GROUND SUPPORT IN KARSTIFIED CONDITIONS

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Abstract

The Lisheen Mine is an underground operation sited in the midlands of Ireland. Using a combination of open stoping and room and pillars 1.5mtpa of zinc /lead ore are mined

The ore body is essentially tabular with a general thickness of 3-8metres but with large local areas in excess of 20 meters.

The host Waulsortian limestone is extremely faulted and karstified allowing major water inflows and weathered rock conditions.

The primary ground control concerns are the extensive wide-open fissures and cavities with clay/ sand infill sometimes with water inflows and the widespread horizontal weathering on the hanging wall contact.

The shallow (200m) nature of the ore body combined with a low stress regime, extensive vertical faulting and jointing inhibited the ability to design large unsupported spans.

It was evident early in the operation that it would be necessary to predict the location and severity of the features and poor ground.

Following an extensive surface and underground drilling program and verified by early underground exposures a ground condition prediction plan was developed.

The ground classification was simplified into four types using local parameters, for each of which a support design and methodology was developed.
This assists in the design layout of the stope panels and location of long-term access ways.

A simple extensometer monitoring and ground behavior observation program was carried out with limited numerical modeling and back analysis using suitably modified rock parameters.

Given the non-homogeneous nature of the hanging wall rocks this was essential in confirming the effectiveness of the support and design of the pillar dimensions.

The analysis combined with the late introduction of paste fill caused major mining design change from a drift and fill operation to a predominately room and pillar mine.

A reappraisal of our support requirements was then carried out which indicated a far more proactive rather than passive support method. A robust set of support procedures was developed, a ground awareness training program was instituted and a suite of support equipment was either purchased or modified.

Mechanized roof bolters were allocated to the mining sections and a dedicated rehabilitation crew established to deal with non-standard support requirements.

To deal with the weathered ground in access development a combination of tunneling and mining technology was employed initially using fore poling and lightweight steel sets and brattices.

An NATM type combination of shotcrete and cable support is currently employed with significant improvements in advance rates and safety.

A truss cablebolt methodology has been developed to negotiate through open features some as wide as 3m and usually infilled with sand/clay and more often than not making water.

In open stopes with no hangingwall access fiberglass cablebolts are remotely installed in extended production blast holes to reduce dilution and control hanging wall stability in weathered ground.

Where access is possible passive cable bolts and shotcrete are successfully used to support weathered ground over large spans.

The ability to predict poor ground conditions has allowed the mine design to be tailored to suit area conditions. A support methodology is developed to match the required development and subsequent stoping.

The specialist rehabilitation crew focuses on supporting critical development ends and preparing stopes for scheduled production. This allows a combination of resources and skills to be concentrated on what may be extremely bad ground and the best solution applied.

1. Introduction

The Lisheen carbonate-hosted Zn-Pb deposit is located in County Tipperary in central Ireland. It contains 17.9 million tonnes of massive sulphides averaging 15.8 % Zn and 2.6 % Pb. The deposit is largely flat lying at a depth of 130-200 m from surface. It exhibits a high level of variability in grade, geometry and geotechnical character due to complex geological controls that governed its genesis.

The mine is owned and operated by Anglo American plc and employs about 350 permanent staff. It is an underground, trackless operation, accessed via a decline.

Production started in September 1999 and, at an annual production rate of 1.6 million tonnes of ore, is scheduled to continue until early 2014.

Three separate mining methods are employed: Room and Pillar, Drift and Fill and Long Hole stoping.
Selection of the mining method is mainly determined by ore thickness but other factors including grade continuity, geological complexity and economic value are also considered. The majority of development is planned in ore and a major mining constraint is the high water inflow of 86ml a day.

1.1 Geological setting

The deposit is hosted by Lower Carboniferous hydrothermal breccias. These are developed at the base of a 200 m thick, massive biomicrite unit, the Waulsortian Limestone Formation, which in the mine area is extensively dolomitised.
This unit lies conformably above a package of medium to thick-bedded, argillaceous bioclastic limestones (ABL) that form the lithological footwall to the mineralisation.

1.2 Structural setting

The Lisheen deposit comprises three main economic orebodies, i.e. Main Zone, Derryville Zone and the three Bog Zone pods.

These orebodies are sited in the hanging walls of extensional faults with displacements of the order of 200 m referred to as the Killoran, Derryville and Bog faults, respectively. They form a series of northerly dipping, echeloned structures.

The faults are considered to be the primary control on the location of the orebodies. The ore is thickest in their immediate hanging walls, mineralisation is largely absent in the ramp-relay zones.

The detailed geometry of the deposit, however, is controlled by smaller displacement, low-angle faults and slides with short strike length. These faults appear to be confined to the Waulsortian – ABL contact zone.

1.3 Alteration

Two post-mineralisation structural episodes have significantly complicated the local orebody geometry.

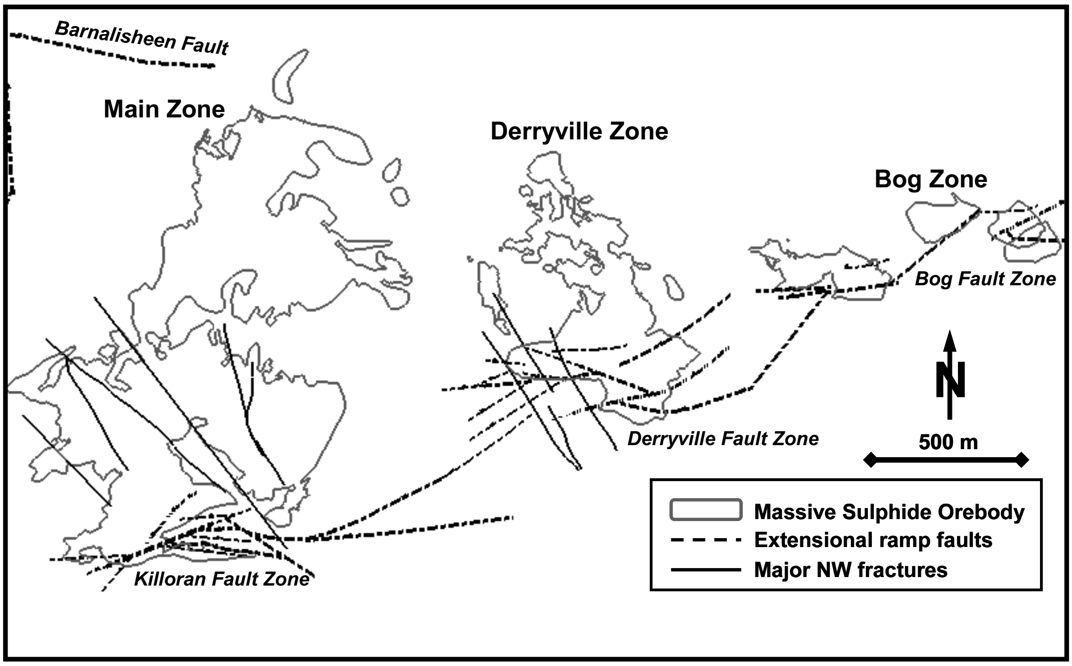
A compressional event has inverted many of the pre-existing normal structures. Folds are commonly developed, centred on or sub-parallel to the smaller extensional faults. Larger compressional features are present where there has been buttressing against the footwall of early extensional structures. Here, thrusting has severely impacted orebody geometry and in Bog Zone East has duplicated the ore horizon.

A second episode produced sub-vertical, NW dextral wrench faults termed F-series with widespread associated NNW accommodation faults.

Most of these structures have minimal displacements and short strike length, although some can be mapped across the mine and can be up to 3m in width. They are typically filled with a coarse dolomite or a calcite gangue and are the main source of water inflow to the mine. These structures locally dislocate the orebody and are extensively karstified and severely impact geotechnical conditions.

Areas where these fault types coalesce are normally zones of intense disruption with very poor ground conditions over a large scale horizontally that tend to be cavernous.

The pervasive jointing is steeply dipping, sub vertical and sub parallel to the F-series faults. It is more intense in the hangingwall rocks and can be highly weathered.



1.4 Stress Environment

The horizontal to vertical stress (K) ratio of between 2.0 -2.5 is extrapolated from regional measurements. The orientation of maximum principal stress is assumed to be NW-SE i.e. parallel to the F-series faults. The horizontal stress component normal to the principal is substantially lower given that many of the major structures have extensive cavity development.

2. The challenge

The primary ground control concerns are the extensive wide open fissures and cavities with clay/sand infill sometimes with water inflows and the widespread horizontal weathering on the hanging wall contact.

Ground failures ranging from mudflows from fissures to large chimney type caves to unsupportable spans have to be anticipated.

The shallow (<200m) nature of the ore body combined with a low stress regime, extensive vertical faulting and jointing inhibited the ability to design large unsupported spans.

The location of the mine in what is a valuable agricultural area means that the integrity of the surface must be maintained.

The ability to manage what effectively is a loose rock mass in a low tensile hangingwall beam by a combination of mining design and rock reinforcement has been the challenge at Lisheen mine since startup.

3. Approach

The approach adopted to deal with this challenge can be outlined as follows;

3.1 Identify the risk.

Following an almost disastrous intersection with a major water bearing feature while developing the main access way a reappraisal of ground conditions was undertaken.

This identified the karstified ground conditions with the accompanying water inflow as the major risk for the mine. The water inflow varies between 85 - 95ml a day.

A major geotechnical review of all surface boreholes was carried out. In addition a series of flat underground well holes were sited in the hangingwall of the orebody for dewatering.

These provides a two dimensional model of the major features and ground conditions.

3.2 Prediction

As well as geotechnical logging each hole the ore zone and immediate hangingwall was photographed and placed on a networked database.

It was apparent early on that none of the more common ground classification systems were suitable for describing the ground conditions at Lisheen and a site specific system was developed.

The most critical parameters affecting local ground conditions were selected. These were Rock Quality Designation, Joint Set Number, Fracture Frequency and Joint Alteration.

This information was then overlaid with the known and predicted structure to produce a simplified computer layer showing the ground conditions for a 2m thick beam in the hangingwall.

Four ground condition types were selected for each of which a support design and methodology was developed.

This prediction layer is used to assist in the mining design as well as scheduling of development rates and extraction sequences.

3.3 Methodology

Over the life of the mine approximately 20% of the ground exposed will be in the poor to very poor class. Typically this will occur as either singular fissure type features or extremely weathered roofs in development drives. In wide spanned stopes this may result in an uncontrollable hangingwall causing massive dilution of the ore and chimneying to surface.

The New Austrian Tunnelling Method (NATM) was considered to be the best approach for supporting the poor ground and the design and construction methods were adopted to suit local conditions and resources.

Utilising this method the ground around an excavation is deliberately mobilised to the maximum extent possible by allowing controlled deformation.

Initial primary support is installed having load-deformation characteristics appropriate to the ground conditions and installation is timed with respect to ground deformations.

The initial ground support is provided by shotcrete followed by bolting. This is usually followed by a combination of fibre reinforced shotcrete and birdcage cable bolts. On occasions reinforcement in the form of weld mesh, lattice girders, spiling or truss cables are used.

A set of support standards was designed to cater for good ground conditions and situations considered normal in mining. However it was decided that non standard conditions required a focused team and approach so as not to impact on development.

3.4 Resources

The ‘soft’ and wet nature of the hangingwall rock made the adoption of a resin bonded non yield rebar necessary. The need to install approximately 20,000 rebar's a year necessitated the usage of an automated bolting system.

Three Atlac Copco Boltecs provide the standard support for the mining sections. They drill and install a 2.4m long Y25 rebar in a 33mm hole tensioned using two speed resin to 5 tonne.

The dedicated non standard support crew is provided with a Spraymec 1050 WPC shotcrete machine to spray approximately 8,500m3 of shotcrete per year. The requirement to construct an engineered backfill barricade utilises approximately 35% of this shotcrete, the remainder going to support.

A minimum thickness of 50mm is used to seal poor ground with an unreinforced shotcrete. In very poor ground a 75mm thickness of synthetic fibre is used at the rate of 6kg/m3 to achieve a strength of 50MPa at 28 days with an energy absorption of 700 joules.

An Atlas Copco LC2 jumbo was modified with a basket and shorter slide to serve as a cablebolter. Using extension steel, holes as long as 25m by 51mm have been successfully drilled to install cablebolts.

The standard cablebolt used is a 15.2mm Birdcage with a nominal cage size of 38mm and a bearing capacity of 250kN. The bolt length can vary but the standard is 6m long. Most cables are face tensioned. This type of cable is very suited to the soft ground conditions allowing a weaker water cement ratio to be used to obtain a better bond strength and fill all cavities and cable cages.

4 Implementation

4.1 Development

The geotechnical layer is used to assist in predicting features and ground conditions. The features are then probed to find the extent of bad ground and water. The appropriate support is then planned. Development will continue with a standard 1.5m diagonal rebar support pattern being installed until the poor ground is encountered. Three distinct types of support may then be required;

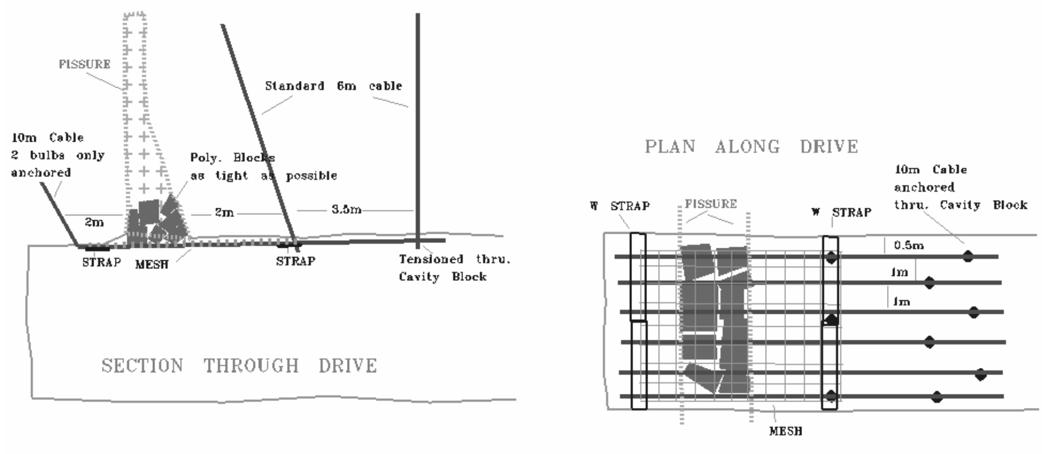
4.1.1 A NATM style approach is used where it is possible to utilise the ground to develop a self supporting arch. The early application of a thin layer of shotcrete to seal the ground is followed by a pattern of bolts or cables to provide rigid support and deep anchorage. Permanent support is then applied as a thicker layer of synthetic reinforced shotcrete sometimes with mesh and straps or a combination to suit the ground.

4.1.2 In areas where it is not possible to develop a ground arch i.e. flowing ground or ground with short stand up time, a ground improvement approach is adopted. This is normally done by spiling with a fan of birdcage cables, dewatering if necessary and sequentially excavating the ground by taking shorter rounds and resuing from the bottom up. It may require several passes to stabilise this type of ground but once the required excavation profile is achieved permanent support in the form of mesh or lattice brattices is installed and a thick layer of shotcrete applied.

4.1.3 Open fissures with the risk of loose material falling from a height are negotiated and secured using a truss sling method.

Once the fissure is intersected and opened its full width (usually the same round) the brows on both sides are scaled and secured by shotcreting. Ahead of the fissure a series of short holes are drilled parallel to one another and angled upwards. A modified Birdcage cable with only two bulbs is then installed and grouted in place. Weld mesh sheets are threaded through the parallel cables and worked under the fissure. The free ends of the cables are passed through a locking block already installed on cables securing the brow ~5m back and loosely slung.

Polystyrene blocks are cut to size and placed on top of the mesh and manoeuvred into position under the fissure. They are used to fill as much of the open cavity as possible. The truss slings are then tensioned and the sealed cavity shotcreted to minimise the risk of fine material falling through. If water is present in the fissure it must be channelled off by shotcreting in appropriate lengths of 50mm pipe.



NEGOTIATING FEATURES USING TRUSS CABLES

4.2 Stopes

The extent and severity of the poor ground will dictate the stope span, orientation, sequencing and support method.

In most of the mine, stable spans of 10-15m are possible without additional support. No man access is allowed and mucking is by remotely operated LHD. Stand up time is minimised and paste backfill is used to fill the cavities, confining the sidewalls and roof as soon as possible.

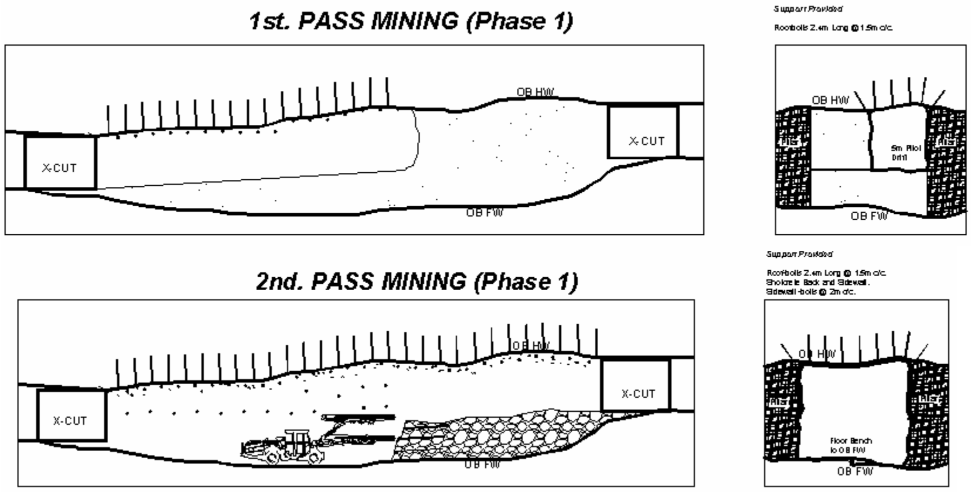
However, where ground conditions are poor three separate methods are used to safely maximise extraction.

4.2.1 If access to the hangingwall is possible a development drive is made and supported as described in 4.1.1 above. From this access additional support is installed to allow the optimum width of the stope to be obtained, usually 8-10m.

Depending on the thickness of the ore the remaining body of the stope can then be removed by either benching or longholing from a footwall drive.

Failure to presupport these hangingwalls can result in very quick unravelling and chimneying (in one case 18m high) that are difficult to contain and stabilise.

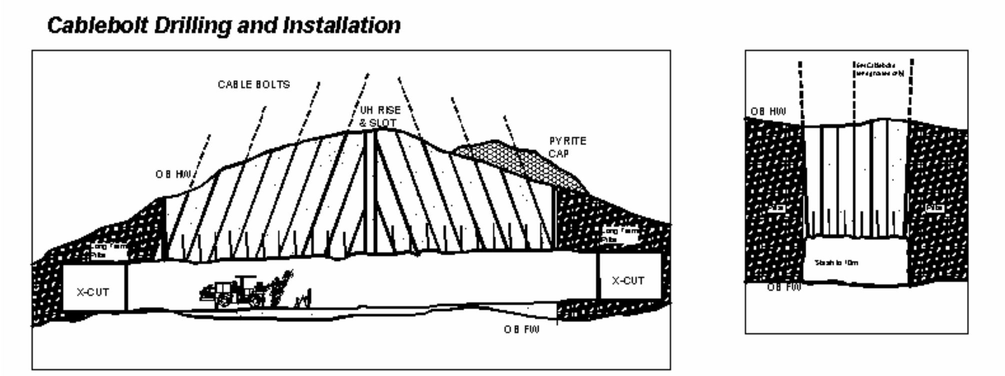
The utilisation of the shear component of a mandolin style design of long (25m) cablebolts was found necessary to stabilise one such failure.



4.2.2 Where access is not possible or the ground is extremely poor it is necessary to presupport the hangingwall from the footwall.

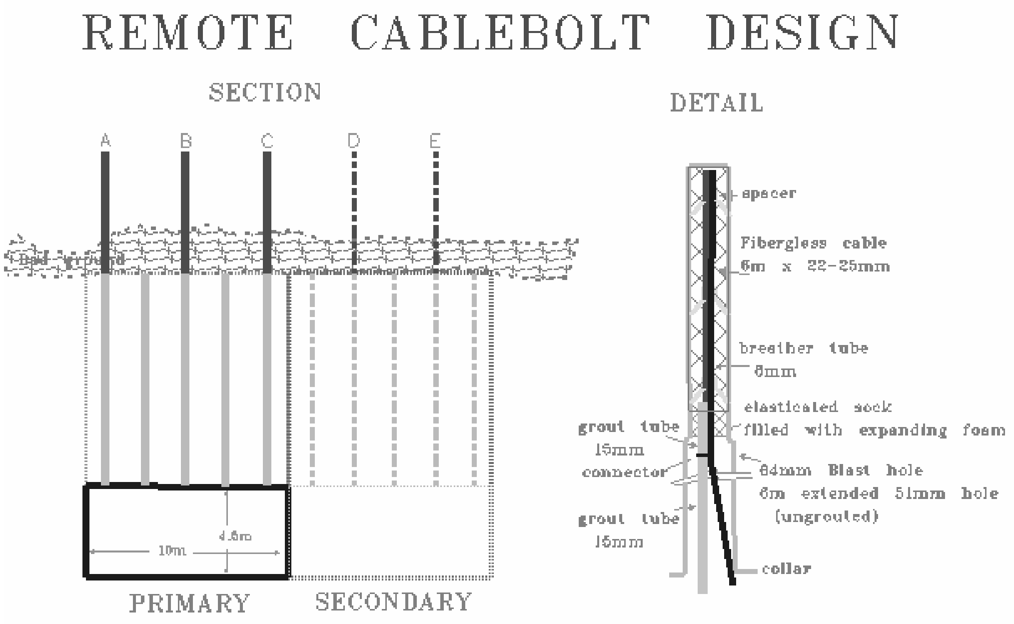
This is accomplished by developing the footwall drive and longhole drilling off the stope with 64mm holes. The critical areas are then identified that, if left unsupported, would cause either unacceptable dilution or an uncontrolled collapse of the hangingwall.

Following a designed pattern some production holes are extended into the poor ground using a 51mm diameter hole. A 6m long 22mm solid fibreglass cable is then installed remotely into the end of the hole. Using expanding resin foam in an elastic stocking secured to the cable and grouting tubes a delayed seal is be obtained at a predetermined position. This allows the support unit to be grouted leaving the production hole clear for charging.



4.2.3 Where the orebody is between 5-7m thick a drift and fill method is used. The standard practice is to develop a 6m wide drive and, in the case of secondary stopes, between paste filled primaries, install additional support in the form of cables to cater for the enlarged spans.

A hammerhead is created at one side of the drive when it reaches its designed limit, opening the span to 10m wide. The 4m wide sidewall pillar is then longhole drilled and mined in incremental stages using remote mucking. It is imperative that these stopes are prepared, sequenced and mined in a controlled manner as they are one of a series creating spans in excess of 150m and relying on paste backfill to provide panel support.



4.3 Pillars

The unconformability of the orebody geometery means that several areas must be mined using a room and pillar technique. With the poor roof conditions forming the hangingwall of many of these panels it was found impossible to develop a realistic pillar design. Because pillars are in good quality massive sulphides, the pillar strength always exceeded that of the poorer quality hangingwall, and the possibility of designing narrow pillars that would punch the roof was always a risk.

It was therefore decided to reduce the risk by limiting the span of the rooms and keeping the pillars at a standard safe dimension to allow easier extraction on retreat.

The completion of the primary development in a panel would give a 76% extraction rate depending on the orebody thickness and ground conditions.

Following economic, structural and geotechnical evaluation of the panel, an extraction sequence would then be developed. A lot of preparatory work may be required to manage water makes and install additional support and remote monitoring before mining can commence.

The size of the pillars at 6-10m wide allowed us to longhole drill and blast them in one pass followed by remote mucking. The maximum unsupported span is kept to 50m. The void is either packed with waste rock pushed tight to the roof with a 'rammer jammer' fitted to an LHD bucket or paste backfilled. The main purpose of this filling is to limit the extent of any roof failures. Practice has shown, and monitoring confirmed, that timeously and strategically placed waste/paste filling plays a significant role in maintaining the interlinking of the hangingwall. Panels of 150m square have been successfully extracted with an average recovery of 97% of the ore.

5. Managing

5.1 People

An emphasis on ground awareness at Lisheen has enabled the workforce to be very knowledgeable of the various ground conditions. More detailed training on reading the ground is given to all people involved in support work. At supervisory level the emphasis extends to risk assessment, panel examinations and monitoring.

The geological technicians who examine each working face act as an early warning by reporting any change in ground conditions.

All incidents of a geotechnical nature are reported, recorded and are discussed quarterly to identify trends and find solutions.

5.2 Control

The three sections of the mine use the Boltecs to install standard development support. However when poor ground is encountered the specialist rehabilitation crew is used to focus on supporting the critical development ends and stopes.

This allows a combination of resources and skills to be concentrated and the best solution applied.

In many cases it is necessary to use a multi stage approach to the problem and a support design is drawn up. However in most cases the experience of the crews is such that the application of non standard support is almost standard.

5.3 Monitoring

The almost total extraction of an orebody of the extent of Lisheen and at such depth would in itself be reason for close monitoring. The additional problem of such poor hangingwall conditions requires a staged approach to ensuring the stability of the mine and integrity of the surface. The approach has been to ensure that every excavation is stable from development drive to stope to panel.

Tell tales or magnasonic extensometers are used to monitor near field stability in sidewalls or roofs. Multi Point Borehole Extensometers are installed in selected panels to monitor the roof beam behaviour. Contractometers are installed in paste pillars to monitor paste behaviour and tertiary pillar removal.

Vibrating wire stressmeters are used to monitor stress redistribution in regional pillars. In addition, an extensive network of precision levelling stations is installed on surface and these stations are currently read twice a year.

6. Continuous Improvement

Experience at the Lisheen mine shows that mining in karst ground conditions is possible with the adoption of relevant ‘soft ground’ tunnelling techniques. We believe that there is room for further improvements both in techniques and equipment that can contribute to safer and more efficient methods of supporting such ground. The main emphasis at Lisheen in the future in seeking such improvements will be on the following.

6.1 Cablebolting

Poor ground conditions require a cablebolter able to remote drill, thus removing the man from the risk of falling ground. The ground itself will require the installation of a modified cable. The ability to precondition the ground by spiling or grouting would be a major advantage.

6.2 Shotcrete

The irregular nature of the excavations and geometry of panels means that the nozzelman must have direct control of the spraying. To allow closer contact between the nozzle and face and yet keep the nozzelman safe radio remote controls are now used.

The availability of suitable sands and aggregates is a constant quality control problem. The requirement for short life duration of most of the excavations and the advent of a new generation of plasticisers leaves room for work on replacement of some of this materials with crusher dust or mine tailings, both of which are readily and cheaply available.

Shotcrete is expected to support a large variety of ground conditions ranging from a dry cohesiveness sand to a well jointed rock mass with running water. This can result in poor quality shotcrete being placed. A range of ground improvement additives now available will be investigated with the aim of obtaining a consistent acceptable material.

6.3 Bolting

The installation of weld mesh is labour intensive and exposes men to the risk of unsupported ground. A method of remotely installing mesh using the current Boltecs is required and will be investigated.

The structures developed in paste means that, when exposed by mining alongside, support is required. This consists of bolting which is primarily used to assist in the adhesion of a shotcrete layer. An appropriate soil nailing technique is required that is both cheaper and more effective than a Y25 rebar.

7. Conclusions

The ability to identify and predict poor ground conditions has allowed the mine design to be tailored to suit area conditions. Support methodologies are developed to match the required development and subsequent stoping.

The use of a specialist rehabilitation crew to focus on supporting critical development ends and preparing stopes enables schedules to be maintained. It allows a combination of resources and skills to be concentrated on what may be extremely bad ground and the best solution applied and managed.

Acknowledgements

The paper is based on the observations and experience at The Lisheen mine and draws on its practical application. The author gratefully acknowledges the support of Anglo American and The Lisheen Mine for permission to publish this paper.

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