Plug Construction to isolate active zones of inactive zones in coal mine. WATERCHEM Project

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ABSTRACT

In the last years, a progressive abandon of underground coal mines is taking place as a consequence of different factors. Frequently, these closed mines or sections of mines are connected through galleries to other mines still in operation. In these cases it is necessary to maintain the water extraction in the zones already abandoned in order to prevent the flooding of the areas in operation, with the consequent increase of operating costs. A possible solution to this problem is the construction of concrete plugs in order to seal the connection between active and abandoned zones.
Nevertheless, due to the depth of the mining works, which frequently exceeds 400 m, the hydrostatic pressures that will support the plugs are much higher than the pressure held by the conventional dams so they will require an efficient design and anchorage. On the other hand, in order to guarantee the sealing capacity of the plugs, a careful selection of the most appropriate location for the plugs with regard to the mechanical and hydraulic characteristics of the rock, and a detailed knowledge on such hydrogeological environment is necessary so to avoid the communication through possible groundwater preferential pathways. In addition, it is of the utmost importance to design and install appropriate monitoring systems to survey in real time the behaviour of the plug and the rock formation into which it is placed, given the catastrophic effects that a hypothetical failure of one of these plugs might have on the adjacent active zones of the mine.
Hunosa and Aitemin are analysing, in the frame of the Waterchem Project sponsored by the RFCS, the factors that determine the construction of this type of plugs in order to establish its constructive characteristics, monitoring systems and ideal location to guarantee its safety and effective functioning. A comprehensive state of the art has been compiled with diverse sealing experiences throughout the world, a generic design of a plug based on the shotcreting technique has been developed, and a conceptual monitoring system has been designed to survey its performance.

INTRODUCTION: the WATERCHEM project

Ever since coal has been mined, problems connected with controlling mine water have been among the most important ones faced by miners and mining companies. The RFCS (Research Fund for Coal and Steel) project entitled “OPTIMIZATION OF MINE WATER DISCHARGE BY MONITORING AND MODELLING OF GEOCHEMICAL PROCESSES AND DEVELOPMENT OF MEASURES TO PROTECT ACQUIFERS AND ACTIVE MINING AREAS FROM MINE WATER CONTAMINATION” (Waterchem) pretends to reduce such problems by developing several research lines.
For instance, the abandonment of zones in underground coal mines, in which galleries connect with other productive areas, produce an increase in pumping costs in the operational parts of the mine, being one solution to this problem the construction of underground barriers to control or confine water in galleries. One research line of Waterchem project is intended to determine how to seal the parts of the mine that are left abandoned, in a safe and efficient way, being some of the proposed goals: to study alternative designs for the construction of underground plugs and dams, to develop and test methods to improve the quality of existing plugs, to investigate novel approaches for the construction of barriers (fast plugs), etc.
Although underground barrier construction for mines has been know for long time, there are still number of problems to be solved. In fact, there is no commonly accepted design method for constructing plugs for this purpose.
Due to the depth of the mining works, which frequently exceeds 400 m, the hydrostatic pressures that will support the plugs are much higher than the pressure held by the conventional dams (Figure 1) so they will require an efficient design and anchorage. In addition, tunnel plugs used for mine closure are often exposed to aggressive water (low pH, high sulphate) that can significantly reduce their service life.

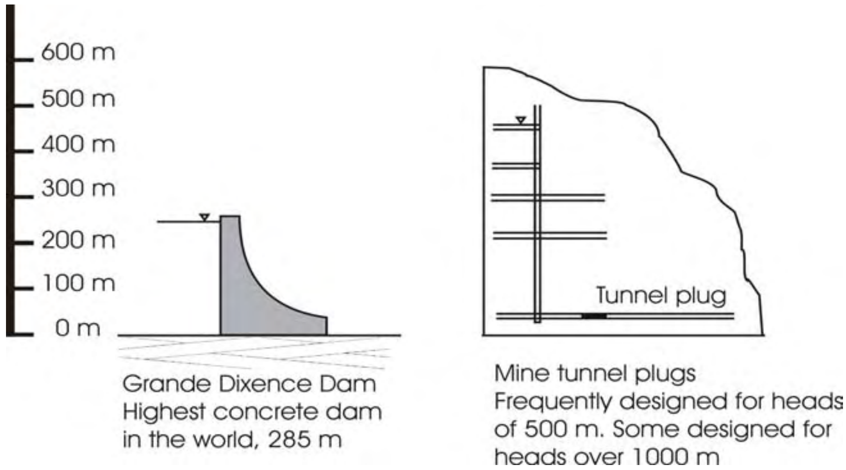


Figure 1: Comparison of Highest Dam to high Head Plugs *[1]*

Therefore, in order to guarantee the sealing capacity of the plugs, a careful selection of the most appropriate location for the plugs with regard to the mechanical and hydraulic characteristics of the rock, and a detailed knowledge on such hydrogeological environment is necessary so to avoid the communication through possible groundwater preferential pathways. In addition, it is of the utmost importance to design and install appropriate monitoring systems to survey in real time the behaviour of the plug and the rock formation into which it is placed, given the catastrophic effects that a hypothetical failure of one of these plugs might have on the adjacent active zones of the mine.

The experimental area selected for Waterchem Project is in the Caudal river basin, in Asturias. The main objective of the investigation is to assess the possibility of isolating San José and San Antonio coalmines by means of concrete plugs. San José and San Antonio coalmines are connected at the third level. San José mine was abandoned several year ago but it has to be drained in order to prevent the flooding of San Antonio that is still active.

This article summarises the results of the studies carried out up to date regarding the hydrogeologic study for the effective location of the different plugs, the sealing experiences throughout the world, the rules for a correct plug design, and the basis of a monitoring system for assessing its performance.

GENERAL HYDROGEOLOGICAL SETTING OF WATERCHEM PROJECT

The area of study is partially occupied by the hydrogeological unit of Oviedo-Cangas de Onis that is used for groundwater extraction for domestic and industrial water supply. It is constituted by sands, silts and clays. Its average thickness changes between 50 and 400 meters depending on the sector, and provides good quality water both for irrigation and for domestic and industrial supply.

The rest of the zone of study is occupied by the coal formation, which thickness can be more than 6.000 meters. Two sets of materials can be distinguished: the lower one is about 3.500 m thick and the upper one is 2.800 m thick. As a whole, these formations constitutes a fractured medium with very low permeability where they are not altered by the mining activities.

The hydrogeological boundaries are an inverse fault of great entity and the Caudal river (West limit) and different water divides (locals and regional) by the East and South. The northern limit is the Nalón river (see Figure 1).

The regional groundwater flow is supposed towards the Caudal River while intermediate and local groundwater flow should be towards smaller rivers and creeks.

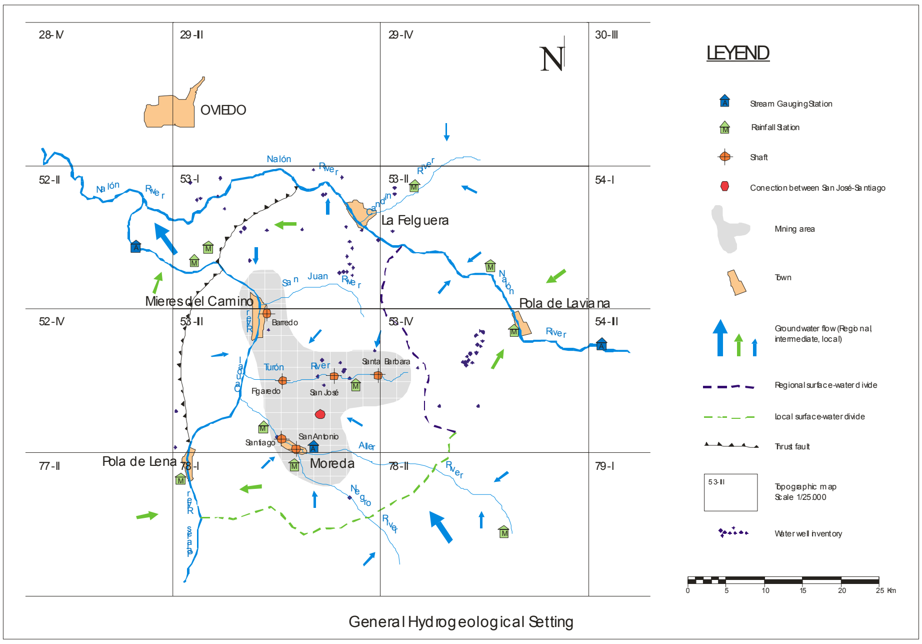


Figure 2: General Hydrogeological Setting

To know the hydrodynamic system in the area of study, it has been carried out an exhaustive summary of information to develop a conceptual hydrogeological model to select the most appropriate points for the location of plugs. The main data that has been collected are the following ones:

Geological information.

Information about the mining activities (maps of galleries, connections between mines, mountain coalmines, strip mines, etc.) and about the geological characteristics of the site (lithology, tectonic, geological frameworks, etc....). The main exploited coal units in the zone can be seen in Figure 2, which shows the site geological map at -100 m a.s.l.

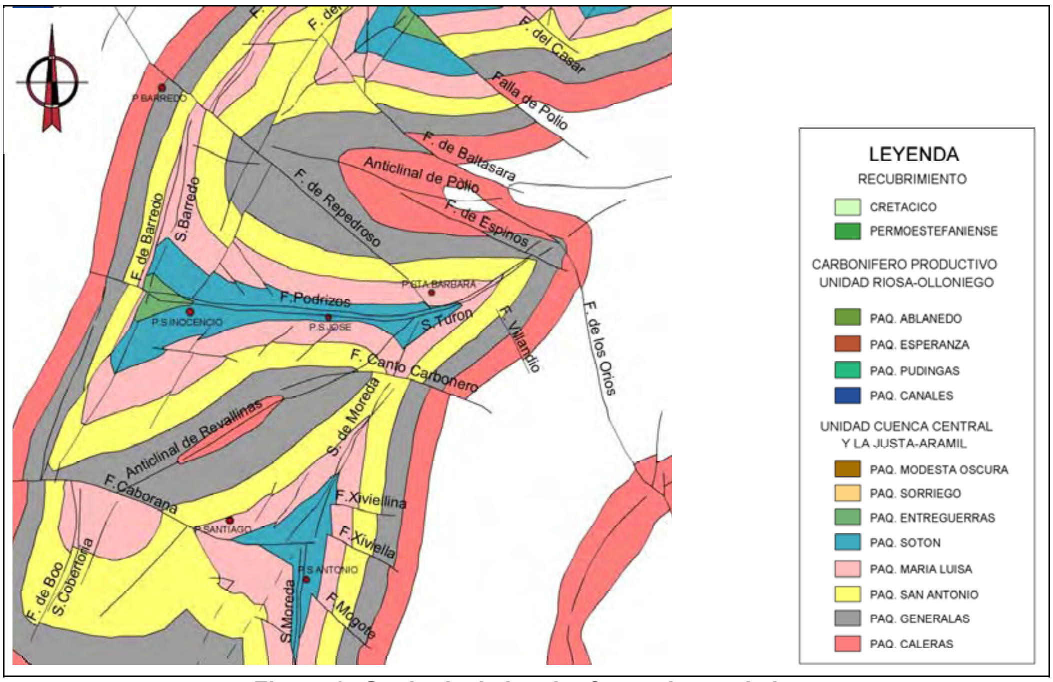


Figure 3: Geological sketch of experimental site

Climatologic data and surface water data.

Rainfall and temperature data from the nearest meteorological stations, and main rivers discharge data (Nalón, Caudal, and Ayer rivers) have been compiled to estimate the water balance in the area. In Figure 2 can be seen the situation of meteorological station and river gauging station used in the hydrogeological study. Figure 3 shows the water outputs of the main rivers between 1999 and 2004.

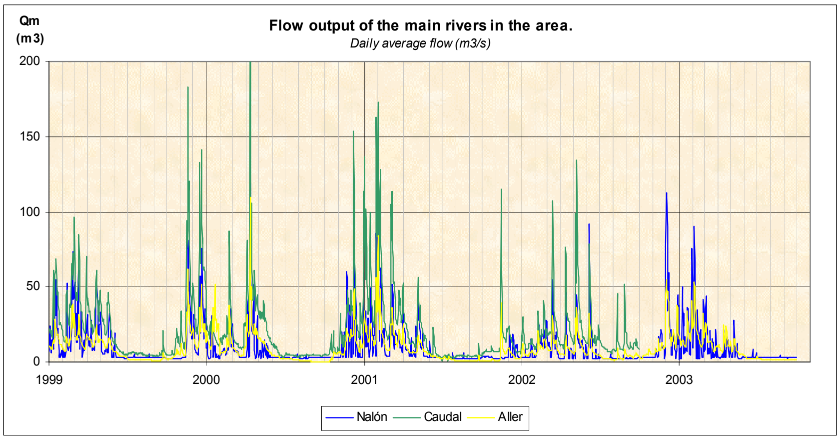


Figure 4: Main rivers discharge

Water well inventory around the investigation area.

In order to prepare the conceptual hydrogeological model of the experimental site it was carried out an inventory of groundwater points. Around the site there are 57 springs with very low output and situated at different elevations, 7 drainage galleries and 1 drilled well (see Figure 2).

Water pumped in mine shafts

In order to estimate the infiltration in the zone is necessary to know the quantity of water pumped in the different mine shafts. In the Figure 4 there is a comparison between the monthly volume of water pumped in San Jose Mine and the monthly rainfall in Santa Cruz de Mieres Meteorological Station (from 1999 until the end of the year 2004). It is possible to observe that a clear relation exists between both records. This suggests a rapid infiltration, owed probably to old mining activities near the surface, which facilitate the direct infiltration of the rain.

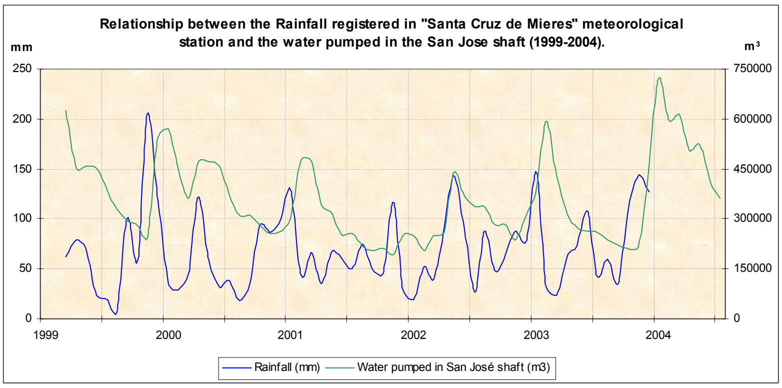


Figure 5: Relation between rainfall an water pumped in San Jose mine

UNDERGROUND BARRIERS

When designing and constructing a barrier for the purpose of impounding water, several general criteria should be met:

- The barrier should be designed to withstand the static forces of hydrostatic pressure rather than dynamic forces (i.e. an explosion).
- The barrier should be constructed from a material, such as concrete, which will resist deterioration by water.
- The barrier should be constructed sufficiently thick and properly anchored, and the surrounding strata should be pressure grouted to minimize water seepage.

There are different types of underground barriers:

- Dams, generally used in underground mines to store water for drilling purposes or for settling sumps. Typically, they are no more than a couple of metres in height. Dams are generally constructed of concrete but can also be made of timber or sand/cement filled sandbags.
- Fill-Retaining barricades, normally used for retaining backfill in mine stopes and in other cases to increase ore recovery. These structures use water heads not exceeding 100 kPa (about 10 metres of water or 5 metres of liquefied tailings). They can be constructed of waste rock, shotcrete, timber, cable slings and wire mesh, or a combination of them.
- Bulkheads. The term “bulkhead” and “plug” are many times used without distinction. One difference is that bulkheads are intended to last for less time than plugs, and also that bulkheads are constructed for low water head conditions. When designed for retaining backfill, bulkheads can also be constructed of waste rock, shotcrete, concrete, timer, cable slings, or a combination of them.
- Plugs. Tunnel plugs are structures used to impound water or tailings at pressures exceeding 100 kPa (10 m of water). As tunnel plugs must be permanent structures (more than 20 years), they normally incorporate higher

factors of safety and meet more rigorous quality control and quality assurance specifications during construction than bulkheads.

Tunnel plugs can be constructed as monolithic plugs or hollow core plugs, used in large diameter tunnels, to favour heat dissipation where the heat from cement hydration is high. Plugs can be constructed parallel, as a slab, or as a tapered one, where the load is transmitted from the plug to the rock walls by compression.

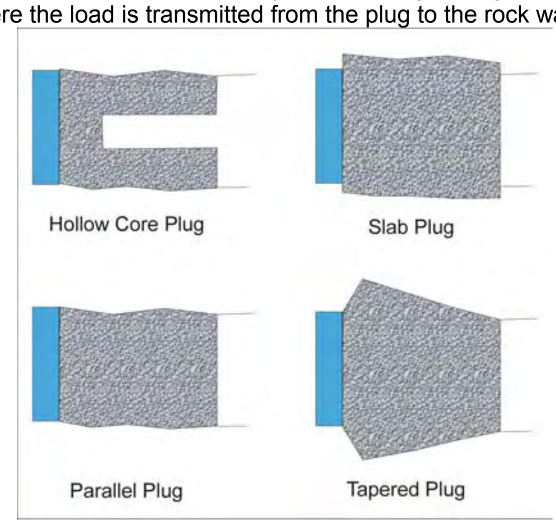


Figure 6: Plug shapes

PLUG CONSTRUCTION

Pre-requisites

Tunnel plugs are significant engineering structures which require of several pre-requisites to be constructed.

A suitable location must be selected within the area considered and therefore, a site investigation must be carried out to assess the geotechnical and hydrogeological characteristics of the site upon which the design will be based. The rock structure and mechanical properties of the rock as well as the initial stress conditions must therefore be sufficiently well known for making the design.

This investigation will be important too for the preparation of the site and for the pre-grouting of the surrounding rock if needed. The anchorage done in the rock depends on design parameters, as well as on strata conditions.

Geological assessment

The site of the plug should be situated in an area of sound homogeneous rock. This infers that the ground for a distance of three plug lengths is free of structural weaknesses such as faults, fissures, shales, schists, friable or soft material or other excavations. If possible, a 3-dimensional structural geological investigation, including discontinuity classification, should be carried out via face mapping and cored holes to confirm that there are not detrimental structural, geological discontinuities or lithologies that could impact on the stability of the plug and surrounding rock mass forming the water barrier. However, this is an ideal requirement that is not always practicable [2].

To facilitate structural design and any associated mathematical modelling of the plug under service conditions, the compressive strength, stiffness, Poisson's Ratio and shear strength of the surrounding rock mass should be obtained. As an example, Dolezova space model was used to model the numerical interaction of the plug pressure and rock massif in the plug construction of Háje-Pribram. [3].

During the geological study, the impact of ongoing mining in the vicinity of the proposed water barrier should be investigated as well. Blasting could open discontinuities within the barrier or damage the rock/plug contact zone. Another factor conditioning the selection of the plug location is the minimum rock cover (C_{RM}).

Hydrogeological assessment

An hydrogeological assessment of the rock mass surrounding the water barrier is required as well, in order to identify potential connections as far as possible, to predict the changes in the water regime when the plug is completed, and to determine the probable resulting water seepage around and beyond the plug in service.

Where faults and joints are encountered, their persistence (continuity) should be assessed. If these features contain thick infill/gouge materials, the in situ fabric and mineral content of the materials, together with ground water chemistry, should be studied to determine dissolution rates and risk of erosion for the known hydraulic gradient over the service life of the plug.

In order to evaluate if rock mass grouting is necessary, and its extent, a profile of watertightness surrounding the plug location must be obtained by means of borehole permeability tests. The holes should be drilled beyond the mining induced fracture zone, e.g. at least 6 m into the surrounding rock mass, and deeper if permeable conditions are encountered. Multi-pressure Lugeon test are recommended since the results permit assessment of the flow characteristics of the permeable discontinuities. Afterwards, all exploratory holes should be backfilled with a cement grout as thick as possible.

Plug design

For the effectiveness of the plug, a rough rock/plug interface is essential, in order to provide frictional bond and mechanical rock-plug interlock, and to reduce the hydraulic gradient along the interface of the plug.

Plugs should be designed to resist failure from five possible failure modes, namely:

1. Hydraulic jacking of rock surrounding the plug.
2. Shear failure through the concrete, along the rock/concrete contact or through rock mass alone.
3. Deep beam flexure failure.
4. Excessive seepage around the plug and possible backwards erosion.
5. Long term chemical/physical breakdown of concrete, grout, or surrounding rock.

While the design of the concrete body and reinforcement is a relatively simple issue, the problem of anchoring the plug in the rock without causing stress conditions that favour flow along or close to the plug is more difficult. Thus, the very strong force acting on the plug must be transferred to the rock without causing significant fracturing or displacement.

The resistance of a plug to water flow either along its contact with rock or through the adjacent fractured rock will depend on some factors:

- Hydraulic gradient. Resistance of the rock to the water flow improved with the pre-grouting.
- Length of the plug.

The length of a plug should be calculated by the mechanic and hydraulic ways and the plug length will be the longer of the two obtained values. From W.S. Garrett and Campbell Pitt studies [4], in most cases the length is determined more by the leakage (hydraulic) than by the structural strength (mechanic). For this reason they recommend parallel plugs better than tapered ones, because the extra site preparation, with its subsequent increased rock de-stressing, time and cost, is not justified.

Another key factor is the chemistry composition of concrete, especially important when there is ARD (acid rock drainage). Aggressive underground water (low pH, high sulphate) can significantly reduce the service lifetime of a plug.

Where the plug must resist highly acidic mine water and the anticipated design lifetime is long (about 100 years), consideration should be given to the dissolution of the concrete at the wet face. If dissolution is deemed a potential problem, the application of a layer of low permeability inert material upstream of the plug will be prudent, since this will inhibit dissolution of the concrete.In such circumstances, the dissolution of cement-filled fractures in the surrounding rock mass should also be assessed.

To resist degradation of the concrete in contact with ARD, it is recommended to use a specific concrete formulation adapted to such case. The parameters to be considered by a cement chemist include source, type and rate of acid production after plug closure, neutrality of groundwater in surrounding rock, availability of free oxygen, permeability of cement grout, hydraulic gradient at plug, permeability of grouted rock mass, and cement content in the annulus of grouted rock around the plug.

Preparation of the site

As already indicated, the plug must be located in sufficiently competent ground. However, ground movements (roof convergence and floor heave) are inevitable in most underground coal mines, so supplemental roof supports should be also installed.

Depending on the rock type, it could be necessary to carry out a scaling, in order to obtain a sound rock, but where stress-induced fracturing or friable rock is encountered, scaling should continue for a higher depth before approval of the surface is given.

After scaling and cleaning, the plug dimensions should be surveyed at one-meter intervals to estimate the volume of the plug, determine the final shape, to ensure that the natural irregularities in the shape are adequate, and to prepare as-built drawings. Afterwards, and if a tapered plug type has been designed, anchorage will be done.

Concerning the pre-grouting of surrounding rock mass, during the design phase and if needed, the most appropriate type of grout and the injection pressures should be determined. A series of holes will be drilled into the strata and water will be injected to determine the acceptance characteristics of the local rock; that is, the rate at which the rock will take up grout at given pressures.

Where it is judged that permeable features are remote, e.g. greater than 2m, measured normally from the face, stage grouting of these features in a primary-secondary sequence should be considered in advance of plug construction, as it may not be possible to carry out cost-effective grouting via conventional inclined plug tightening holes after construction of the plug.

Study of the range of fracture thickness determines the most appropriate grout mixes to be employed. There are four basic grout materials: Portland cement, asphalt, clay and chemical grouts. Technical literature and field experience show that Portland cement and chemical grouts are the most effective for coal mine strata [5].

Start of pre-grouting should commence at a distance from the gallery rock face of, e.g., 1 m. A grouting of 1 meter radius will overlap with the future plug, avoiding the flow of water between the limit of grouted zone and the plug.

On completion of pre-grouting, independent verification holes located between the grout holes should be subjected to water testing to determine the residual watertightness attained in the rock mass. Supplementary grouting can be directed, if necessary, until the specified residual watertightness is attained.

An important experience from rock grouting is that the penetration depth of even fluid grouts into natural fractures is small and the sealing effect rather limited if the rock is not confined or supported. Thus, grouting of the walls of a blasted tunnel is not effective, while post-grouting around when the plug has been constructed, may give good results.

Plug construction

There are several methods to construct a plug:

Mass concrete

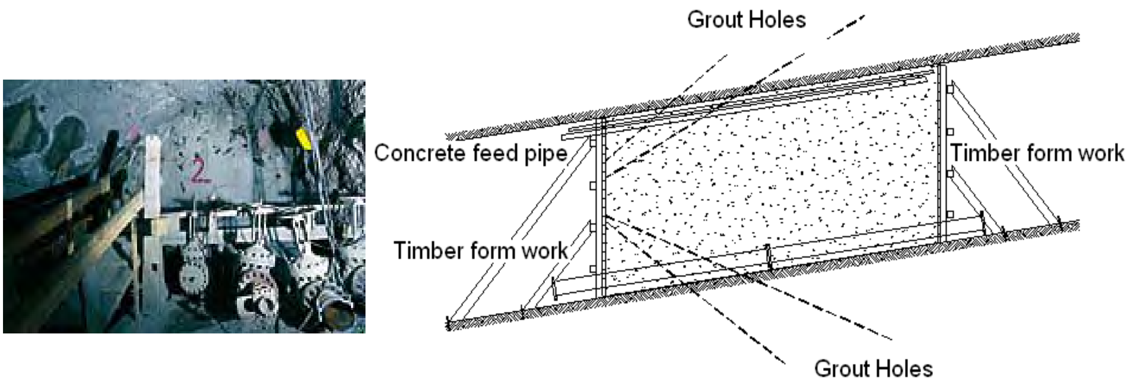
This method has been the most used since the first plugs were constructed to seal tunnels (middle of the 20th century). It consists on the pouring of the concrete by gravity displacement in vertical layers of a thickness. The concrete is retained by forms (generally constructed in timber) during placement and curing. The thickness of each layer is regulated by the dimensions of the gallery and by the hydration heat of the concrete. When a batch is finished, the form is taken away and replaced to construct a new batch. The dry face of the plug is scabbled by chiselling or by grit blasting in order to expose the concrete and create a rough surface onto which the new batch can bond, avoiding preferential leakage path.

Figure 7: Front view and longitudinal section of the plug constructed at McArthur River Mine (Can.) *[6]*

Mass concrete plugs have been used for major water ingress emergencies in a mine, for waste isolation, or for the design of a mine closure. In the first case a number of pipes are used in order to evacuate the water from the upstream side during plug construction, remaining in place through the plug after the construction.

Shotcrete

Shotcrete or sprayed concrete is a basic cementitious mix projected pneumatically at high velocity onto a surface to produce a dense homogeneous mass compacted by its own momentum. Shotcreting provides a very good



contact between concrete and rock, filling all voids and holes, even at the roof part. In addition, a good quality shotcrete has a lower porosity and permeability than standard concrete, and can be easily reinforced using fibres. Another practical advantage is that forms are not needed, and therefore the plug can be constructed very quickly. On the other hand, shotcrete is normally used in relatively thin layers (max. 30-40 cm) to able the release of the hydration heat of the concrete, and the construction of a plug several meters long requires a careful consideration of aspects such as construction time, cohesion between layers and the thermal effects during setting.

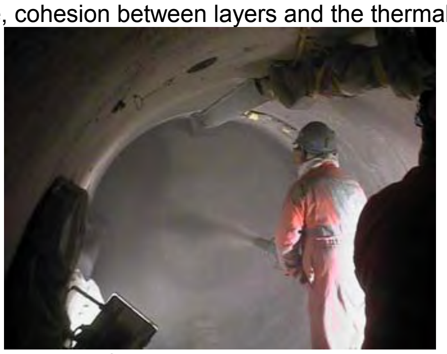


Figure 8: Example of shotcrete plug at Febex experiment *[7]*

Use of other materials

A low-permeability bentonite/soil mixture can be an alternate design to lengthen a plug at a lower cost than concrete and grouting. Bentonite clay provides the low permeability needed in the plug and its swelling properties improve contact at the crown of the tunnel, which is often hard to fill with concrete (when using mass concrete). Swelling of the bentonite/sand mixture upon contact with water precludes the need for expensive contact grouting. A filter zone surrounding the bentonite/sand core provides confinement as the bentonite is hydrated and also protects the core from erosion.

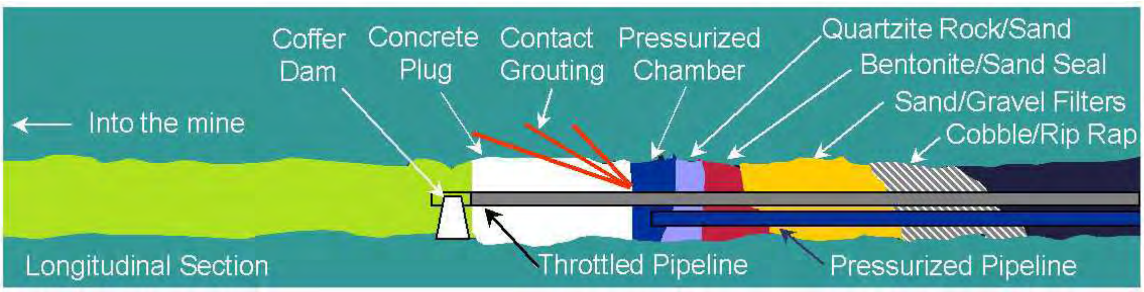


Figure 9: Millenium plug *[8]*

Earth-plugs are analogous to earth-darms but constructed underground. The underground earth-plug consists of an impermeable sand/bentonite clay core and a graded earth filter zone downstream and shells.

INSTRUMENTATION FOR PLUG PERFORMANCE SUPERVISION

Due to several reasons the performance monitoring is an essential component of successful plug construction and operation. Then, instrumentation is used to determine the initial conditions at plug site, monitoring during construction, and assist long-term monitoring.

The basic criteria for adequate instrument selection are:

- Reliability of measurements (range, resolution, accuracy, repeatability).
- Long-term stability and instrument longevity.
- Environmental conditions such temperature and humidity.
- Ease of automation for real time monitoring and efficient data management.

However, recommended instrumentation for plug performance supervision will depend on the type of plug constructed and the functions to be fulfilled.

The basic parameters to be monitored to asses the plug performance are:

Pressures

The host rock is always under pressure. The pressure carried by the rock particles in contact with each other is called *effective stress*. The pressure of the water in the voids is called *pore pressure*. The combined pressure of the weight of a rock and any applied load is called *total pressure*, being then equal to the effective stress plus the pore pressure. Therefore knowing the total pressure and the pore pressure is feasible to know the effective stress.

There are commercial instruments available to measure such parameters:

A total pressure cell measures the total pressure applied to the rock. It consists of two steel plates edge-welded together to form a sealed space (see Figure 10). The space is filled with fluid. A high pressure tube connects the cell to a pneumatic or vibrating wire pressure transducer. One plate acts as active face of the total pressure cell and is placed in direct contact with the rock. The other plate may be in contact with rock or fixed to a recess in a plug. Loads applied to the active face are transmitted to the fluid inside the cell and measured with the transducer.

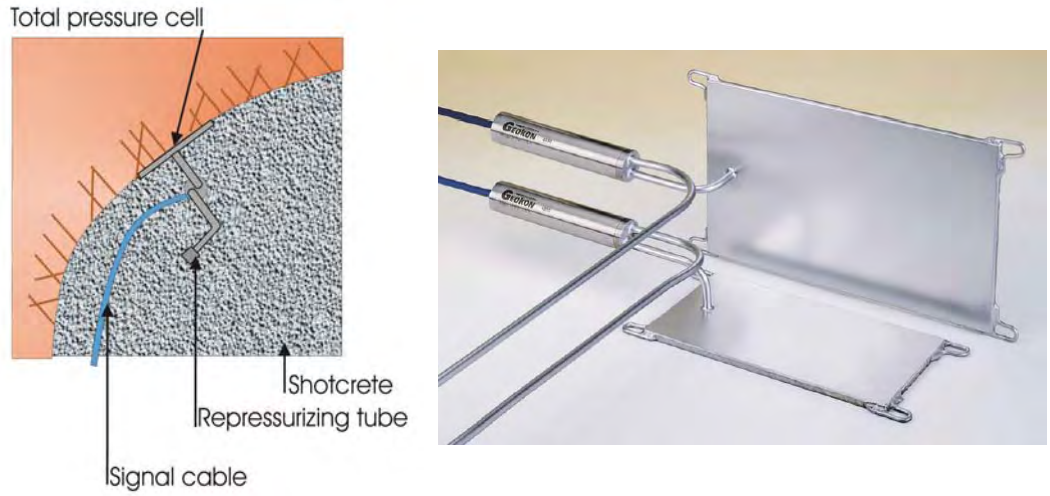


Figure 10: Total pressure cell *[9]*

A *piezometer* measures pore pressure and ground water levels. It is based in a small filter chamber that is confined inside a rock borehole or in the plug body (see Figure 11). The filter chamber is filled with water that with time reaches equilibrium with the pore pressure. The chamber is connected with a pressure transducer that measures the pore pressure.

They used to be applied to measure:

- Total pressure at the rock-plug contacts.
- Pore pressure in the plug and in the surrounding rock.

Figure 11: Pore pressure sensors *[9]*

Movements and displacements

Ground movements (roof convergence and floor heave) are inevitable in most underground coal mines. Furthermore, movements of the rock and of the plug could be provocated by the pressure applied to the plug and transmited to the rock.

There are several commercial instruments available to measure such movements:

The *tape extensometer* is used to determine changes in the distance between pairs of reference studs or eyebolts grouted into shallow drill holes in the structure or excavation (see Figure 12).

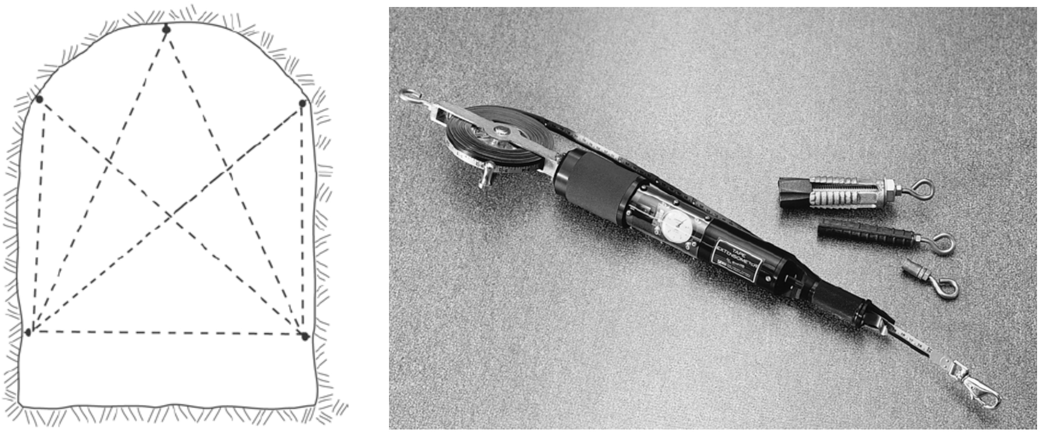


Figure 12: Tape extensometer

Typical applications are:

- Monitoring radial movement, convergence and deformation of tunnels and shafts.
- Studying the effectiveness of the roof of a mine or underground cavity and monitor its behaviour during the excavation operation.
- Displacement and stability of retaining walls or other concrete structures.

The *crackmeter* is suitable for surface monitoring of movement at joints and cracks in concrete structures or rock. One-dimensional crackmeter will be used if the expansion of a joint is the only movement to control (see Figure 13). However, it is possible measuring displacement in 3 axes.

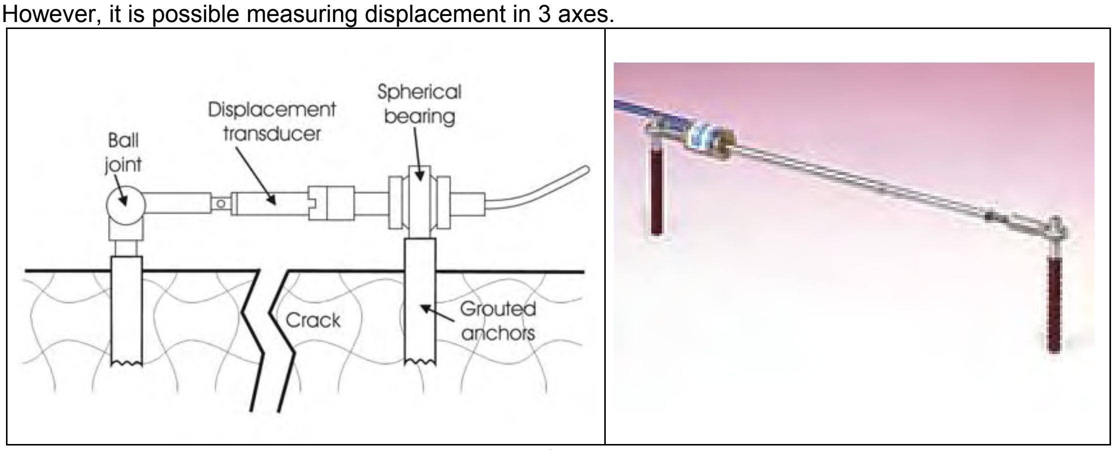


Figure 13: Crakmeter *[9]*

Typical applications are displacement of surface crack expansion joints and relative movements of the plug with regard the rock.
Conventional extensometers (type LVDT, potentiometer or similar) are suitable for plug surface monitoring or in-borehole rock relative movements.
They used to be applied to measure:
- Surface rock movements with regard to deepth fix points (borehole type)
- Displacement of the plug face

Temperature

The evolution of the temperature in the rock around the plug could be used to detect changes in the water distribution, in the rock stability, strength and chemistry processes. During construction phase, the temperature evolution in the concrete plug need to be controlled to avoid cracking.

Seepages

To detect changes in the plug performance with regard to water isolation, the water flowing around the plug influence area should be collected and measured. One way to do so is to locate concrete ditches across the gallery to divert the water to a gauging box or slot where the water level is measured, for instance using an ultrasonic transmitter.

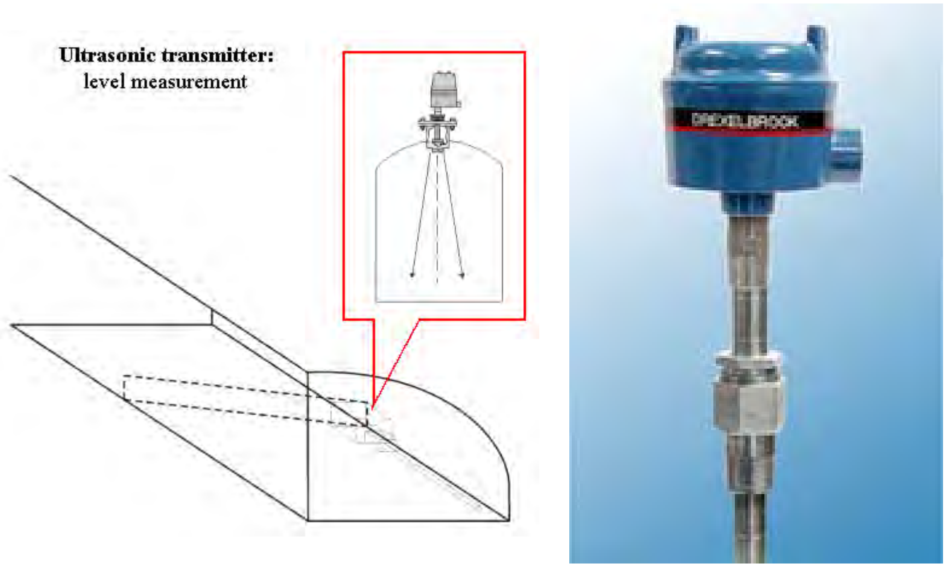


Figure 14: Flow measurement principle. Ultrasonic transmitter.

In active mines, where access is still available, routine inspections of the dry side of the plug looking for visual seepage or leakage through or around the plug are envisaged.

Pressure release

In active mines and when necessary, the plug can be provided with a pressure release pipe equiped with a valve and local water pressure measurement in order to reduce the pressure applied to the plug. A generic scheme of the instrumentation that can be applied for the plug performance supervision is given by Figure 15.

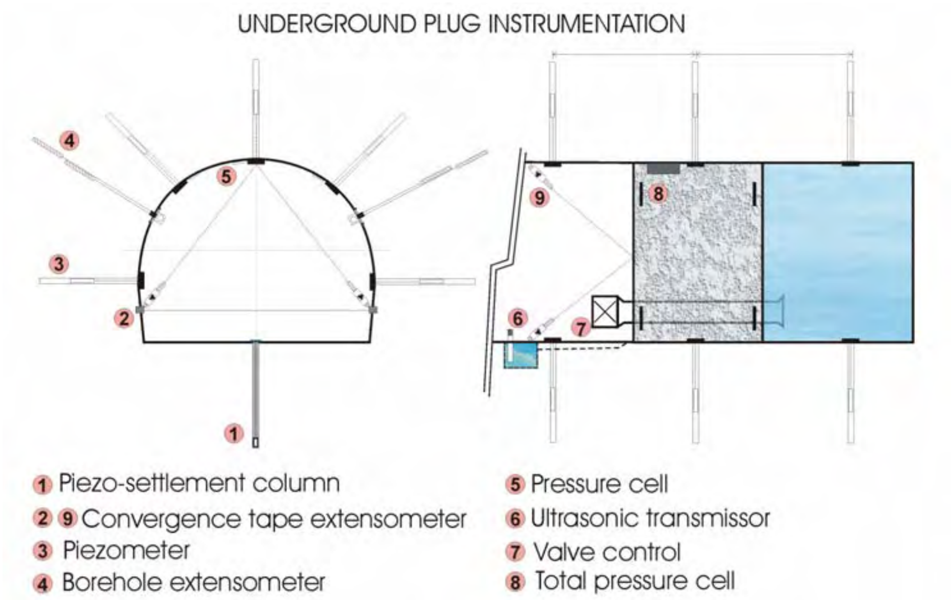


Figure 15: General scheme of instrumentation for an underground plug monitoring

SUPERVISION AND CONTROL OF THE GROUNDWATER LEVEL

Monitoring the potential preferential pathways is necessary to evaluate the hydrogeological performance of plugs. In order to carry out this control a water level observation net must install around the plugs.
The net must be integrated by boreholes intercepting the main geological structures (main potential preferential pathways). Each borehole must be completed with packers to isolate the main structures. The water level must be measured with pressure sensors on each borehole section: above, below and in the structures.

GENERAL REMARKS AND CONCLUSIONS

Tunnel plugs are significant engineering structures. Plug failures like those succeeded in the Marcopper Mine (Thailand), Merrispruit Mine (South Africa), or in Colorado Mine (USA) [9] shows us that a good construction and design, a well recognized assessment and a quality plug performance are basic to build a safe structure that will remain secure for a long period of time.
Long term sealing of mine adits can be effectively achieved using unreinforced concrete plugs. The length of the plug is governed by the allowable hydraulic gradient and the shear strength of the concrete and surrounding rock mass. A thorough geotechnical and hydrogeological assessment is recommended for any permanent plug. These studies will ensure that the plug is located in the best possible location to ensure the effectiveness of the seal and to reduce construction costs.
An allowable seepage and positive expected results in the plug testing will ensure the correct construction of the plug. Instrumentation of the plug is recommended, and its monitoring will change according to plug's feature, security design and expected service lifetime.
When a longer term than 100-year service lifetime is required, the designer must consider measures above and beyond the standard requirements presented. These measures may include installation of impermeable coatings upstream of the plug to reduce seepage, a longer plug length, and/or a clay core "earth plug" analogous to an earthdam.
The best design could be useless if there is not a strict quality assurance control during construction. It is strongly recommended that the design engineer be on-site during construction to modify the design if necessary and to ensure that the final as-built plug complies with the design objectives.
Concrete combined with other materials or concrete plugs are chosen depending on the time to actuate and the different characteristiques of each plug. Shotcrete plug is a technology used recently that offers new advantages with regard to mass concrete plug construction.
Hunosa and Aitemin will continue with the research activities in the frame of the Waterchem Project. Next step will be to look for a good place in an underground mine where to put in practice a water sealing plug using the shotcreting technique.

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