the ground water table, shortly before grouting, is now accepted as a way of avoiding a sudden blockage in the grouting process.
- Computer controlled grouting is an obvious pre-requisite for optimal grouting work. That 'in several projects the graphs were plotted without drawing conclusions' is a pity because so many pieces of information can be obtained from these plots.

One must agree with Professor Ewert's main conclusion that the grouting parameters must be carefully selected in accordance with the rock mechanic characteristics of the site. Additionally, when selected, these parameters must be strictly enforced. Unfortunately, in a number of cases, they appear to have been randomly selected, without any thought to the scope of the project, nor to the geological conditions, and implemented in a very approximate manner. However, taking into account the geological aspects of the problem it is obviously not a sufficient reason to ignore the rheological ones.

Indeed, in more than just the few cases mentioned by Professor Ewert, the correct use of the GIN method has led to excellent results and they should be published from time to time. The mistakes presented by Professor Ewert confirm however the soundness of the GIN principle, as well as the incorrect ways in which it can be used. Professor Ewert must be thanked for the clear confirmation he has given to the validity of the GIN principle.

References

*1) F.K. Ewert. **The Gin principle - a helpful method for rock grouting?** Part 1 and 2. International Water Power & Dam Construction, February and April 1996. pp17-19 and pp36-40.*

*2) R. Bremen. **Use of additives in cement grouts.** The International Journal on Hydropower & Dams. Vol. four, issue one 1997. pp71-76.*

*3) G. Lombardi. **The role of cohesion in cement grouting of rock.** CIGB, 15th Congress of Large Dams, Lausanne, 1985. Q.58 R13. pp235-261.*

*4) G. Lombardi and D. Deere. **Grouting design and control using the GIN principle.** International Water Power & Dam Construction, June 1993. pp15-22.*

*5) L.Turcotte, B. Savard, G. Lombardi and H. Jobin. **The use of stable grout and GIN technique in grouting for dam rehabilitation.** Annual Meeting of the Canadian Dam Safety Conference CDSA and CANCOLD, Winnipeg, Manitoba. October 1994. pp137-161.*

*6) G. Lombardi. **Selecting the grouting intensity.** The International Journal on Hydropower & Dams. Volume three, issue four 1996. pp62-66.*