THE CONTROL OF WATER IN UNLINED MINE SHAFTS AND TUNNELS

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ABSTRACT

Proper control of ground water is in many cases the most important factor influencing the success or failure of an underground mining project. Water seeping into an underground opening can impede the mining progress by making it difficult for men and machinery to work efficiently, and in many cases, inflowing water will halt operations.

This paper discusses various methods used in the control of groundwater in mining projects from the initial design, to the construction and the abandonment of the mine. Some of the control methods need a large inventory of specialized plant and equipment in order to carry out such remedial measures as grouting, freezing, dewatering and others. The main focus of the paper is on methods of water control in tunnels and shafts.

INTRODUCTION

Various ground water control methods are employed throughout the working life of an underground mine. The planning and design phase of a mining project is probably the most important stage in a mine and information on the ground water hydrology plays a vital part. In most projects, the shafts and tunnels will be designed with limited information on the sub-surface conditions. Based on the results from preliminary field investigations several options for groundwater control systems are usually considered. If water poses a severe problem, more detailed investigations are necessary, such as, full-scale pumping tests, detailed environmental analyses or pilot sections testing the primary water control system.

The final selection of a control method can be made during the shaft sinking operation. During that stage such important information as soil and rock parameters, thickness and permeability of the various strata, rock fractures and joints, water inflow and chemistry can be obtained.

The natural sources of water in soft porous ground may be in the form of unconfined or confined aquifers and locally entrapped bodies of water. If the shaft and/or tunnel is to be driven through rock, the water supply may come through faults and joints from a natural source, such as the groundwater table, lake or an underground cavern. The inflow of water will automatically stop once the water level is lowered below the invert of the tunnel or the bottom of the shaft. The amount of water which can be allowed to seep into a shaft or a tunnel depends on the hazards involved permitting this leakage. In the following sections the various groundwater control methods employed through the four main phases of a mine, namely planning, construction, mining operation and abandonment, are discussed. The different techniques in minimizing water inflow are outlined and their capability to cope with unexpected groundwater conditions during the operational life of the underground project are illustrated.

PRE-CONSTRUCTION PLANNING

The planning and design stage is probably the most important phase in achieving a successful and cost efficient mining project. In most cases the underground works and water control system will be designed with limited information on the groundwater geology.

A program of sub-surface evaluation during the planning and design phase of a water control system may include the components, such as, stratigraphy, hydraulic gradients and permeabilities, extent of groundwater regime and other factors, which are, to some extent interrelated.

Geohydrology

The existing groundwater geology has a pronounced influence on the type of water control system which should be employed during the construction of the shaft and tunnel. In particular, the characteristics and distribution of aquifers, aquitards and aquicludes, as well as the sources of the groundwater supply must be established. This information will give an indication of both the flow rate, the flow pattern of the groundwater and the quantity of water which can be expected during the sinking of shafts or driving of tunnels. In order to verify these factors the program of sub-surface investigation should also include the installation of water observation wells. Boreholes which were previously drilled to ascertain the soil and rock properties can be used to establish levels, fluctuations and gradients of the groundwater regime. These wells could also serve to sample the quality and chemistry of the groundwater. Boreholes may also be used for pumping and recharge tests in order to establish the hydraulic conductivity (permeability) of the formations to be tunnelled through.

CONTROL METHODS DURING CONSTRUCTION

There are many methods in use to control excessive water inflow and some techniques can be used in either stage, before and during construction. Very often a technique used during construction is merely a continuation of the preconstruction water control system. The final selection of a control method is based on technical and economical considerations, as well as the availability of equipment and experience of the contractor.

Dewatering

Dewatering or predrainage of soil and rock formations prior to the actual construction is probably the most common and economic control method.

Widely spaced deep wells with submersible pumps below the water table are quite efficient in sandy and gravelly soils or fractured rocks. They have the advantage that the progress and amount of drawdown can be controlled effectively by choosing pump size and by the number of wells. However, the drawdown has to be monitored carefully in order not to pump larger quantities than necessary. Careful considerations must be given to soil subsidence which is always associated with lowering of the water table and that this will not affect detrimentally nearby structures. A typical deep well installation is shown in Fig. 1.

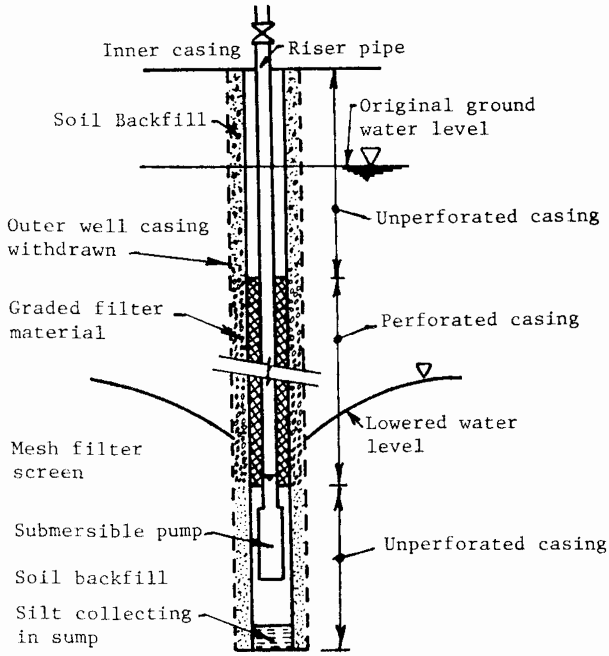


FIG. 1 Deep Well Installation (After Tomlinson (1980))

Well points or vacuum wells are a smaller version of deep wells, except that the pumping is done from the surface. They are quite frequently spaced and work efficiently in sandy and gravelly soils and where small drawdowns are needed. Their total lift is limited to five or six metres and therefore are not suitable for most tunnelling projects. The amount of drawdown and water pumped can be controlled by either turning on or shutting off individual wells. They also require a good seal (Bentonite) at the surface in order to prevent loss of vacuum. This method is probably the most cost efficient system for open pit mines where a multiple wellpoint system can be employed. The system is not suitable in clays or in rock fractions. In sandy or silty soils it can be jetted ahead of the bottom of the shaft during sinking operations. But in these soils it is necessary to stabilize the sides by either a bracing system or by another stabilization technique discussed in the following sections.

Grouting

Grouting is the most commonly used method for water control in pervious soil below the groundwater table. It involves the injection of fluid substances into the pores or voids and thereby preventing water flow. A variety of grouts are currently used and the choice depends on the soil grain sizes or rock openings, the ability of the grout to permeate these voids, the setting time, the cost and the toxicity. Grouting affects the soil or rock foundation in three ways which are beneficial to tunnel construction. The permeability is decreased considerably, the strength is increased and the danger of surface settlement is minimized. Grouting can be carried out from the surface in vertical or inclined drill holes for low depth tunnels or from the face of the tunnel. High pressure jet and slab grouting techniques have recently been introduced in Europe [1]. These methods will enable the contractor to construct a complete watertight concrete box section from the ground surface along the alignment of the shaft or tunnel. Completion of the excavation is accomplished in the "dry" by conventional excavation techniques. The grouting pressure is dependent on the soundness of the rock formation and on the depth of grout application, i.e., location of tunnel below the ground surface. A guide for grouting pressure in rock is given in Fig. 2. Fig. 3 shows a typical cross-section and longitudinal view of a grouted tunnel region.

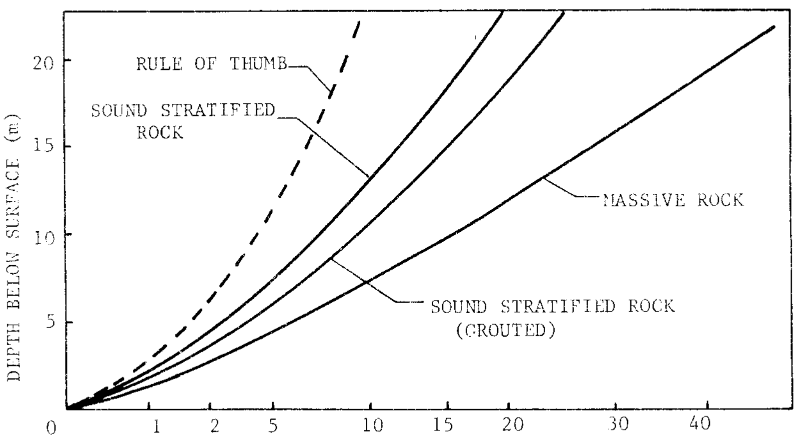
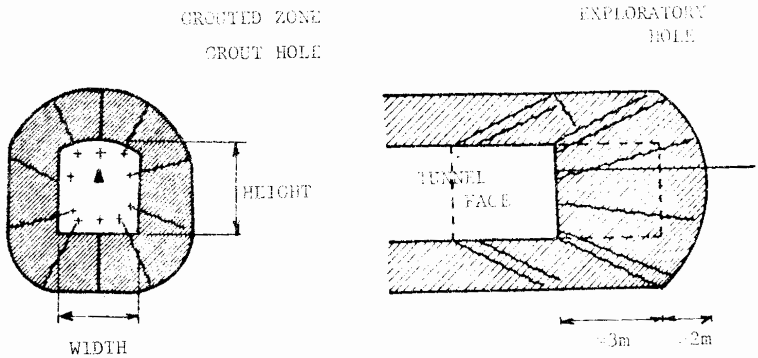


FIG. 2. APPROXIMATE GROUTING PRESSURES



(a) CROSS-SECTION (b) LONGITUDINAL SECTION

FIG. 3. GROUTING FROM INSIDE OF TUNNEL

Compressed Air

The compressed air method is applicable to tunnelling below the water table in fine-grained soils or rock formations with low permeabilities. Theoretically, the excavation can be carried out to any depth below the water table as long as the supplied air pressure is sufficient to balance the water and soil pressure at the face of the tunnel. But in practice the maximum air pressure to which workers can be subjected is strictly regulated by safety and health codes. The U.S. Department of Labour Safety and Health Regulations for Construction (1974) limits the air pressure to two bars, whereas the Construction Safety Assocation of Ontario in Canada (1984) has adopted a one bar upper pressure limit in order to prevent health problems to workers. Of course, tunnels and shafts constructed under compressed air require permanent water proof liners once the air pressure is removed. Generally, in stable rock and soil formations, it is more economical to employ a dewatering system in conjunction with a lower air pressure to control water inflow. Extreme caution must be used in pervious soils (gravels and sands) where blow-outs and rapid air losses could occur. A relationship between water depth and the air pressure inside the tunnel to prevent water inflow is shown in Fig. 4.

Slurry Shield

The newest technique in the large arsenal of water control methods is the slurry shield method developed in Japan and Europe [2]. It combines a tunnel boring machine and a fully fluid supported face. The fluid, which is commonly a Bentonite slurry, is kept under pressure by an air chamber which also compensates for any fluid losses. The soil material is removed by either a rotating cutter head, in the case of large diameter tunnels, or hydraulically by high pressure water jets in small diameter tunnels. The loosened earth is removed either by conveyor belts or siphoned off with the slurry. The workers are stationed behind the pressurized bulkhead under atmospheric conditions. Tunnels under very

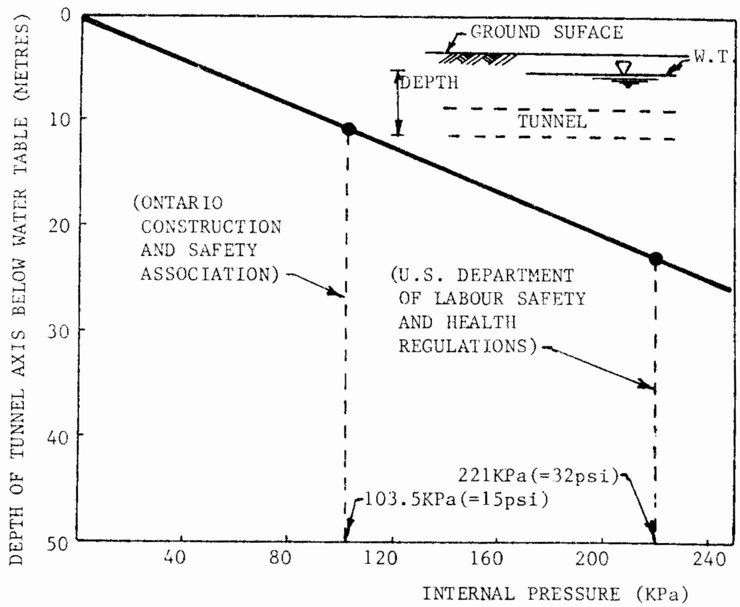


FIG. 4. DEPTH-PRESSURE RELATIONSHIP (EMPIRICAL RELATIONSHIP)

little overburden have been successfully constructed by this method with minimum surface settlements [3]. Accurate tunnel alignment is another advantage of this technique. Problems may arise in mixed face conditions and where large cobbles are encountered.

In general, the earth and water pressures at the face of the tunnel are kept in balance by the Bentonite fluid pressure. The excavated material is either removed by a screw conveyor or by the slurry return line. Fig. 5 shows a schematic diagram of the components involved in the slurry shield method. Since the Bentonite slurry is quite viscous and has thixotropic properties, loss of fluid at the face is quite minimal and blowouts are not as frequent as in the compressed air method. The material removed from the tunnel face is pumped to the surface with the Bentonite slurry, where the solid particles are removed either by a screening or by a cycloning process. The cleaned slurry is re-used for several cycles until it loses its thixotropic properties.

Ground Freezing

The principle of ground freezing is to convert the water in the ground into ice by a heat removal process (cooling) which is achieved by means of refrigeration. The frozen water has two functions, firstly, it forms a waterproof barrier and, secondly, it binds the soil or rock formations together. The freezing operation is accomplished by supplying a coolant usually brine (calcium chloride) or liquid nitrogen. Freezing elements

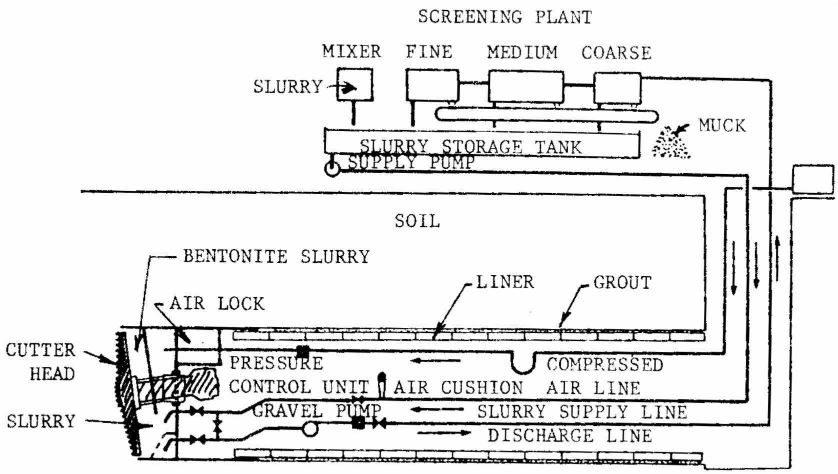


FIG. 5. SLURRY SHIELD METHOD

are installed in predrilled holes. The coolant removes sufficient heat from the ground to freeze the porewater. Excavation of the tunnel or shaft is then carried out through the stabilized soil formation. As soon as the tunnel liners are installed the freezer pipes are advanced to a new section. This process is quite expensive, but has become quite cost efficient in recent years [4]. Successful soil freezing depends to a large extent on the accurate drilling of the freezer holes. Vertical holes or slightly inclined holes guarantee better alignment than horizontal ones, in particular if mixed soil conditions are encountered.

Two common circulating freezer systems are shown in Fig. 6. These techniques are quite expensive and are used generally in cases where other water control systems cannot be used for various reasons.

Electro-Osmosis

Electro-osmosis is a unique process of stabilizing saturated soft clays and silts of such low permeability that they cannot be drained by any other way. This technique is relatively expensive, compared to other methods, and needs a considerable equipment plant. It involves the insertion of electrodes in the waterbearing formation. The application of a high direct current will separate the water molecules (electrolysis) and the water collects at the negatively charge cathode where it is pumped away. There are no cases reported in the literature where this method has been used in underground tunnel and shaft construction, but it would find a useful application in open cut construction in order to stabilize the sides of the excavation. The principle of the Electro-osmosis is shown in Fig. 7.

COMPLETED SHAFTS AND TUNNELS

The active methods used in completed shafts and tunnels consists mainly of "sumping and pumping." Water is collected in sumps at the bottom of

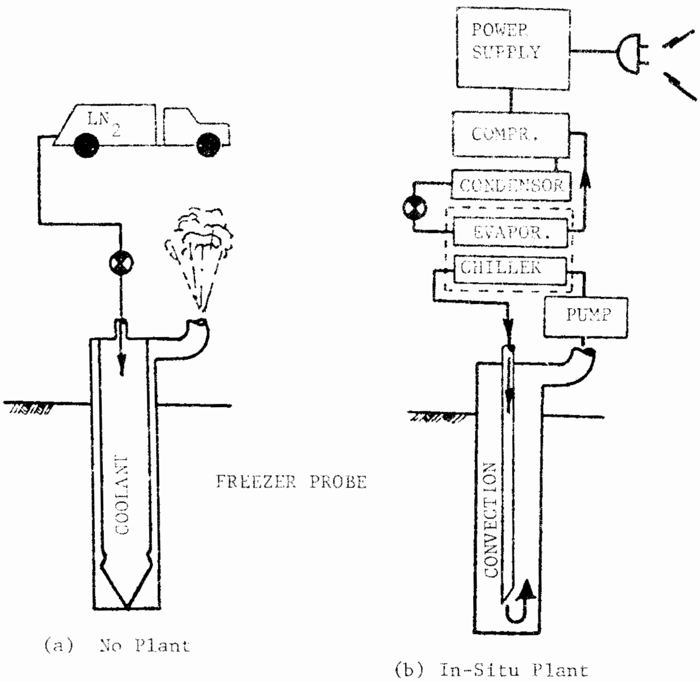


FIG. 6. SCHEMATIC OF FREEZING SYSTEMS

the shaft and then pumped to the surface usually in stages. In many cases this is done in conjunction with grouting and concreting of the water bearing formations. The tunnel and shaft openings behave as drains and the seepage forces will act normal to the perimeter and tend to cause instability. Temporary or permanent lines or bracing systems are commonly used to safeguard against collapse.

Permanent extraction and lowering of the groundwater can be applied to keep the tunnel region dry. The method adopted can be similar to those discussed for the preconstruction and construction stages. This approach, however, is associated with high operation and maintenance costs.

After abandoning of a mine, which was operated with active water control system, the groundwater level generally rise to its static level. This is associated with a slight rebound of the land surface, which is a reverse effect to subsidence and settlement usually occurring during groundwater lowering. But the rise in the water table can have series effects on pipelines and watertight tunnels as they will be subjected to buoyancy forces and also to infiltration. Many countries, where mining is an important part of the economy have stringent restrictions with regard to changing the groundwater regime that may have adverse surface effects.

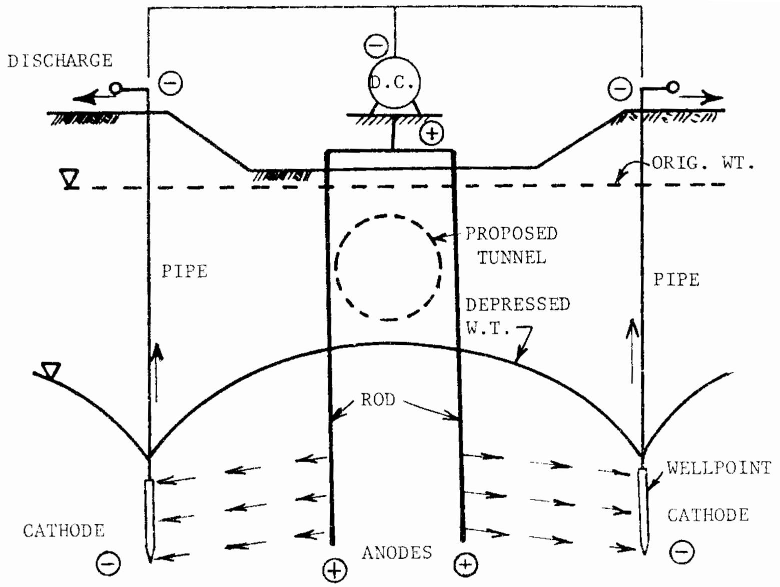


FIG. 7. PRINCIPLE OF ELECTRO-OSMOSIS

CONCLUSIONS

Groundwater control prior and during the construction of an underground mine forms a vital part of the safe and economic operation of such an undertaking. Water control methods use presently, and will need for the foreseeable future, highly sophisticated equipment operated by specialized firms. In order to make advances in this field, new techniques as well as solutions to difficult problems should be publicized widely. Therefore, engineers and companies involved in the design and operation of water control methods must be encouraged to publish detailed and concise reports on both successful and unsuccessful projects in order that the state of practice can be advanced.

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