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Drilling for Underground Excavation and Support in Sedimentary Rock

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ABSTRACT: It is a well-known fact that the drilling is carried out differently depending on the rock soil conditions. This paper will deal with drilling for blast holes, bolt holes, grout holes and use of support measures like bolting and spiling that are depending on well performed drilling. As there from drilling point of view does not exist a well-defined border between igneous rock and sedimentary rock discussions on the mechanical behaviour of the drilling equipment as well as the response of the rock can be performed in the same way for the two types. This discussion will be held in general terms without any deeper mathematical analysis, and will end up in some general conclusions. A couple of cases on support ahead of the tunnel face will also be given showing the possibility to achieve longer excavation rounds which hopefully will end up in safer cheaper and faster tunnel excavation.

1 DRILLING IN VARIOUS TYPES OF ROCK

1.1 *Drilling technology*

It is well known that there exist two methods of drilling namely percussion drilling and rotary drilling. Rotary drilling is almost 100% used for larger and longer holes in all types of rock and most well known is the oil drilling where the hole-diameters are in the range of 12 to 25 inch (300 to 600 mm). The roller bits are rarely smaller than 3 inches (75 mm) and that means that they are almost never used in under ground construction and mining. In specific mining applications and in some construction in very soft ground so called rotary drag bits are being used. To be able to use the dragbits it İs necessary to ensure that the soft rock does not host any layers or seems of hard rock, as they will most probably stop the dragbit drilling. A good example is mining of salt from the underground. The salt formations normally have a massive character without any intrusions of other rocks.

The percussion drilling is widely used as it can cope with all kinds of rock though less successful with very weak rock like soft sediments. Percussion drilling is however not one of a kind and there is a number of factors to consider when designing percussion drilling tools and few words will be spent on these. The most important parameters to consider are related to the piston, the bit, the rod and the loads that are applied. Concerning the piston it is the mass, the geometry, the frequency of blows and the velocity at which it strikes the rod, for the bit it is the type, the diameter, the rotational speed and the kind of flushing and finally for the rod the geometry and the thrust force. To make this factor operate at an optimum in every situation is very difficult and somebody would say impossible, as rock is very variable. How is the variation in rock relevantly characterised with respect to percussion drilling and also rotary drilling? Two parameters have been found to have a very good capacity to fulfil this target and those are the so-called stamp strength and the brittleness value. These rock parameters are retrieved from the stamp test, which is shown in the figure 1 below. In the test a circular indentor with a defined radius is pressed into a flat surface of the actual rock. At first the rock surface deforms elastically but as the indentor is forced deeper into the rock the tensile stress at the surface exceeds the strength and tensile cracks arises around the indentor and the rock just under the indentor itself is crushed as it has lost its side support. In connection with the collaps of the under and around the mdentor debris of finer and coarser İs scattered around and a crater in the flat rock surface has been created. This indentation resembles very much of what İs happening under the buttons in a bit in the bottom of a bore hole irrespective of it is rotary or percussion drilling and will inform what loads are required to be able to penetrate the rock. There are two more parameters to be extracted from this test that is correlated to the drilling rate and they are the penetration depth corresponding to the maximum fracture force and the volume of the crater.

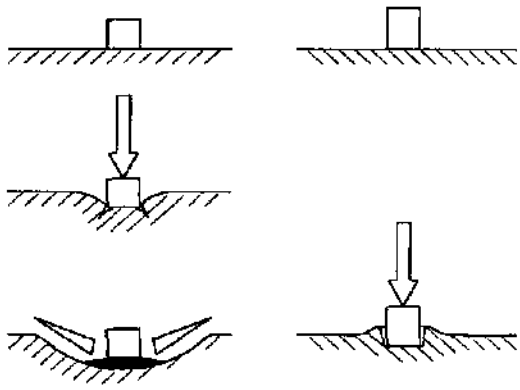


Figure 1. Indentation in brittle (left) and very ductile rock material (right)

Stamp test on brittle rock results in fairly deep and wide craters see figure 1 (left). For a very ductile rock the crater volume is only slightly larger than the indented volume (indentor area times indentation depth). The rock has flowed up around the indentor without fracturing. The material acts almost like a chewing gum that after a bite shows the groves of the teeth. In figure 1 (right) is this schematically demonstrated. Conclusively it can be said that in brittle rock only percussion is required for effective fragmentation in bottom of the borehole why very ductile rock is favoured by both percussion and drag.

2.1 *Sedimentary rock versus igneous*

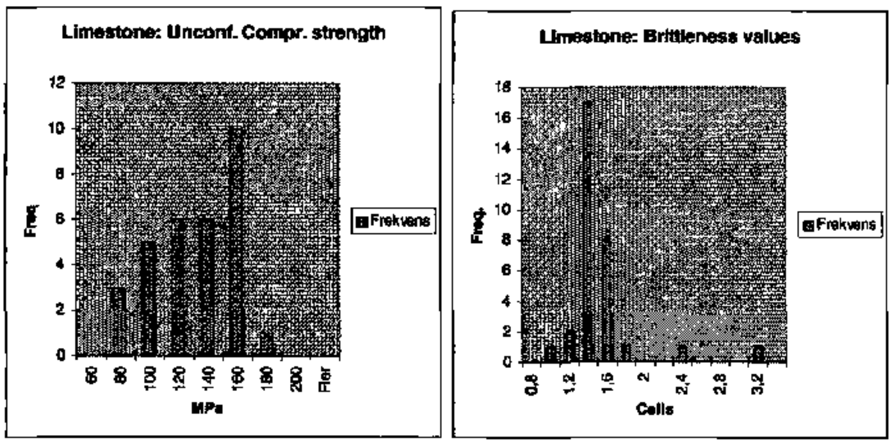
Igneous rocks are considered brittle and they are to a certain extent. Sedimentary rocks are often believed to be ductile and they are in some cases but in many cases they may be just as brittle as the igneous rocks. In Atlas Copco throughout the years some extensive rocktesting has been carried out with respect to Brittleness, Abrasivity, Strength and Density. Density is only of importance for the flushing. The results from a number of these tests are shown in the figures 2- 4 below and there are also some igneous rocks for comparison.

As can be seen it is not that obvious difference between sedimentary and igneous rock in general. There are sediments mat are ductile and has typically low strength like shales of various kinds not shown here. Sedimentary rocks are estimated to cover some ^3A of the continents of the earth and not less than 70% of them are considered to be shale still the number of test results from shales normally are far less than those from limestone and sandstone in any reference library. Man seems, in his construction activity, to avoid shales and this might be explained by the fact mat shale is frequently highly weathered and can easily be excavated by regular backhoes without any blasting operation.

2.2 *Performance in sedimentary rocks*

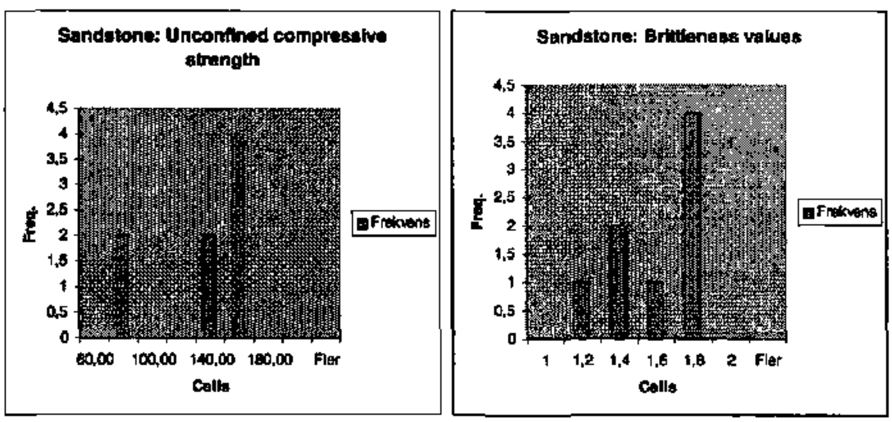
What drilling results can be achieved in sedimentary rocks when comparing with igneous rocks. To give an answer to that five typical rocks have been defined namely a shale, a limestone, a sandstone and for reference a granite and a basalt. In order to illustrate how not just Atlas Copco drill machines cope with this kind of rock machines from other suppliers have been tested in the simulation model created by Atlas Copco named Diarot. This computer model is based on a number of algorithms derived from theoretical considerations and later confirmed in laborotary and field tests.

Input values are for the rocks those described above namely stamp strength, brittleness and abrasivity. For the drill machines the machine's characteristics like the geometry of the hammer its velocity and frequents are stored in the program files. The same applies for rods and bits where geometry and design features are entered. The drill string İs a limiting factor when transmitting the blow generated by the drill machine in one end to be used by the drill bit in the other end. When comparing the various drill machines having roughly the same energy output the criteria for running them is that the relative steel stress in the rod should not exceed 100 % of practical fatigue limit from experience. The results are shown in figure 5 and 6 below where the accumulated drilling rate is very variable due to the fact that the suppliers of the machines have different opinion on what is the optimum design. The variation in bit life is though far less affected.



(a) *(b)*

Figure 2. UCS and bnttieness test results performed on hmestone samples



(a) *(b)*

Figure 3. UCS and bnttleness test results performed on sandstone samples.

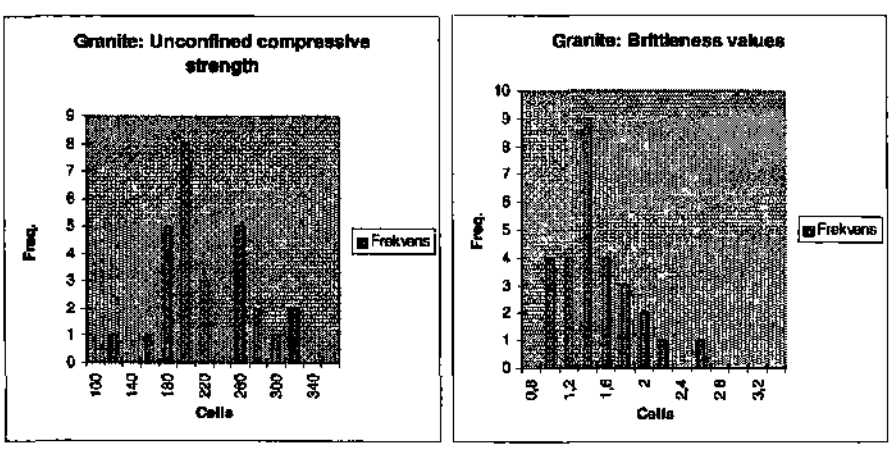


Figure 4 UCS and bnttleness test results performed on grämte samples

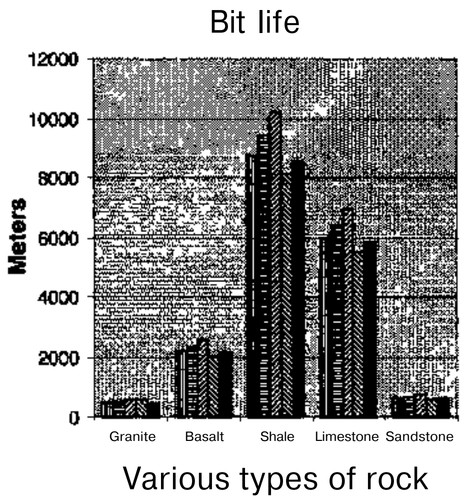


Figure 5. Bit lives within various type of rocks

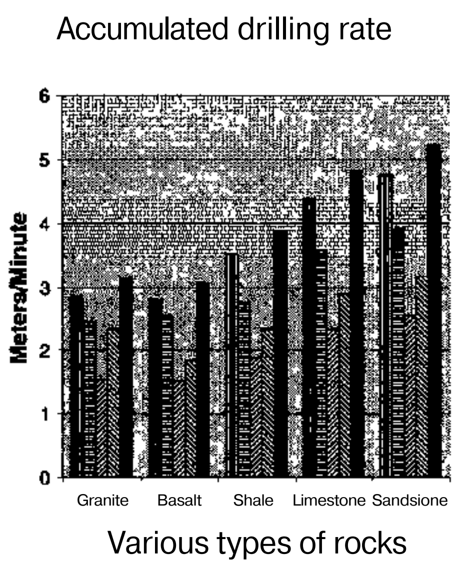


Figure 6. Accumulated drilling rates within various type of rocks.

2.3 *Adjustments of drill machine setting with respect to rock condition*

As the rock may vary from one round to another as well in one hole it is an advantage if the machine settings can be adjusted as the rock conditions vary. Atlas Copco has solved this on their 1838 and 1440 by introducing a rotation pressure controlled feed force and impact force. They are given the abbreviations RPCF & RPCI this means that both the hydraulic pressures for the feed as well as the percussion is ruled by torque that is required to turn bit and rod. A too high torque is interpreted as a too high feed force which will result in too tight threads of the drill string and the feed pressure is then reduced which will hopefully result in a reduced torque. If torque still is too high the RPCF will reduce the impact pressure. If still not sufficient, the drill string will be retracted and a new drill start is initiated. A too low torque will result in too loose threads which eventually will lead to pitting and a too fast wear of the rods.

2.4 *Drillbits*

The design and selection of drill bits is a science İn itself and can only be touched upon. In weak and ductile rock typically a shale there are problems to achieve torque large enough to maintain tight joints. There is obviously a need for a bit that penetrates deeper into the rock in the bottom of the hole. At the same time there is a demand for a bit that has some of drag bit characteristics. As the ballistic button bits are longer than the sperical ones they simply stay longer in the hole during a longer transversal movement, which tn fact is the drag.

Drilling in sedimentary rocks often means higher drilling rates and this means a demand for increased flushing. Some designers have sorted that problem by giving the bit larger or more openings and by creating flow routes on the outside. The front flush of the bit is often omitted as it has a tendency get clogged. Another mean is to increase the flushing pressure, which also will result in an increased flow.

Increasing the pressure and flow is not a problem as long as the bore hole is stable but in weak sedimentary rock this is not always the case. Air flushing has a far less eroding effect on the bore hole wall than water and is therefore a viable alternative in unstable conditions. As air flushing is unhealthy in underground drilling some minor quantities of water has to be added in order to trap the dust. This is normally called water mist drilling. The water bearing compressed air that enters the flushing channels shall have a pressure of not less than 0.7 MPa.

3 STABILISATION AHEAD OF THE TUNNEL-FACE A MEAN TO DEAL POOR GROUND-CONDITIONS

Drilling ahead of the tunnel-face and install bolts or grout is a common way of improving the rock-quality before the actual excavation takes place. Atlas Copco has as a supplier been involved in a number such projects both in mining and construction and few cases will be presented below. The first two cases is a reprint from a paper presented by Mr F. Charette Atlas Copco North America and J.F. Lessard Louvicourt Mine Canada on use of Swellex as spiling and a third case is support of a tunnel portal for a highway project in Japan where so called Odex drilling by use of a regular Boomer was applied.

3.1 *Use of Swellex in support ahead of the tunnelface*

Pre-reinforcement is a different way of approaching ground control. Instead of relying on supporting the ground following excavation, pre-reinforcement increases rock strength prior to excavation. There are several benefits to this. First, a pre-reinforced rock mass will be less damaged and influenced by the excavation process, namely the blasting and the elastic and non- elastic stress redistribution. Second, the rock mass is never without support, even at the split second following blasting of the round. Third, the support can be more active when installed early, rather than passive when installed later. Fourth, pre-reinforced ground will not deteriorate or collapse as rapidly as a totally unsupported excavation, allowing a safe working period for installation of regular support.

Figure 7 shows a well-known relationship between the unsupported stand-up time of an excavation in relationship with its rock mass quality. Empirical observations have shown that, for a given excavation size, a linear reduction in Rock Mass Rating (Bieniawski, 1974) will lead to a logarithmic reduction in unsupported stand-up time. Hence, a linear increase in excavation span results in a logarithmic increase in instability potential. For large span drifts the time period available to install roof support is significantly lower than for small drifts. In the case of a 4,3-meter span tunnel driven through poor to very poor quality rock, it may be logistically impossible to support the roof before it collapses. Obviously, the operational and safety implications of such cases are tremendous.

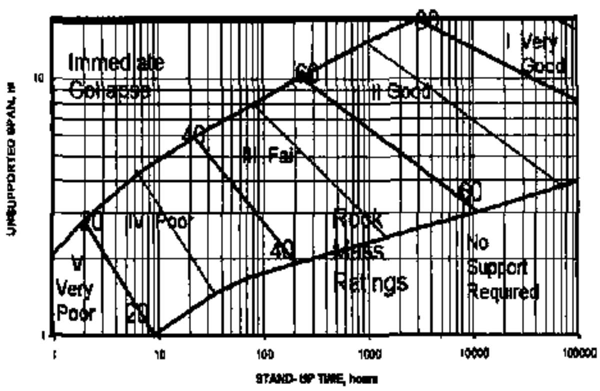


Figure 7. Unsupported Stand-up Time and Support Requirements (After Bieniawski, 1984)

Field observations show that cable bolts installed in slopes before the first blocks are blasted are more effective than cable bolts installed after the slot or cut has been excavated. Firstly, for cable bolts installed prior to stope exploitation, the grout curing period is generally respected. This is not always the case for cable bolts installed during stope exploitation, when production concerns may override ground support design concerns. Secondly, the cohesive effect of the cable is greater when added to undisturbed ground than when added to weakened and disturbed ground.

In tunneling, a pre-reinforcement method called "umbrella grouting" exists. The method consists of pre-supporting the planned roof area with steel rods. Large holes are drilled in the future roof perimeter, and high-pressure-grouted with high strength/small particle size cement grout. Through each cemented hole a smaller hole is then drilled, In which a high-strength reinforcement bar is cement-grouted. Although highly effective for shallow tunnel's driven in very adverse ground conditions, it is easy to see that such a work-intensive operation would be deemed neither practical nor economic for mining applications, although the underlying concept could definitely be useful.

3.2 *The Mine Doyon Experience*

A variation of the umbrella method was attempted at Mine Doyon, located near Rouyn- Noranda in northwestern Quebec. The Mine Doyon property is one of the most important gold-bearing orebodies in production in Canada. The mine is located 40 km east of Rouyn-Noranda. At least 4 major ore zones are found on the Doyon property. Economic mineralization is found on a corridor that extends at least 2 km E-W, and from surface reaches a depth of over 1000 m.

The ore zone which will be discussed here, the No.1 Zone, is defined by a major quartz and sulphide vein system, oriented east-west. The orebody is also oriented E-W, dips steeply south and has an average width of 8 meters at depth. It is surrounded by sericitic schist corresponding to the sub-unit 4b of the Blake River Group (Savoie et al, 1991). Mining method is long hole stoping with cemented rock fill. Mill production is around 3500 tons per day.

Several tectonic events have been identified, among them a N-S compression followed by a N-S extension; an inverse shearing caused by a NW-SE compression; and a polyphased fracturing caused by an as-yet undetermined stress gradient.

The footwall of the No. 1 Zone İs located İn very poor quality sericitic schist, with RMR values between 0 and 30. This alteration zone runs for about one hundred meters up to the ore body, located itself in very weak chloritic schists (Fig. 8). Stope development in this ore zone was delayed due to repetitive caving in access drifts.

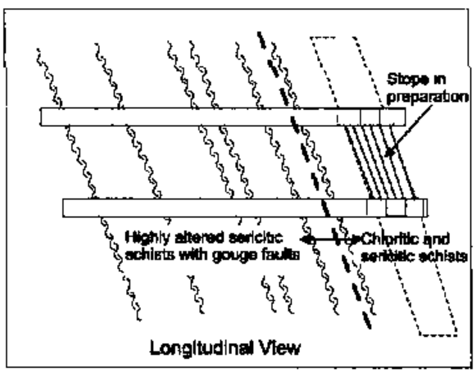


Figure 8. Structural geology setting of the Zone 1 at Mine Doyon

The author, employed at the time as Rock Mechanics Engineer at Mine Doyon, designed a pre-reinforcement method using cable bolts installed over the future roof of the access drifts. An array of nine 50-foot cable bolts was used to pre-support the roof during drift development (Fig. 9). The method wag, successful from a rock mechanics point of view, allowing three to four rounds to be taken before installing heavy support consisting of vertical cable bolts and shotcrete. Primary support could be installed during the normal cycle without safety problems.

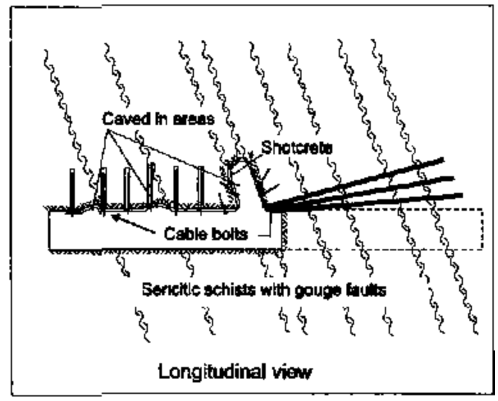


Figure 9. Failure patteras and pre-reinforcement with long cable bolts.

Although stability was achieved, however, high productivity was compromised, since the bolter was tied up in stope preparation and rehabilitation work. Also, since several levels were being developed concurrently, travel time for the equipment and cable grouting crew was significant. A better solution was needed. Requirements were: 1) easy integratioP in the normal development cycle; 2) installation before the next drift advance; 3) effective support; and 4) reasonable cost.

In order to increase productivity and regain some flexibility, it was decided to try pre-reinforcement using Super Swellex bolts instead of cables, and to slightly reduce drifting length to about 3 meters. Five to sbt Super Swellex, parallel and spaced 60 to 75 cm apart, are installed subhorizontally over the perimeter holes. Holes are drilled using the development Jumbo drifter. Pre-reinforcement holes are 50 to 60 cm longer than drifting length, to accomodate the 3,6-meter long bolts. Inflation pressure is 240 bars. Figure 10 illustrates the principal components of the method. Several variations of the method were used to secure pillars and cuts in stopes (Charette, 1996).

With the Super Swellex bolts, productivity actually increased to the same level as for ramp and drift development in fair to good quality rock.

Since the few extra holes required for the spiling bolts are drilled at the same time as the blasting holes, and the bolts are installed in the short period between drilling and loading, this pre-reinforcement method adds no additional time to the excavation cycle. The experience was a total success, and the method became a standard at Mine Doyon for bad ground conditions. Presently, around 300 meters of access drift and stope have been developed using this method. Close cooperation between the engineering and production departments made this success possible.

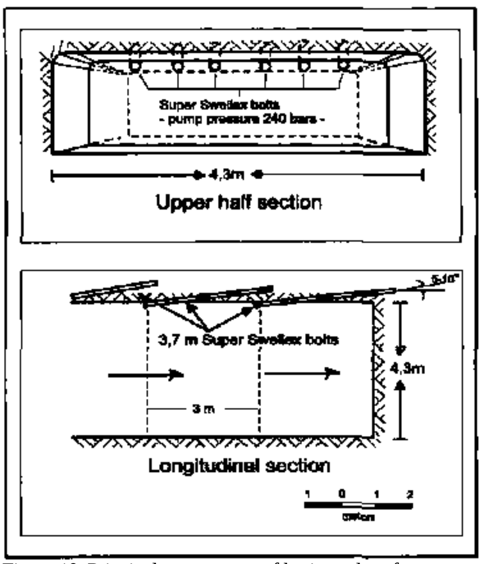


Figure 10. Principal components of horizontal roof pre-reinforcement with Super Swellex bolt.

3.3 *The Louvicourt Experience*

The Louvicourt Mine is a polymetallic orebody of copper, zinc, silver and gold, 25 km east of Val d'Or in northwestern Quebec. It is a volcanogenic massive sulphide deposit starting 47,5 m below ground surface. It is part of the Abitibi Greenstone Belt within the Precambrian Shield of eastern Canada. The orebody dips 70° North and strikes E-N-E with a plunge to the east. Dimensions of the orebody are 300 m along strike and 500 m along dip. Thickness varies from 20 to 100 m. The mining method is long hole stoping with paste backfilling.

Systematic stability problems are encountered while drifting through fault zones disseminated in the orebody. The gouge associated with the faults, the unfavourable dip of the two main joint sets, and the intense black chlorite alteration of the joints, contribute to the formation of high roof and unstable ground conditions (Fig. 11). Gouge thickness can reach up to 90 cm.

An efficient solution to this problem has been to use Super Swellex bolts as a pre-reinforcement method (see Fig. 12). Three to four rings of 3,6-meter long Super Swellex, on a 1,5 X 1,5 m to 2,0 X 2,0 m pattern, are installed on tie roof of the drift before the next advance in the fault zone. The holes are drilled 50° upward, using a Jumbo drifter, and the bolts are inflated to 300 bars using a pneumatic Swellex pump. Steel straps are sometimes used to increase support capacity and cohesion. The immediate support effect, and simplicity of the operation, with minimum handling, are definite advantages to using Swellex instead of cable bolts in this case.

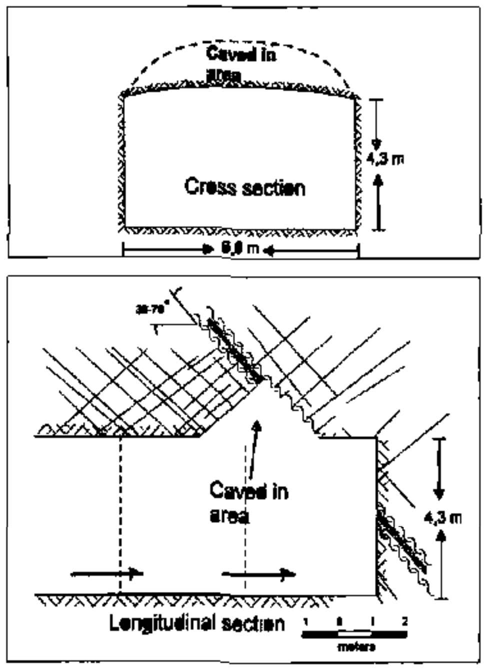


Figure 11. Unstable ground conditions at Louvicourt Mine

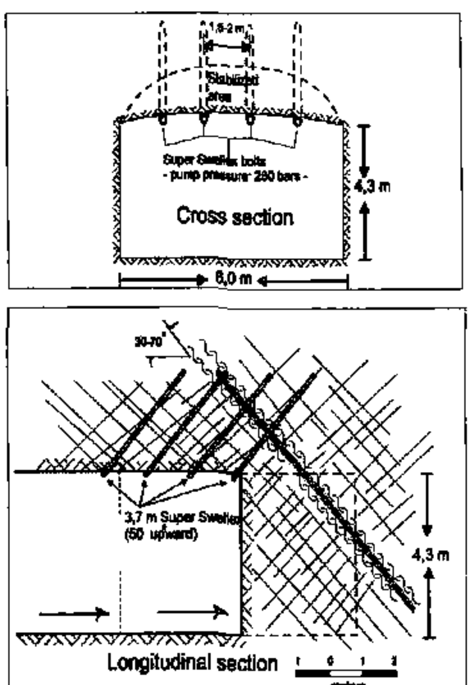


Figure 12 Use of Super Swellex to secure unstable fault zone

The method creates a small increase İn normal cycle time, but the drilling and installation time are more than justified by the cost, risk and lost time associated with rehabilitating a caved roof. The collaboration of the production department was crucial to developing the method.

3.4 *Support ahead of the tunnel-face by use of long grouted tubes so called Boodex.*

So called Odex drilling is a well known drilling method in suface drilling irrespective of the type of rock. In fact Odex stands for overburden drilling using excentric drillbit. The method is used for drilling through soil thus leaving a casing tube and then continue İn rock with or without casing. This drilling tool has turned out to work very well in horisontal drilling using a regular large Boomer like 352 and 353 for tunnelling as drilling machine. Long holes in the range of 10-40 meters are drilled just outside the periphery of the tunnel with a moderate look out angle of some 5 degrees giving enough head room for another set of holes to be drilled. The drill-holes are placed at a spacing of 1 meter down to 0.3 meters depending on the ground conditions. The casing tubes that are functioning as lining of the hole has an outer diameter of 115 mm. In underground application 1,5 meter long sections of the tube is used due to the weight and bulkiness of the rod-tube assembly.

When applying Boodex in the portals 3 meter long sections can be used as it is possible to use a small crane for the handling.

When the drilling has reached the the requested depth the excentric drill bit and the rod is retracted.. The pipe will then be used for grouting of the ground around it by either use of a probe that is sent into the tube bringing the grout to the valves in the tube or by individual hoses. This grouting has a lot in common with die tube a manchette method.

There are not many cases where this method has been used but one site will be described briefly. The first site where the Boodex was used was in the Tsuda tunnel in Japan where it was necessary to improve the quality of the ground before the excavation could start, see figure 13, In this case it was decided that not less than 28 nos of 36 meter Boodex pipes should be installed in the crown of the 60 m^3 large tunnel and grout the whole crown by use of individual grout-lines to every valve of the Boodex-pipe. To complete the drilling of one pipe the time was cut to 7 to 8 hrs. The Boodex - installation took 20 days working on dayshift only. The deviation of the pipes did not exceed 2 %. The result of the ground-improvements fulfilled the expectations. The road that is located only 3 to 5 meters above the crown had a settlement after excavation of only 1 mm in some places.

Figure 13. Drilling and grouting with Boodex-pipes, Tsuda-tunnel portal, Japan

4 DISCUSSION

Experience with Swellex bolts as a pre-reinforcement method shows that it can be a valuable improvement to current excavation methods. Faster support action, smaller effect on excavation cycle time, and active roof arch building are some of the obvious results achieved.

However, there is still a lot to learn about the optimum application of the technique. The installation angle in relation to joint orientation and dip, the inflation pressure in relation to rock strength and fabric, and the optimal distance between bolts have yet to be defined, in order to obtain a quantifiable approach to Swellex pre-reinforcement.

Although some experiences were not totally succesful, they have taught us a better way to use the bolts. Because the Swellex is not a passive reinforcement dowel, the way it works must be well understood in order to achieve the expected results, and avoid local detrimental effects on roof stability.

5 CONCLUSION

The two examples presented here show that Swellex bolts can be efficiently used as a pre-reinforcement system in order to improve productivity and safety while excavating mining tunnels in incompetent rock. The method can be applied to systematically support roof, or to prevent caving from a nearby fault zone. The method is fast, improves safety, and can be easily integrated *into* development operations. Cooperation of the underground department İs paramount to the success of the technique, as the experience of the miners and supervisors is a valuable asset in improving excavation techniques.

It is often claimed that drilling sedimentary rock is completely different from drilling in crystalline rocks. This may be the case but rarely in sandstone and limestone may be just as brittle as igneous rocks By fully understanding the mechanics of the failure of the rock when exposed to percussion drilling the design of the drill machines can be optimised. In this optimisation the drill machine, the rod bit and rock is treated as one unit. This means that just the nominal figures on a drill like power and frequency etc. will never tell the performance characteristics in its full range. The Atlas Copco computer based program, Diarot, certainly improves the opportunities to advice an optimized drilling result.

Sedimentary rocks are in many cases also weak rock and as such requires improved strength and deformation capacity ahead of excavation. In these cases the Atlas Copco Swellex bolts and Boodex system offers opportunities to perform this pre-strengthening of the ground beyond the tunnelfase in what many consider a cost efficient way. The savings are manually on the time side but use of longer rounds means also cost reductions.

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