COVER GROUTING : A RATIONAL APPROACH

W.F. Heinz
RODIO - ROSOND. West Road. Midrand
email: RODIO1@INFODOOR.CO.ZA *fax*: +27 11 3101342

ABSTRACT

Cover grouting and drilling is the term used in South Africa for creating an umbrella, "shield" or tunnel by means of drilling and grouting ahead of any excavation in order to mine, develop or sink under or through the rock formation in safety.

Cover grouting and drilling is done as a matter of routine in the mining industry in South Africa, varying only in the intensity of the treatment depending on in situ conditions such as quality of rock, permeability etc.

"Grouting is more an art than an engineering science". This statement may be true but in essence it has always been an admission of our lack of understanding of the success of grouting. In recent years cement and chemical grouting have developed a new dynamism driven by a better understanding of the grouting process, by an improved understanding of the behaviour of grouting materials, by the development of new grouting materials (micro fine cements) and techniques (jet grouting) and, of course, by many new good publications (books and articles) on the subject. Other factors such as environmental concerns and computers have also contributed to this new dynamism in the grouting field.

Most of these developments have been initiated in the civil engineering field such as dam grouting, tunnelling, etc.; grouting in underground mining conditions is conspicuously absent in research, development and literature. This paper endeavours to show a more rational approach in grouting particularly for mining conditions, keeping in mind recent developments in grouting engineering and possible developments in future.

INTRODUCTION

In recent years the field of grouting engineering has entered a new era. A new dynamism has evolved driven by new techniques, new materials, new research, etc. Other factors such as environmental issues and computerization, are also contributing significantly to this new forward development of grouting engineering.

This paper highlights some of these fields and shows their significance in future developments. The increasing scarcity of good formations (foundations, underground conditions, etc.) is a given fact, therefore, new techniques and new materials are required to face these exciting, new challenges.

The necessity of utilizing available but less suitable sites will also require improved soil and rock investigation techniques. The characterization and categorization of individual sites with respect to grouting engineering still leaves much to be desired hence for grouting projects the standard site investigation requirements should be extended by grouting tests in order to optimize solutions for the given conditions and available materials and techniques.

Some ideas presented in this paper are not new, some processes have already been evaluated and "passed", others require acceptance - some ideas are speculative.

Grouting engineering as applied in civil engineering is well documented, therefore, in this paper we elaborate on grouting techniques relating mainly to the mining industry.

HISTORY

The history of grouting is summarized below for the period between 1800 and 1950. This very short list does not do justice to some extraordinary results achieved in the 19th and early 20th centuries by many outstanding engineers. No information and data were available during these periods; most practitioners had to start from the beginning and rely on their own tests and experience. This enterprising and pioneering spirit is still present today, indeed necessary in grouting engineering, despite the wealth of information and data available now.

1802	C. Berigny. Repair of sluice foundation at Dieppe by injecting grout of clay and hydraulic lime.
1802 to 1850	Many repairs of foundations by grouting in France based on C. Berigny's method.
1850 to 1900	Many grouting applications in Europe e.g. Shaft Rheinpreuszen 1864, Hawksley 1876
1911	A. Francois, first application of high pressures in rock grouting under mining conditions. Successfully grouted many shafts in Europe and South Africa.
1926	H. Joosten, injection of chemical solutions.
1930 to 1950	Great era of dam building in Central Europe in particular in Switzerland, Italy, France and Spain..
1953	H. Jähde. Injektionen zur Verbesserung von Baugrund und Bauwerk.

I have listed the above pre 1960 milestones which mirror grouting development before 1960. The following years can be divided into two periods. From 1960 to 1980 very few but nevertheless important publications appeared. The most important being the Proceedings of the Symposium in London in 1963 and Cambefort's book on grouting "Injection des Sols"; both are excellent publications and are, in fact, milestones in the field of grouting. After 1980 a multitude of excellent publications on grouting has become available. Indeed now we have grouting knowledge readily available in the literature for the eager student of this exciting field.

There is still a conspicuous lack of information and data in the mining grouting field. A wealth of information exists in the oilfield literature. As can be expected oilfield technology has contributed significantly in the field of rotary drilling, hydrofracturing and high pressure grouting at great depth and in many other disciplines.

CURRENT GROUTING PHILOSOPHY

As an introduction, it is necessary to include some reflections on the current philosophy of grouting, "The-State-of-the-Art" as it were. The easiest and most interesting way of doing this is to look at the various parameters which are important in grouting engineering and reflect on today's typical thinking and approach.

Grouting Pressures. In near surface grouting the tendency today is to aim for higher pressures, typically around 0,5 bar per m depth in reasonable conditions, which is approximately halfway between Houlsby's 1lb/square inch per foot depth and 1 bar per m depth.

In mining conditions, say at a depth of 2000m with water pressures of 10MPa, 15MPa might be a reasonable grouting pressure. Pressure is relative to the strength of the formation and the overburden pressure, nevertheless the tendency is to use higher pressures, with better control, where possible, real time control of the pressure with upper limits approximately 20 to 30% below hydro fracturing pressure.

Thick or thin Slurries: (Stable or unstable slurries, W:C Ratio). Current grouting philosophy requires thicker rather than thinner grouts or more correctly stable grouts rather than unstable grouts.

The ideal grout should behave like water and have negligible viscosity and yield stress during the dynamic phase i.e. during penetration; only thin grouts behave in this way; however, grout requires an instant strength once it has reached its final position and is required to perform its task. The final in situ quality of 'thin" grouts as well as the danger of hydrofracturing at higher pressures during grouting are the most important concerns regarding thin grouts.

Thick grouts choke fissures. Therefore, the tendency today is to use grouts as thick as possible (not to choke fissures) to ensure stability of the slurry and attempt to reduce the flow parameters such as viscosity and yield stress by adding superplastisizers.

The most important limiting factor of "thick" grout is penetration. Where, for economical reasons, penetration of many metres is essential, grouts should be as thin as empirical tests will justify. However, much thinner ratios than W:C 4:1 are not justified, particularly as rheological parameters do not change significantly for slurries thinner than W:C 2:1 for particulate suspensions.

Hydrofracturing. Except where actually required for testing or for the Soilfrac method, hydrofracturing during normal rock and soil grouting should be avoided. Nevertheless, hydrofracturing pressures are important upper limit parameters which can provide valuable in situ information.

Viscosity. In general terms the viscosity is a measure of the internal friction which causes resistance to flow, hence viscosity determines the time required to reach a certain penetration given a certain pressure and fissure system. For a given configuration, pressure, etc., grout penetration is inversely proportional to grout viscosity. The viscosity of water is 1 centipoise (cP). The viscosity of a thin grout with water/cement ratio of 2:1 is typically less than 5cP. In Marsh funnel time the "viscosity" of the same W:C 2:1 grout is below 30 seconds (water 28 seconds) indicating that little is gained in lowering the viscosity by using much thinner than 2:1 water/cement grouts. Lombardi's [16] preferred mix is approximately 0,7 water/cement ratio which will result in 35 to 40 seconds as measured by the Marsh cone.

As an approximate guideline the characteristics of cementitious grouts with water/cement ratios larger than 2:1 (Relative density 1.29) are governed by the liquid phase i.e.water, whereas grouts with water/cement ratios of less than 1:2 (Relative Density 1.83) will start reacting like cement "mortars".

Viscosity is a function of:

a) the concentration of solids;

b) the size and shape of the solid particles;

c) the viscosity of the liquid phase.

It is important to note that viscosity increases with increasing solid content or, for constant solid content, with increasing number of solid particles (fine particles) that is with increasing specific surface (Blaine value). Therefore, the most effective way to lower viscosity is by reducing the solid content i.e. using thinner grouts.

Yield Stress. (Cohesion). The simplest model defining rheological behaviour of particulate cementitious suspensions is the Bingham model which is a two parameter model consisting of a viscosity and a yield stress. The yield stress influences the maximum penetration. It is important to differentiate between static and dynamic yield stress.

The magnitude of the yield stress depends on:

a) the type of solids and their surface charges;

b) the amounts of the solids present (interparticle distance);

c) the ion concentration in the liquid phase.

The static yield stress is the "gel strength" at zero shear rate, as the internal structure of the suspension breaks down at higher shear rates, the yield stress decreases to reach the dynamic yield stress. Both values are important in grouting practice.

Superplasticizers are very effective in reducing the yield stress and hence improve the penetrability of cementitious grouts. As a general rule the yield stress is more readily affected by chemical treatments than e.g. viscosity. Fine grained materials such as micro fine cement grouts exhibit higher yield stresses than normal cements for similar densities; therefore, superplasticizers such as sulphonated naphthalene formaldehyde are almost always required when grouting with fine cements, silica fume or similar materials.

Bleed/Sedimentation velocity. Bleeding, sedimentation and segregation are the symptoms of one and the same phenomena of particulate suspensions. As the particles settle the "upper" part of the grout body gets "thinner" and the lower part "thicker". The driving force behind sedimentation is gravity. Without gravity or with forces in other directions larger than gravity, sedimentation and bleeding can be prevented or at least delayed. Most laboratory tests, such as the sedimentation cylinder, are flawed in that they only give bleed results for slurries under static conditions i.e. where only gravity acts and the velocity of the suspending phase is negligible. However, most applications take place in the dynamic phase resulting in forced bleeding or forced sedimentation. Hence these tests have little relevance with respect to in situ phenomena.

Typically a grout slurry is regarded as stable if the bleed under static conditions is less than 3-5%, however these grouts cannot be expected to be stable under dynamic conditions.

Sedimentation velocity is the speed with which sedimentation takes place and is probably a better criterium for assessing the stability of a slurry than the total bleed percentage frequently used.

Bleed and sedimentation is influenced by the size and shape of the particles, the density of the particles, the motion of the suspending phase, the density of the suspending phase, etc. Hence the fineness of cement as indicated by the Blaine value influences bleed, sedimentation and sedimentation velocity.

Specific Surface/Grain Size. Specific surface or Blaine Value is the surface area per unit mass and indicates the fineness to which cements are typically ground. OPC has typically 3500cm²/g, rapid hardening cement 4500cm²/g and micro fine cement has between 10 000 and 16 000cm²/g. The fineness of cement as expressed by the Blaine Value is an important determining factor of the behaviour of cementitious grouts. Sedimentation velocity, viscosity and yield stress are dependent on W:C ratio as well as fineness of cement. As an approximate guideline the following ranges for cements with specific Blaine Values have been recommended [15]:

5700cm²/g	W:C = 0,8 - 2,0
3000cm²/g	W:C = 0,5 - 1,0

Bentonite. Bentonite is a Na-montmorillonite with thixotropic properties; therefore, bentonite exhibits low viscosity and yield stress at high shear rates but develops high yield stresses (cohesion) at low or zero shear rate. Bentonite is most effective in relatively thin grouts. Bentonite does not improve lubrication as is often erroneously assumed; on the contrary, bentonite due to the formation of large flocs and the effect of electrostatic forces on the small particles (less than 5 microns) actually increases yield stress (cohesion) [2]. However, bentonite does reduce significantly the sedimentation velocity which allows certain fissure sizes to be pumped at lower pressures. Bentonite is usually added in small quantities, typically less than 3%.

Water Pressure Tests (WPT). The water pressure test which is most often specified is the Lugeon test whereby water is pumped into a borehole at 1MPa and the quantity is measured in litres/m/min. to give Lugeon (L) values. If one critically analyses the evaluation and interpretation of the test one will conclude that some aspects of the test are doubtful or completely wrong. For example, if the test cannot be carried out at 1MPa the pressure is reduced to say 0,5MPa and the Lugeon value is then calculated by multiplying the result by 2. This may result in misrepresenting the actual permeability data.

As a parameter to determine the effectiveness of grouting in a before and after study, the typical WPT is still very useful, although the test cannot differentiate between a rock with many fine fissures or a rock with one large fissure giving the same Lugeon value. The individual groutability of these rocks will be quite different.

Mixing. The effect of mixing of cement on the quality of grout has been studied extensively. Today in most projects high speed shear mixing is typically specified, although slow speed paddle mixers can be quite efficient. For relatively thin grouts consisting of OPC, paddle mixers may be adequate, however, for denser slurries and finer cements high speed shear mixers are essential.

Static and Dynamic Phase Grouting [13]. It is important to realise that "stable" grouts in amount are really grouts stable under gravitational forces only. Therefore, stable means either sedimentation is so slow that it is almost negligible or thixotropic action, hydration or other reactions and possible forces prevent sedimentation.
It is helpful, indeed necessary, to distinguish between

STATIC PHASE grouting and

DYNAMIC PHASE grouting of particulate suspensions.

The ideal STATIC PHASE is the measuring cylinder where sedimentation is predominantly influenced by:

particle interference, gravity, very low particle velocity, stationary continuous phase.

Hence low pressure, low velocity grouting (permeation grouting) is so similar to the "ideal" static phase that it can be categorised as static phase grouting; in fact, plug flow or low velocity laminar flow would fall into this category.

In contrast, in the DYNAMIC PHASE of cement grouting the sedimentation process is predominantly regulated by:

High velocity resulting from high pressures, forces which change the resultant force on the particles in contrast to gravity only, different velocities between the suspended particles and suspending phase, selective and forced sedimentation sometimes also referred to as pressure filtration.

Both phases require control and manipulation. It is incorrect to assume as is often done that if the static phase is "stable" the dynamic phase is also "stable". Stable in the dynamic phase requires the properties of the grout to remain essentially similar before and after moving through the rock mass.

POTENTIAL FUTURE FIELDS OF DEVELOPMENT

Future developments in grouting engineering will be significant in the following five fields:

1. Ground (Rock) Formations.
2. Grouting Materials
3. Grouting Techniques
4. Environment
5. Research and Development

1. Ground (Rock) Formations

a)Good, "easy" sites are getting scarce. This is true for civil as well as mining sites.

It has generally been accepted that good easy sites for dams, underground constructions, storage of waste products, etc., are getting scarce.

There are two main reasons:

Firstly on purely technical grounds most good sites have been used and secondly, marginal sites that are left are scrutinized more severely with respect to environmental issues. This scarcity will require innovative new foundation and grouting techniques.

Similarly in the mining field in South Africa and elsewhere, the "easy", shallow, "no problem" mines have practically been mined out. What remains are the deep mines, mines with more difficult and intricate rock formations (Buffelsfontein GM) and "watery" mines (Oryx GM); some operate under high water pressures (15 MPa) and large water inflows.

b) Underground construction increases (Urbanization)

"The pull to the cities continues unabated".

Urbanization is increasing and certain needs for transportation, waste storage, etc., require underground construction. Cities such as Johannesburg encroaching on mined-out areas or the extension of the London transportation system, the Sydney harbour tunnels are all results of these developments. High buildings in less suitable areas, all necessitate new innovative foundations and new grouting techniques.

2. Grouting Materials

a) New cementitious and pozzolanic grouting materials.

Cement is available today in a wide range of fineness from OPC with a Blaine value of 3500 cm²/g to micro fine cements with Blaine values up to 16000cm²/g. If these new micro fine cements are blended with pozzolanic pulverised fuel ash (PFA) very interesting grouting materials are created. These cement/PFA grout slurries have improved workability, pumpability, strength and durability at reduced cost. Effective superplasticizers are essential in the effective application of these micro fine materials. As cement and fly ash are environmentally friendly, micro fine materials have expanded the application of cement into what was formerly the chemical solution range of applications.

b) New chemical, environmentally friendly grouting materials have become available. Today many single component and two component epoxy resins and other chemical solutions are available which can be custom-made for many applications. Especially to stop fast flowing water, chemical products have become an invaluable tool. Non-toxic, fire resistant formulations are now readily available.

3. Grouting Techniques

a) **Improved Understanding of the Grouting Process.**

As stated earlier we now have information which is readily available and includes information and data on grouting techniques successfully applied world-wide such as Lombardi's approach in his Grout Index Number method (GIN method) [16], a better understanding of forced sedimentation in high pressure grouting, the differences between static and dynamic phase grouting [13]. Recent advances in compensation grouting are made possible by a better understanding of the grouting process, more scientific design of grouting materials (economical custom made materials) driven by difficult foundation conditions compounded by congested urban conditions underground as well as on surface. New grouting methods utilizing hydrofracturing have resulted in a better understanding of high pressure grouting processes.

b) **Real Time Control of Grouting Parameters such as Pressure, Volume, Viscosity and Yield Stress.**

Real time control of grouting parameters serves several purposes. Under near surface conditions the objective is primarily to protect important or delicate, valuable buildings and safety in general. Safety considerations are important for the geotechnical process and for the consequences on surface e.g. in the case of tunnelling. For example, where tunnelling takes place close to critical foundations, real time monitoring is a necessity. Similarly lateral support systems in urban areas require close monitoring. The success of the NATM has relied for a considerable time already on extensive monitoring and control.

In the case of Lombardi's GIN method, real time monitoring is required to avoid hydrofracturing of the ground and to achieve optimal grouting results.
For "on-line" control of rheological grouting parameters (viscosity, yield stress) real time monitoring may become routine.

c) **Techniques used for high water pressures.**

As stated earlier with "easy", shallow mines disappearing rapidly, mines with more difficult conditions such as high water pressure and large water inflows will have to be addressed.

Due to the specific situation in South African deep mines, contractors had to cope with those conditions for may years and have developed simple and rugged machines and techniques for this purpose. The attached photos and drawings show a simple high pressure drilling system which has been used routinely up to water pressures of 16 MPa. Air driven screw feed and/or hydraulic machines have been used effectively. Photos 1 to 3 and Drawing 1, show the specific safety configuration utilised effectively for high pressure drilling in the deep mines of South Africa.

4. Environment
Environmental awareness has increased, environmental regulations are becoming more stringent. Probably the two most important fields or disciplines with the potential to effect profound changes in the future are the information revolution and the environmental awareness.
Fortunately cement grouting has always received a clean certificate with respect to its friendliness to the environment, even more so in its hydrated state. Micro fine cements have widened the scope of application of cement. An entire industry has been created around the application of these cements. The use of these micro fine materials has also highlighted the need to know more about rheological parameters in order to control these parameters for better results.

5. Research and Development
Research on Grouts and the effect of Additives.
The most interesting and far reaching research on cement pastes and grout slurries is being carried out at NorthWestern University in the U.S.A. under the guidance of Prof. R.J. Krizek. At the base of this research is a new type of scanning electron microscope with the capability of taking photos in the liquid state. Interesting observations are now possible of the first phases of hydration; observations of phenomena during the first hour after mixing a cement slurry can provide important insights into the characteristics of the slurry. The effect of additives can be studied at levels formerly only possible with the conventional electron scanning microscope in the solid state.
The research has already given new impetus to the development of improved concrete, cement pastes and grout slurries.

COVER GROUTING: *A RATIONAL APPROACH*

Combining current grouting philosophy as described earlier and experience from high pressure grouting under South African mining conditions is the objective of the subsequent section of this paper. This cross-fertilization will widen the scope of application of these current techniques as used in the South African mines.

In an effort to improve the cover grouting techniques currently applied in various mines, a new more systematic and rational approach is necessary. This is true for normal minimal cover grouting as well as cover grouting under high water pressure conditions.

It is the primary objective of this new rational approach to describe a technique that will enable a mine and a contractor to adapt the grouting and drilling techniques to the specific conditions prevailing on the mine making use of the State-of-the-Art grouting philosophy, thereby reducing the time spent on the cover grouting activities and to eventually increase the advance of the mining operations within acceptable safety parameters.

The objective of cover grouting is related to safety; nevertheless, the primary objective of this new approach is to minimize the disrupting effect of cover grouting under normal operations of the mine. In order to maximize the advance, it is essential that the cover grouting procedures and the materials used, be tailor-made to the specific conditions existing on the mine.

In essence cover drilling and grouting procedures depend on:

1. The type of rock formation (strength, fissure characteristics, drillability, groutability etc.)
2. The existing water regime (water table, pressure, direction and volume of flow).
3. The fissure and water regime dynamics (the fissure behaviour as a function of time as induced by the mining operation).
4. The specific mining method.
5. The cover grouting technique:
   a) The type of drilling (percussion and/or diamond drilling)
   b) The grouting technique (equipment, grouting pattern, pressure)
   c) The grouting material used.

In general, in previous years, cover grouting techniques have been reasonably successful, although cement slurries were injected rather indiscriminately. The basic grouting techniques originated from earlier periods of mining where grades were higher, labour costs lower and material costs, such as cement, also lower.

As cover grouting is always an additional cost to mining, it has now become imperative that these costs be minimized without sacrificing safety, yet allowing maximum speed of advance. Even under conditions where cover grouting activities are not on the critical path of the main stream mining activity, cover grouting activities are probably on a sub-critical path in most mines. Where cover grouting is executed simultaneously with development, it may disrupt the mining activities.

As stated earlier, the following steps indicate a systematic and rational approach to designing and implementing a tailor-made grout cover technique which, if properly executed, should result in an optimal, economical result and most importantly an increased speed of advance at acceptable safety standards and acceptable water inflows.

STEP 1 - *Drilling Productivity Curve*

Determine the productivity curve for the diamond or percussion drilling configuration used on the mine. This curve depends on the type of drilling system (machine, power available, bit type, etc.) used on the mine and the type of rock formation predominant on the mine.
The relationship must be expressed in two types of curves:

1. Metres/shift or m/hour for several depths, possible curves are shown in Figure 1(a).
   Curve (2) is the shape sought and shows an example of the maximum depth of drilling for economical results. Curves (1) and (3) are undesirable.
2. Total time required to drill to a certain depth (Figure 1(b)). Curve (1) is the more desirable result.

On the basis of these curves (for core and percussion drilling) an optimal drilling cover pattern can be designed. In general, percussion drilling is faster and hence less expensive and typically deflects more than diamond core drilling; diamond core drilling is safer and preferable for high water pressures but slower and hence more expensive. Diamond core drilling gives vital information required for grouting technique design such as fissure size, direction, etc. In some cases a combination of both types of drilling may be indicated. For operations in mines with high water pressure, safety configurations, as shown in Photos 1 to 3 have been used effectively.

STEP II - ***Determine Water Intersection Pattern***

Determine and analyse the characteristics of the water intersections. Volume of flow and pressure at water intersections should be measured routinely.

A frequency histogram showing water intersections should be compiled as shown in Figure 2.

Pressure and volume must be monitored at each water intersection. This will furnish the mine specific type of intersection pattern. It may vary with different areas of the mine. The histogram should give an indication of the fissure size and thus provides data input for the hydrogeological model. The underlying assumption here is that certain fissure patterns are characteristical for certain areas of the mine.

STEP III- ***Grouting Effectiveness Curve***

The total time taken to achieve the required sealing is vital to the effectiveness of the grouting exercise.

The time required for effective sealing is essentially a function of:
1. Sealing pressure specified;
2. Characteristics of fissures (number, size, extent, width);
3. Type of grouting material used (stable, unstable, fine or coarse grained, solutions or suspensions, high or low strength);
4. Type of grouting equipment (mixers and pumps);
5. Technique of grouting (pattern, etc.)

The grouting effectiveness curve envelope is shown in Figure 3(a). The total time required for each borehole cover must also be shown as a function of the sealing pressure. The underlying assumption here is that higher sealing pressures will result in a longer grouting time required to achieve this pressure. Fig. 3(b).
Post cementation may be required where fissures open again after development has been completed. Therefore, determine effect of blasting on fissure development and zone of influence. (Fissure dynamics).

STEP IV - ***Matching Water Intersection with Grouting Procedures***

Matching of the type of water intersection with the time required for drilling and grouting is an important result. If maximum benefit is to be achieved it is vital that the grouting procedures are adapted to the in situ conditions. If the choice of grouting material, pressure, typical procedure, etc., are well adapted to the characteristics found at the mine an optimal result must evolve.
Figure 4 indicates how this could be done. The relative time between grouting and drilling is an important parameter that requires analysis.
The underlying assumption here is that certain types of fissures result in a specific water inflow e.g. many fine fissures will require a different approach than one wide fissure. In the worst case these two extreme examples may give the same water flow but they would require different grouting procedures and different grouting materials.
A fissure survey should be done after blasting. Where does one get a chance to virtually walk down

a "borehole" and inspect and measure grouted fissures? The fissure survey should attempt to show: width of fissures grouted, frequency of fissures and quality of cement in fissures.

STEP V - *Water Inflow Related to Sealing Pressure*

Match sealing pressure specified and sensitivity to change of sealing pressure with inflow of water (volume).
The underlying assumption here is that higher final sealing pressures may reduce the water inflow into the mine. Therefore, it is very important to monitor water inflow at several critically important positions within the area underground to obtain factual results and to indicate changes when procedures are improved. Figure 5 indicates a possible presentation of these results.

STEP VI - *Fissure Characteristics*

Cover grouting time must be reduced to a minimum in order to achieve minimum interference with mining operations and maximum speed of advance.

The following aspects require attention to achieve a reduction in grouting cover time. Figure 6 aims at showing the fissure characteristics typically found on the mine:

a) More advance information (precementation approach) if area can be made available outside normal mining activity i.e. not on critical path.
b) Grouting adapted to fissures (require characteristics), PV method.
c) Lower ultimate sealing pressures.
   Adapt pressure to water pressure in mine and in situ rock strength.
   Find answer to question: How much water is acceptable to mine?
d) Adapting material that is grouted to fissure size, etc.

STEP VII - *Speed of Advance as a Function of Cover Time*

Ultimately the most important curve giving grout cover time against advance in metres per month must be determined and should be the result of the systematic rational approach to cover drilling and grouting as described above. (Figure 7).

We believe that even relatively "raw" and inaccurate data should already give reasonable indications of certain trends.

The above approach attempts to rationalize cover grouting techniques on the basis of current grouting technology and new techniques currently used in civil engineering grouting practice.

CONCLUSION

In this paper we have attempted to summarize the status quo on grouting technology. At the same time we have highlighted potential fields within grouting technology that we believe will develop significantly in the future.

Finally we have described a rational approach to cover grouting and drilling which we believe can improve grouting engineering application by utilizing State-of-the-Art grouting technology.

We have also shown special safety configurations as used in deep mines that operate at high water pressures.

To make the paper pertinent in the context of the present mining situation in South Africa and elsewhere we have concentrated on processes relevant to the mining industry.

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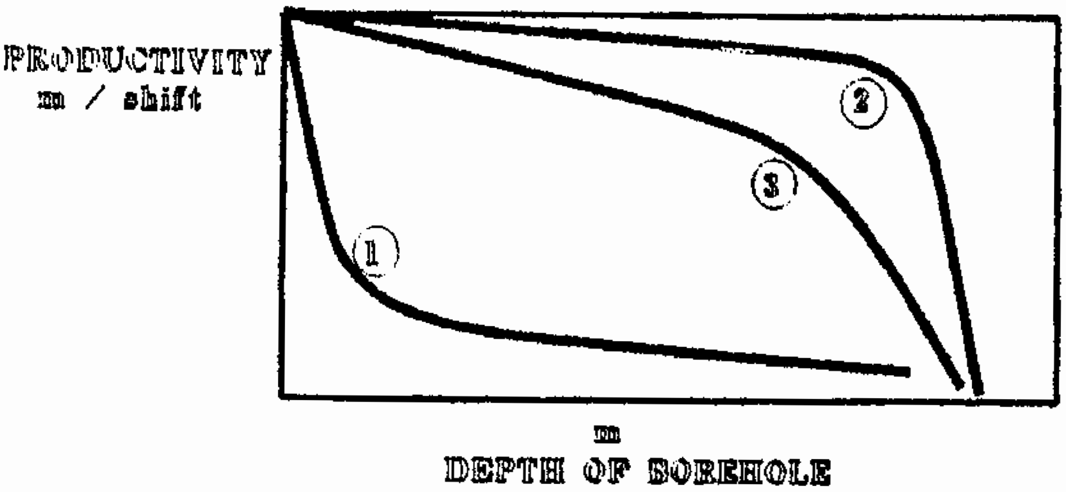


FIGURE – 1(a) : Productivity of drilling equipment.

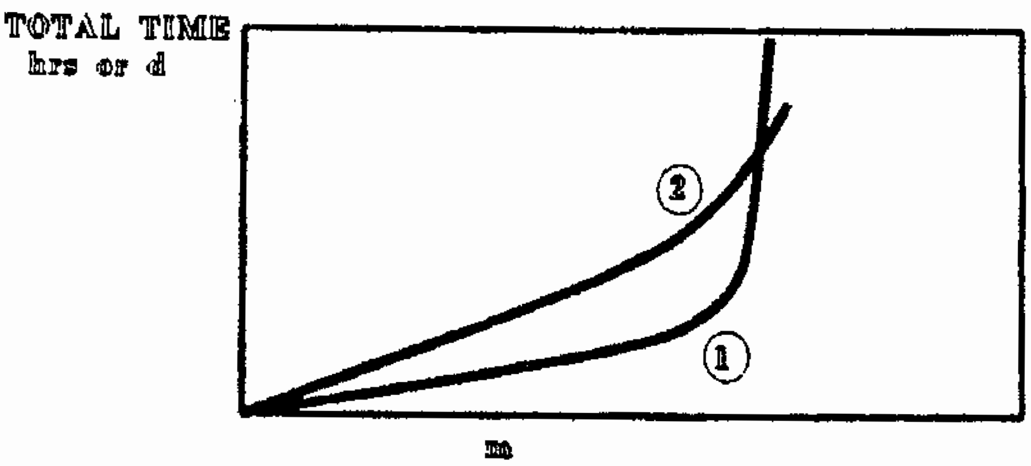


FIGURE – 1(b) : Total meterage of grout cover (per cover).

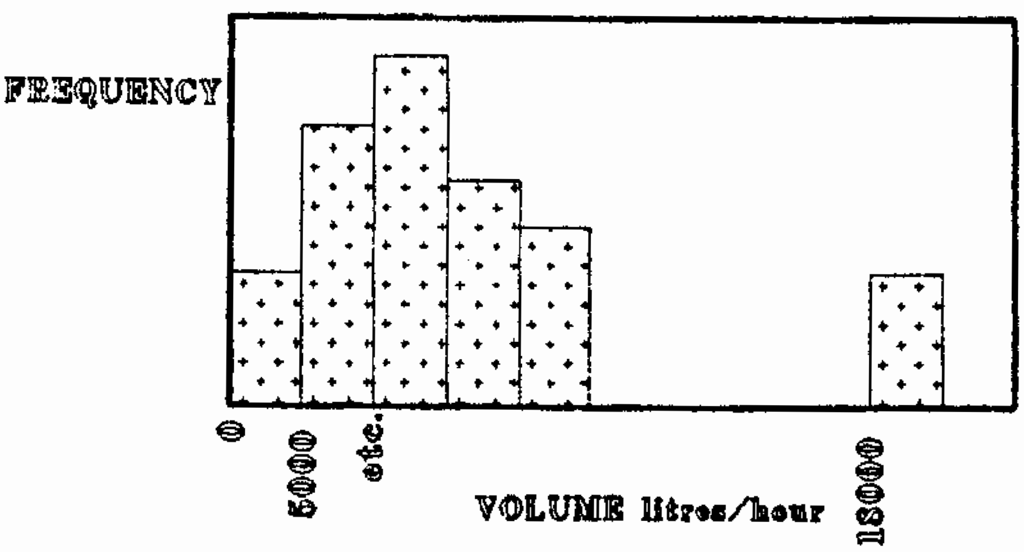


FIGURE – 2 : Frequency histogram of typical water intersections.

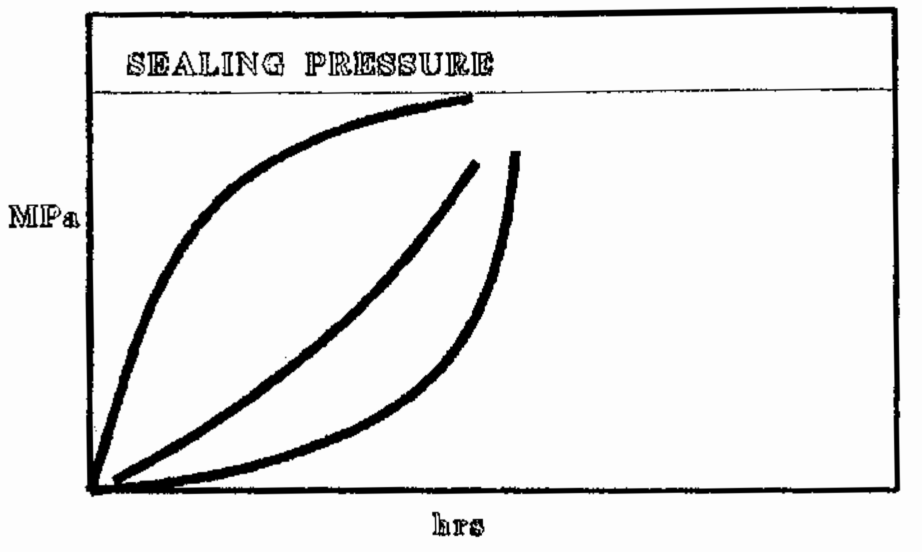


FIGURE -3(a) : Time taken per intersection to reach sealing pressure.

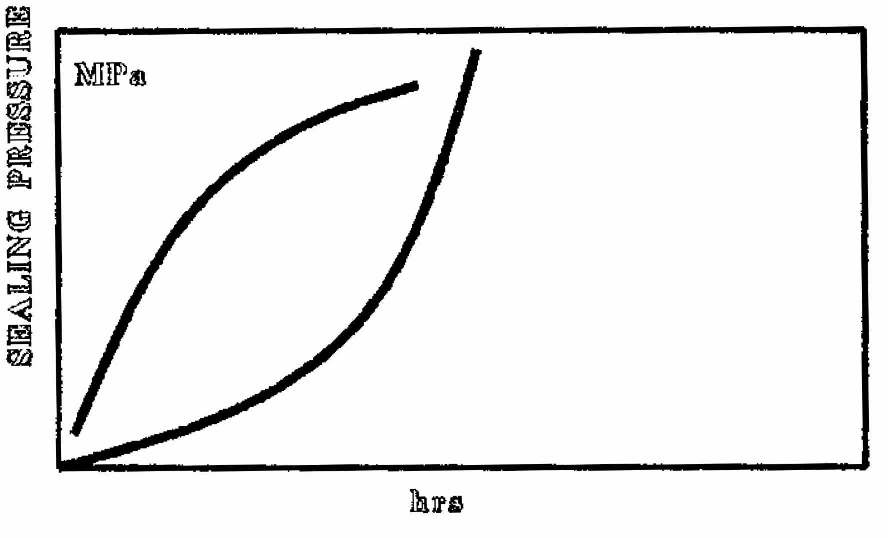


FIGURE -3(b) : Time for all fissures per borehole.

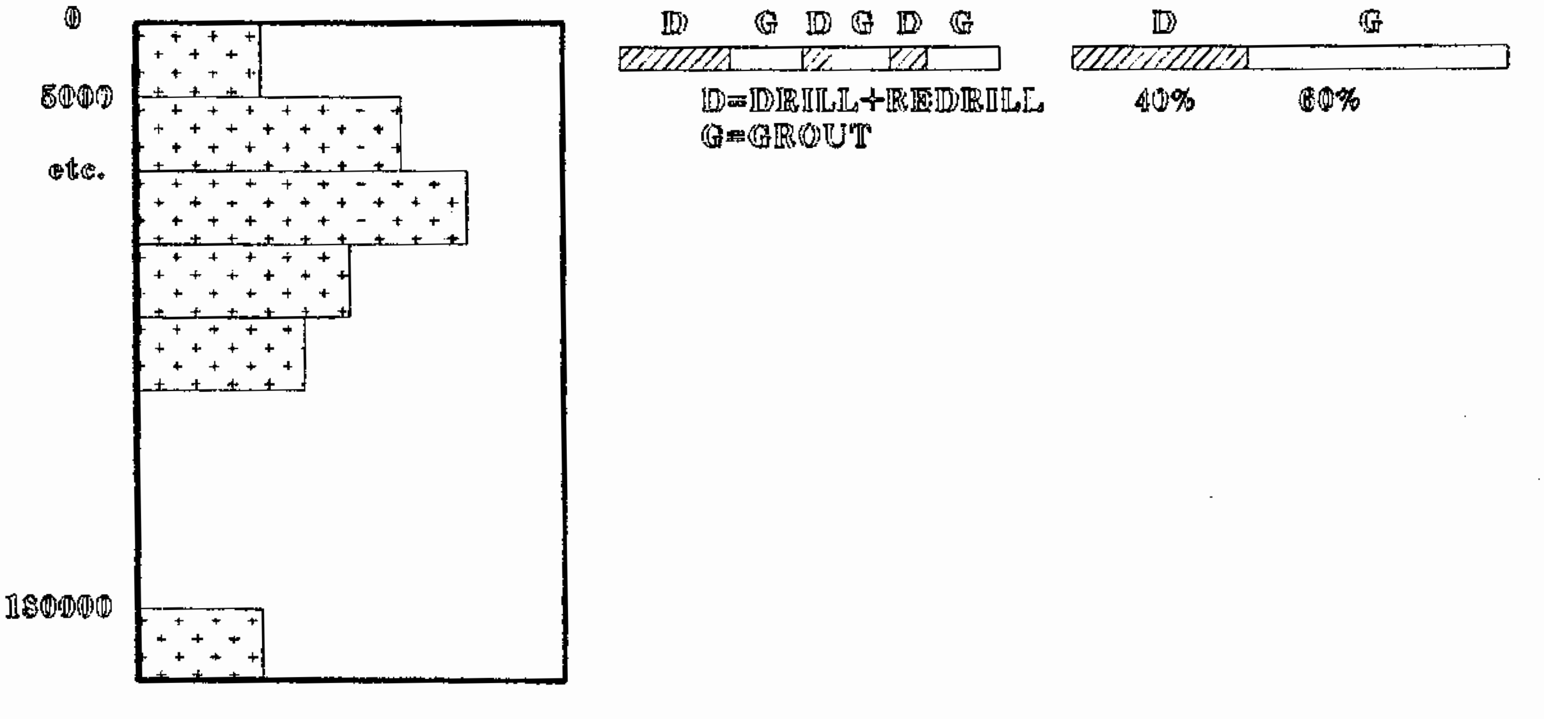


FIGURE - 4 : Matching type of intersection with time taken to drill and grout.

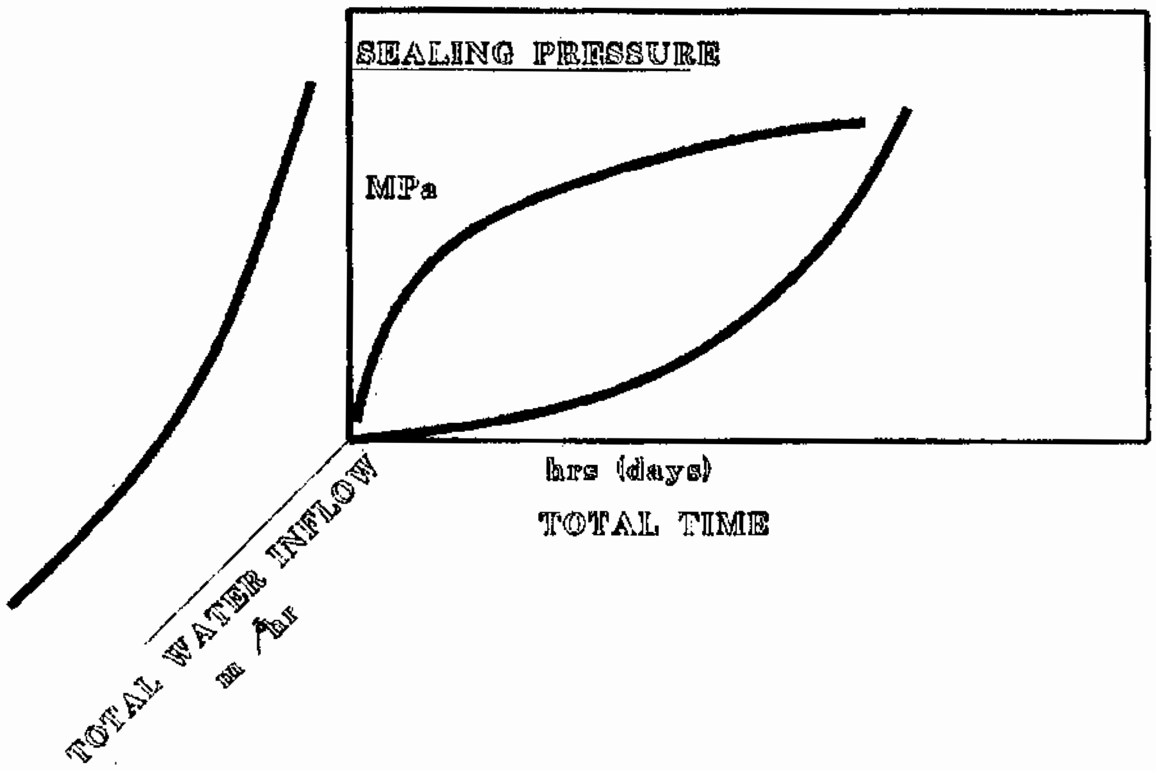


FIGURE – 5 : Total water inflow into mine as a function of sealing pressure typically used on mine.

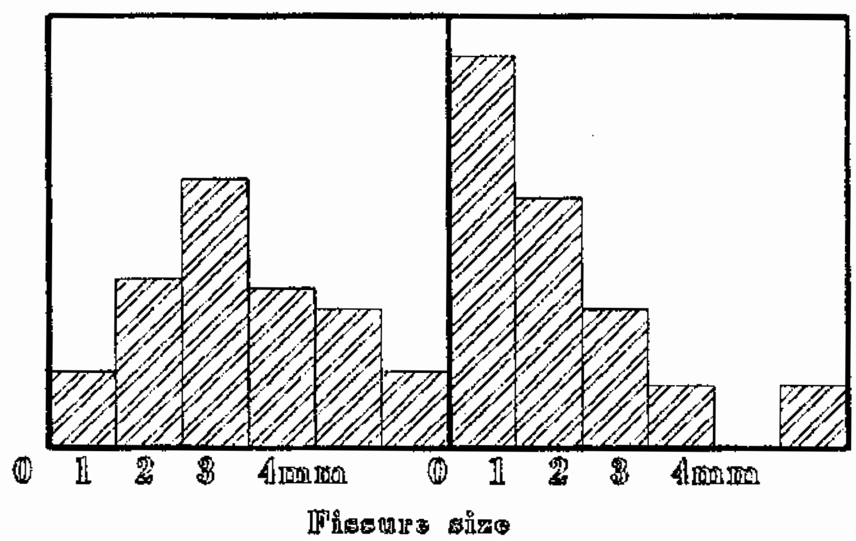


FIGURE – 6 ; Possible fissure sizes and frequencies for typical cover grouting and drilling.

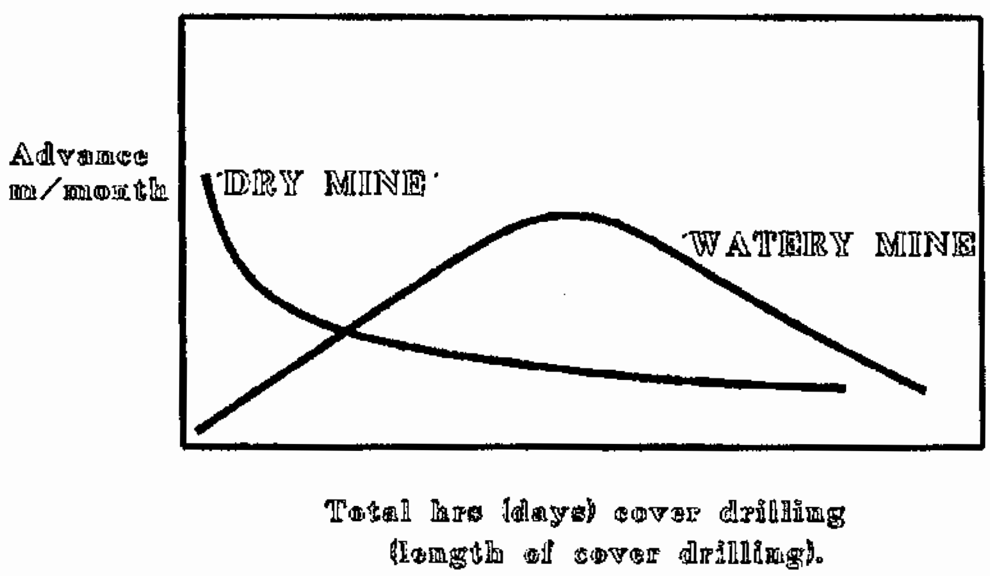
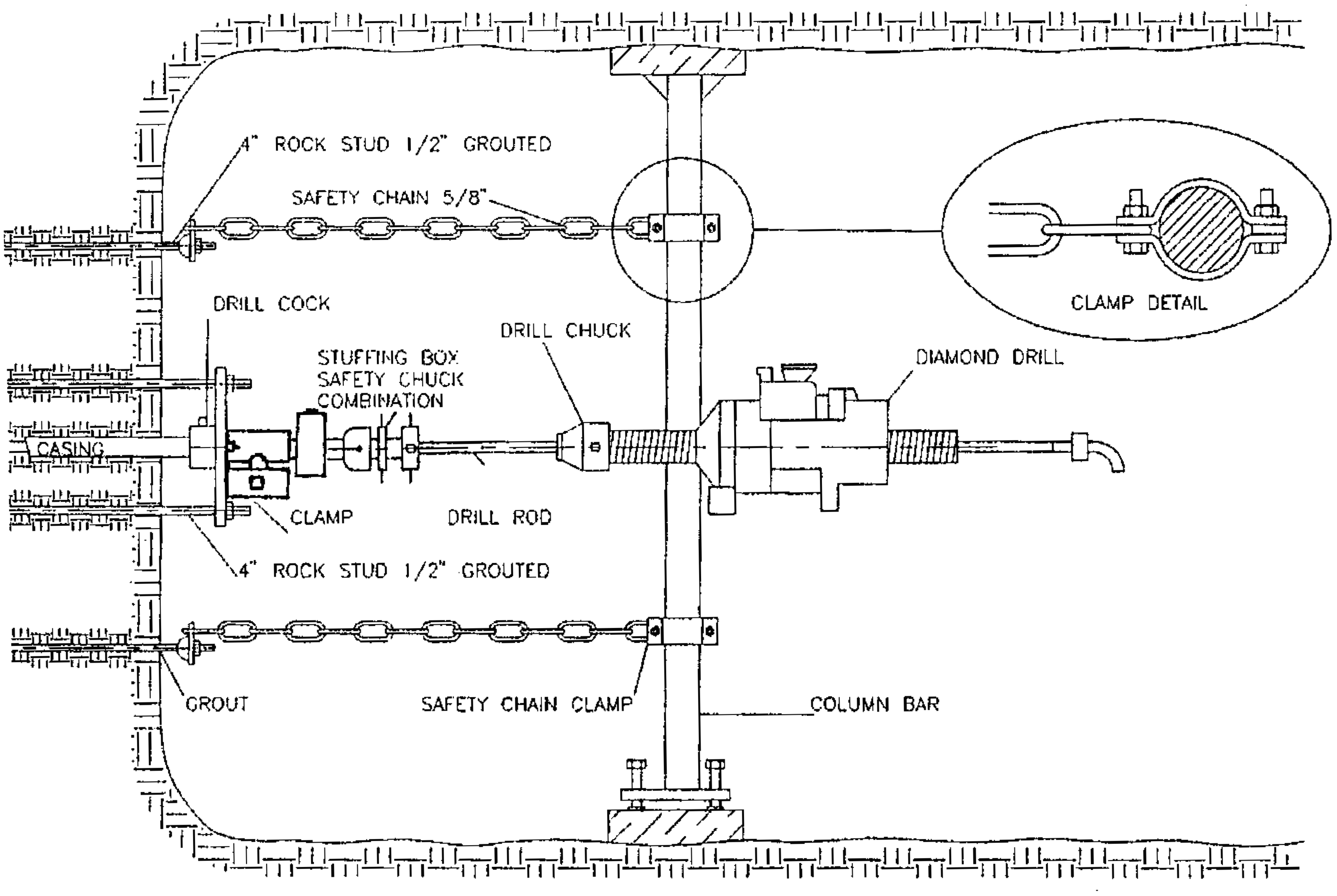


FIGURE – 7 : Mining advance against time spent on cover drilling and grouting.

Photo 1: High Pressure Safety Valves for Drilling Purpose. Side view.



Drawing 1: Shematic presentation showing High Pressure Safety Valves configuration for High Pressure Drilling

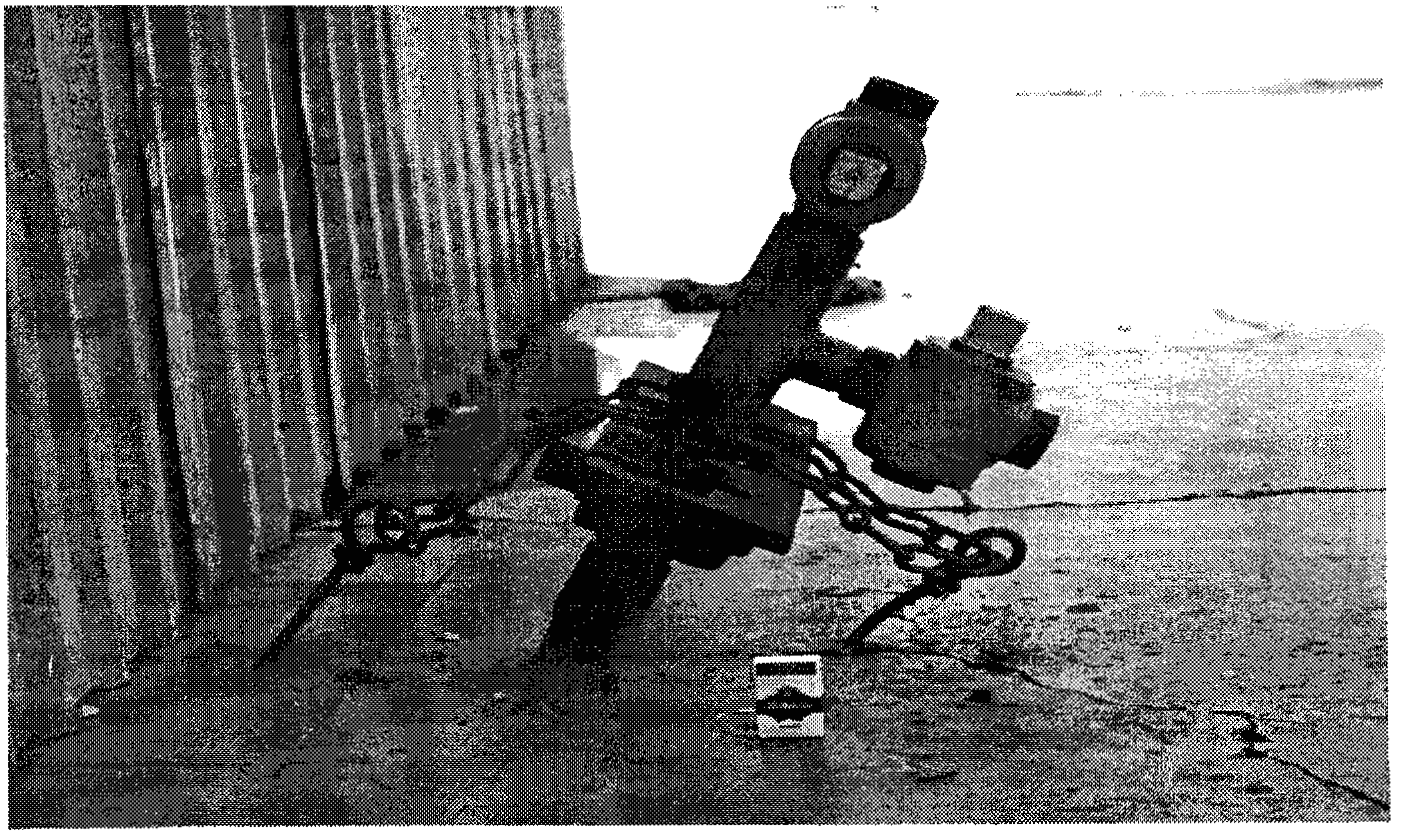


Photo 2 : High Pressure Safety Valves. Side view.

Photo 3: High Pressure Safety Valves. Front view.