Safety and health in mines research advisory board Annual review 2008

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Introduction

The Safety and Health in Mines Research Advisory Board (SHMRAB) is one of the Health and Safety Executive's (HSE) advisory bodies and is a sub-committee of the Mining Industry Committee (MIC). It is chaired by Her Majesty's Chief Inspector of Mines and has members representing employers and employees in the British mining industry. Current members and others who contributed during 2008, are listed in Appendix 1[10].

Contact details for more information on the research houses and individual projects mentioned in this review can be found in Appendix 2[11].

Fire and explosion

Experimental Investigation of Oxygen Hose Failures at Mines

Following a number of incidents involving the failure due to ignition of oxygen hoses in UK mines rescue stations, HSL's Explosion Safety Unit was asked to conduct an experimental investigation into the ignition mechanism that could be causing these hose failures. All of the incidents had occurred during the process of charging oxygen cylinders, although the stage at which the failure occurred had varied during each of the incidents. One common feature however was the presence of a bleed valve unit within the charging line and the presence of a dead end at one end of the hose.

Analytical checks at HSL on the bleed valves showed they were not 'oxygen clean' and all contained some degree of contamination. There were also differences in the bore size of the bleed valves supplied, which varied from valve to valve. In addition, the sintered element on one of the bleed valves was found to be fragmented prior to testing. All of these factors could have contributed to an ignition that was capable of causing hose failure.

During the experimental tests, no ignitions were observed, however transient heating, due to adiabatic compression, was observed within the bleed valve once the charging valve was opened. The temperatures recorded on most of the tests were approaching the Spontaneous Ignition Temperature (SIT) of general engineering grease (a potential contaminant).

Ignition of the grease contaminant could have caused a flame that resulted in the hose failure seen during the incidents described.

Acting on the information discovered during this project, the bleed valves involved have been removed from service. To date no further incidents have occurred that have resulted in oxygen hose failure.

Mine Fire Detector: Combined High-Sensitivity Smoke and NO_X/CO Sensors

In UK underground coalmines, fire alarms detect fewer fires than mine personnel, particularly during the early combustion stages. As collieries become more automated, there are fewer personnel to detect fires and, as drivages become longer, the time for evacuation is increased.

Two types of fire detector are used in UK coalmines based on products of combustion (FIDESCO) and carbon monoxide. However, FIDESCO is not user-friendly, susceptible to false alarms and is obsolete. Carbon monoxide sensors are used to detect spontaneous combustion and more developed fires but are insensitive to smouldering conveyor belt fires, which are the predominant type.

Previous work identified that a sensitive fire detector could be based upon a combination of an optical, high-sensitivity smoke detector (HSSD) and an oxides of nitrogen (NOx) sensor to distinguish smoke from diesel fume. However, the HSSD was fitted with a cyclone to remove coal dust and required a powerful pump to maintain airflow. This complicated its use underground and hinders commercialisation. This joint project (HSE, HSL, UK Coal and TES) was therefore initiated to investigate the performance of proposed alternatives to the cyclone-HSSD:

HSSD (Monitair): based on the differential response of a blue/infrared (IR) sensor which does not require a pump.

HSSD (Stratos): similar to the cyclone-HSSD except it uses a filter to remove coal dust and requires a much smaller pump. It can change its sensitivity to match the background dust levels.

Samdetect: uses a neural network to distinguish fire events based upon the outputs of six semiconductor gas sensors. Once trained for use underground it should not need a NOx sensor to distinguish diesel fume.

The equipment was modified and made pit-worthy before simple laboratory testing to check the detectors could perform as expected.

The detectors were exposed to a series of test fires (coal, conveyor belt, wood, Carbofill+, grease and oil, diesel pool fire and smoke from smoke generators) in an aboveground training roadway. They were also exposed to the exhaust from a diesel-powered Free Standing Vehicle. All the detectors responded to the fires and diesel fume except that the HSSD (Stratos) did not respond to grease and oil and Carbofill+ fires, the HSSD (Monitair) did not respond to Carbofill+ fires, and the Samdetect did not respond to smoke from the smoke generators. The NOx gas sensor distinguished diesel fume from smoke.

The detectors were exposed to conditions and particularly coal dust in an underground, out-bye conveyor drive roadway for four weeks. Initial analysis of the results showed that the HSSD (Monitair) produced a large number of false alarms and the HSSD (Stratos) only produced two. The Samdetect also produced a large number of false alarms but its neural network could be re-trained to ignore these events.

The project will continue with a programme of laboratory and underground testing once the neural network has been re-trained.

Ignitability of Coal Mine Methane by Mechanical Sparking

A review has been completed to look at work done at HSL and its predecessors on the ignitability of coalmine methane by frictional sparking from ferrous metals.

The work had been prompted by a particular set of circumstances that resulted in the application of the mechanical wheel brakes on an underground locomotive for a continuous period of approx. 30 minutes. This caused the cast iron brake shoes to reach temperatures of approx 180 deg C and abnormal sparking was reported.

Despite a thorough review, only a limited amount of relevant papers were found relating to these particular conditions.

Under certain circumstances ignitions of methane/air atmosphere have been found to occur.

Underground Fire

HSL had been asked to investigate the mechanism that caused a fire involving idler rollers at a coal mine. The work is still ongoing and is being conducted in conjunction with the project ‘Evaluation and Interpretation of the failure Mechanism of Idler Rollers on Fast Moving Underground Conveying Systems’. Ignition tests will be conducted on the ‘Lifemaster’ idler rollers involved in the incident once results are complete.

Methane Drainage and other Plastic Pipes

Following discovery of a potential ignition risk from the methane drainage pipes used at a coal mine, HSL were asked to conduct electrostatic charging and ignition tests on a section of Yelomine plastic pipe.

Charge transfer tests have been conducted on the pipe at 50% relative humidity to EN13463:2001. It was discovered that the charge transfer was less than the 60 nano coulomb limit set for a group IIA gas.

Subsequent ignition tests in methane/air atmospheres resulted in occasional ignitions at 50% relative humidity (RH) and regular ignitions at 20% RH.

Early Detection and Fighting of Fires in Belt Conveyors [EDAFFIC]

Research activities within Edaffic will deal with the specific topic of fires in conveyor belts and related ventilation issues. All aspects of conveyor belt fires will be addressed, including fire prevention, early detection, combustion processes, new belt materials and firefighting.

Statistically there are high numbers of rollers on conveyors, with many conveyors having in excess of 5000 bearings per kilometre with a ‘normal’ life of 5 years. Given the published failure rates for bearings under ‘normal’ operating conditions, it is possible that, in the dusty and often wet conditions found in coal mines, this design life could be lower. An analysis of reported conveyor fires shows that many could have been prevented with proper maintenance.

The failure mode for bearings generates heat, and collapsed rollers also result in conveyor belt frictional rubbing against fixed structures, which again often generates heat, with the potential to initiate a fire. Uncleared spillage then has the potential to be the cause of a fire spreading.

Most roller bearings fail by inadequate lubrication (36%), by fatigue (34%), by contamination (14%) or by other causes (16%). In the normal life of a machine only 0.5% of bearings are replaced because of bearing failure. Higher standards of bearings with improved lubrication, dust and water seals, or reduction in pulley bearing or load capacity may extend the period between failures, but are unlikely to eliminate the problem. Detection of bearing failure conditions is difficult, but a range of possibilities is being evaluated, including thermal and acoustic options.

Work planned in the next phase of the research will investigate ‘fire spread’ mechanisms and the measurement of fire signatures and point detector responses.

Mine environment

Guidance on Measuring Diesel Particulate

To support preparation of a guidance document on control of diesel exhaust fumes in mines, information was requested from HSL on measuring diesel particulate in coal and non-coal mines. The information provided was based on two existing reports; OMS/2005/04, **‘Controlling and Monitoring Exposure to Diesel Engine Exhaust Emissions in Coal Mines’ and HSE Research Report 252, ‘Controlling and Monitoring Exposure to Diesel Engine Exhaust Emissions in Non-coal Mines’** and the following topics were covered: collection of samples, sample analysis, tailpipe measurements and the ‘blackness’ relationship.

Previously, the ‘blackness’ relationship has been determined using a Bosch Smokemeter, a device which allows mines to measure the amount of diesel engine exhaust emissions (DEEE) from both tailpipe and personal sampling on-site without the need to send samples for laboratory analysis. Unfortunately, this unit is now obsolete and so separate information was provided for those mines with a Bosch Smokemeter and for those without one.

The next phase of the project was to try to find a suitable replacement for the Bosch Smokemeter, to enable mines to continue monitoring exposure to DEEEs and to include this information in future guidance to mines.

One device investigated was the Wohler RP 72 Soot Testing Pump Set. This is designed to determine the soot number in heating systems that use liquid fuel. HSL purchased one of these kits and sent it to the Salt Union mine in Winsford, Cheshire for evaluation of its effectiveness and to determine whether it is a suitable replacement for the Bosch Smokemeter.

Other options also investigated included: the use of an office scanner to measure ‘blackness’ (the Information Services Team at HSL looked at whether this would be feasible and provided a plan for the proposed work), the Aethalometer® Optical Transmissometer OT21 and the Spectro-color® pen were considered but both of these devices are significantly more costly than the Wohler device.

The outcome of the project was that the Wohler Set was found to be the most suitable replacement for the Bosch Smokemeter and it was decided that further work should be carried out to investigate this device more thoroughly before including its use in guidance provided to mines.

Mine Emergency Support Technologies [EMTECH]

The central objective of this project is to ensure that European standards and procedures to be used in the event of a mine incident continue to be at the forefront of world best practice. The research will address all aspects associated with an emergency, from the infrastructure that is in place at the time of the incident, through to coordinated search and rescue involving mines rescue teams.

MRSL’s main research task is to contribute towards the design and development, across the European Union, of refuges and related evacuation support technologies for the use of miners in emergency situations. In principle, the designs will be based on the avoidance of contaminated air entering the refuge, and in ensuring a system to guarantee the air quality inside. Crucially, the refuge environment must provide both respiratory protection and a tolerable thermal environment. The latter is of particular concern in deep, laterally extended workings where the mine environment is characteristically hot and humid. In order to assess the effectiveness of these systems, real scale tests in reference mines will be undertaken. The objective is to set up guidelines for underground refuge designs.

The siting of refuges in deep hot mines, together with the metabolic heat generated by the shelter occupants, gives rise to significant challenges in terms of cooling and air conditioning. Evaluation of heat release rates, combustion products and toxic

gases from expected mine fires will be carried out to evaluate the range of external environments.

A second area of research is to provide supporting theoretical analysis for the development of an advanced means of independent emergency communication between rescue personnel situated underground, and the control centre on the surface. It is envisaged that the equipment will support through-strata operation, the transmission of location and status data and an automated and accurate location facility. MRSL is proposing that several novel antenna systems be evaluated, and is considering filing a patent application to cover one such novel system.

Occupational Health

Review of the Health Effects of Wearing Mines Rescue Breathing Apparatus

This work was commissioned following concerns expressed about the apparent early deaths of ex mines rescue brigadesmen from cancer and internal organ problems.

The project had the following objectives:

- To investigate the claim that ex Mines Rescue Service personnel are suffering ill health as a result of wearing closed circuit breathing apparatus during their service.

- To carry out a literature review relating to the wearing of closed circuit breathing apparatus and discuss the findings.

- To discuss the construction and workings of past breathing apparatus and comment on some of the materials used in relation to potential health effects.

- To look at available statistics for mortality rates of the general population as a comparator with the information provided.

The information originally provided was largely anecdotal and somewhat limited in both numbers and detail. As a result, it was not possible to carry out a detailed statistical analysis. A simple analysis showed the figures provided to be roughly in line with national statistics for mortality rates.

No evidence was found to support the claim that wearing closed circuit breathing apparatus caused short or long-term health effects. The literature review produced no papers covering the subject area, even when the search was widened to cover industries other than mining.

Early breathing apparatus did use chemicals that would not be used today (asbestos, caustic soda), but there were no indications that these were a potential health hazard for the wearer of the apparatus.

It was recommended that the information contained in the report be conveyed to the Mines Rescue Service and other interested parties to allay any fears or concerns

regarding the wearing of closed circuit breathing apparatus and the potential for it to cause long-term health effects.

Ground control

Development of a British Standard for the Use of Long Tendon Reinforcement Bolts to Support Mine Workings

This project has involved attending and hosting meetings of a sub-committee that is drafting Part 2 of BS 7861. The work has required liaison with other organisations with expertise in strata control. The draft is at an advanced stage with final changes from the sub-committee now being incorporated and it should be in a form for submission to BSI and public comment by the end of March 2009.

Roof Collapse Incident

A fall of ground occurred at a coal mine on 3rd November 2007. It was reported that a mineworker was fatally injured in the incident. Two rockbolts were recovered from the fallen ground and submitted for metallurgical examination.

The two rockbolts were identified as SAT strata bolts, a design that has a continuously threaded rib pattern. The rockbolts were tested for compliance with BS7861: Part 1: 2007 '**Strata reinforcement support system components used in coal mines – Part 1 specification for rockbolting**'.

The two rockbolts had experienced slight permanent bending from strata loading but they had not failed. The bending did not appear to have weakened the bolts and there was no significant degradation due to corrosion or pitting.

The tensile strength, elongation and chemical composition of both rockbolts met the requirements of BS 7861: Part 1:2007 '**Strata reinforcement support system components used in coal mines – Part 1 specification for rockbolting'.** The yield strength of one bolt was slightly below the minimum required.

Both of the rockbolts had a lower resistance to brittle fracture than that required by BS 7861: Part 1:2007 when assessed by Charpy testing. The low results on the two rockbolts may be due to them having been manufactured around the time that UK Coal first adopted SAT rockbolts. There was no evidence that the low resistance to brittle fracture had adversely affected the integrity of the two rockbolts in the incident.

Geotechnical Classification, Modelling and Exploitation for Safe and Efficient Mine Layout and Tunnel Support Design.

The final report of this project, which was completed in 2006 and submitted in 2007, is now available from the EU Bookshop website (catalogue number KI-NA-22964-EN-S) (http://bookshop.europa.eu/eubookshop).

Development of More Innovative Support Systems for Gateroads Under the Influence of Rock Stress.

Work on this project was completed during the year but the final report has still to be approved and published by the European Commission.

RMT's work on this project was mainly concerned with development of improved instrumentation for design and safety monitoring of rockbolted roadways. It also included a study of long tendons supported by an HSE research contract (now completed, see below). Work on improvements to geotechnical numerical modelling and roadway risk assessment was also undertaken. RMT's contribution was in close collaboration with UK Coal, a partner on the project.

The instruments developed during the project included the following:

- New sonic extensometer system
- New strain gauged rockbolt readout and data logger
- Strain gauged GRP rockbolts for rib stability monitoring
- New rib wire extensometer
- New rib shear monitor
- Borehole video camera system suitable for rockbolt diameter holes
- Software for rib closure data monitoring analysis
- Improved Remote Reading extensometers and software
- New high roadway and low roadway telltales

All of these instruments are now commercially available to the industry and in regular use in UK mines.

Evaluation of Tensioned and Non-Tensioned Long tendon Reinforcement Systems in UK Deep Mining Conditions.

This Contract was allied to the above RFCS contract and was completed in September 2008. The extensive final report has been submitted to HSE but not yet published. The main task was to provide technical support on revision of BS7861 Part 2 on cable bolting consumables for coal mines. The impetus for the work was response to the rapid introduction and adoption of tensioned cable bolting systems into the UK industry over the last few years and a concern that these were poorly understood and needed to be covered by the new Standard. The main chapter headings of the report are:

- Theoretical aspects of tensioned tendons
- Laboratory and underground testing of tensioned tendons
- Underground monitoring of performance and effects of tensioned long tendons
- Improved modelling of flexible long tendons
- Advice and drafts provided to BS revision committee
- Laboratory testing of alternative rib reinforcement systems
- Suggested revision of former Deep Mines Coal Industry Advisory Committee (DMCIAC) cablebolting guidance.

The work has shown both potential advantages and disadvantages of tensioned systems and highlighted some major problems associated with one particular top down grouted, tensioned system which had been introduced into the UK industry.

The manufacturer has responded to these problems following their identification. It has also highlighted the potential dangers associated with poor mixing and watering down of cementitious grout, particularly the thixotropic variety.

It has been strongly recommended that the DMCIAC guidance document on cable bolting should be revised to incorporate the cable bolting practices and systems currently in use, including tensioned systems. A draft revision has been suggested as a basis for discussion which incorporates provisions to alleviate the potential problems discovered.

RMT's work on this project was extended by 6 months through a subcontract from HSL in order to undertake a final overview of the draft British Standard. This coincided with the accident at Welbeck colliery involving a cable bolt falling from the roof during installation and a number of improvements have been made as a result, concerning retention devices and specification of hole sizes. This issue should also be covered in a revised Mining Industry Committee (MIC) guidance document.

Increased Productivity and Safety of European Coal Mines by Advanced Techniques, Knowledge and Planning Tools Enabling Strata Control of the Face-roadway Junction.

RMT and UK Coal are both partners on the project. The emphasis has been investigating and finding solutions to the rib control problems being experienced at UK colliery (A). Early work was involved with identifying the mechanisms associated with the rib fall which occurred in the coalgate of a retreating longwall panel in January 2007 in order to develop strategies to prevent re-occurrence. The work has been regularly reported to a bi-monthly rib working party at the mine chaired by HSE, which has been very successful at driving ground control standards and practices at the mine.

Analysis of the rib fall mechanism indicated a need for reassessment and analysis of remedial rib reinforcement, the reinforcement placed on drivage, choice of roadway drivage horizon and consequently roof reinforcement. It also indicated a need for better monitoring of the ribs and development of appropriate risk assessment and support management systems.

The rib fall analysis, which included significant numerical modelling, indicated that remedial long tendon rib reinforcement should be installed in vulnerable areas identified in the gates for safe completion of the panel, that improved rib and roof reinforcement consumables would be necessary for remedial support in the gates of the next panel, prior to and during retreat, and that improved rib and roof reinforcement would be required for installation on drivage for future gateroads at the mine. The latter consumables would need to be suited to the selected roof horizon (stone or coal).

Large diameter (28mm), much stronger steel and GRP rockbolts were tested according to the new British Standard (BS7861 Part1 2007) and DMCIAC guidelines and field trialled underground. Extensive numerical modelling was used to design an appropriate rockbolting pattern for the new gate roadways to allow use of a coal roof

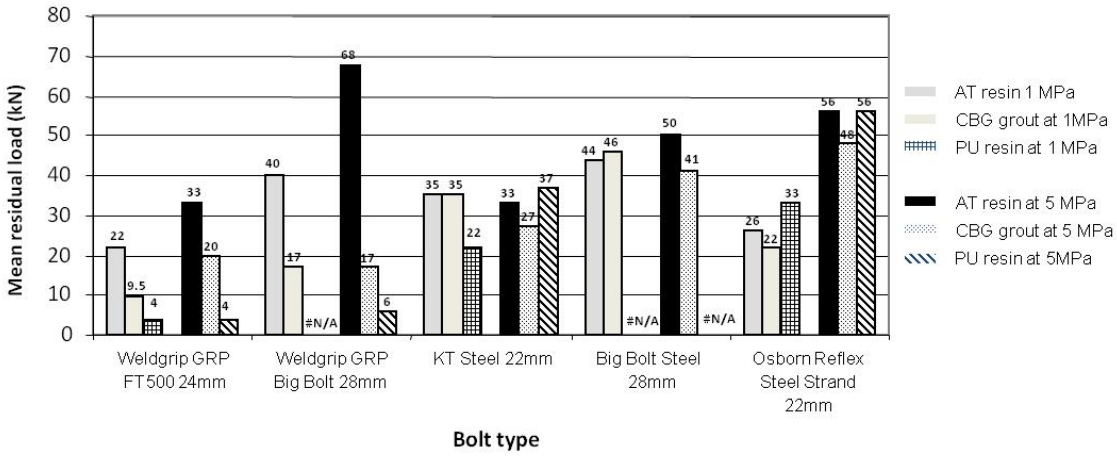
which, in turn, is expected to reduce rib deformation and improve face end conditions. These roadways are now being driven using these consumables.

A large laboratory testing programme of alternative reinforcement system behaviour in coal was completed this year. This comprised approximately 100 laboratory short encapsulation pull tests and covered the following consumables:

- 24mm GRP bar (FT500)/cable bolting grout (43mm hole)
- 24mm GRP bar (FT500)/AT resin (27mm hole)
- 24mm GRP bar (FT500)/PUR capsules (27mm hole)
- 28mm GRP “Big” bar/cable bolting grout (43mm hole)
- 28mm GRP “Big” bar/AT resin (32mm hole)
- 28mm GRP “Big” bar/PUR capsules (32mm hole)
- 28mm GRP bar (manufacturer 2)/AT resin (32mm hole)
- 22mm steel KT bar/cable bolting grout (43mm hole)
- 22mm steel KT bar/AT resin (27mm hole)
- 22mm steel KT bar/PUR capsules (27mm hole)
- 28mm steel “Big” bar/cable bolting grout (43mm hole)
- 28mm steel “Big” bar/AT resin (32mm hole)
- 22mm flexible bolt (Reflex)/cable bolting grout (43mm hole)
- 22mm flexible bolt (Reflex)/AT resin (27mm hole)
- 22mm flexible bolt (Reflex)/PUR capsules (27mm hole)

One purpose of these tests was to identify which consumables were capable of generating a bond strength of 100kN per metre of embedment which was shown by numerical modelling to be necessary for effective rib control. All systems tested exceed this criterion at both 1 MPa and 5 MPa confinement, except for PU embedded GRP bolts. It was found, towards the end of the programme, that the performance of the PU systems could be increased considerably by paying very careful attention to the quantities of components and method used in mixing the PU. This sensitivity, in itself, militates against PU being a reliable reinforcement encapsulant.

As rib reinforcement can be expected to well exceed initial bond yield displacements, the residual load at 50mm displacement was assessed, in addition to the usual bond strength and bond stiffness criteria. The results are summarised in the graph below. GRP bolts generally achieved lower or similar residual loads and other performance indicators when compared with the equivalent steel bolts, encapsulant and confinement, with the exception of the 28mm GRP bolts in AT resin at 5 MPa confinement. It was concluded that the 28mm GRP bolts can provide significant reinforcement to coal ribs, though their inherent weakness in bending should always be taken into account.



Work on this project also includes modelling to examine recent and potential future face end problems at 2 other UK collieries due to stress windows, interaction from overlying pillars, horizontal stress concentrations and choice of face handing.

Advanced Drivage and Roadheading Intelligent Systems.

This project commenced in July 2007 with both RMT and MRSL as partners. RMT's main objective is to develop practical strategies for designing, driving and supporting coal face headings to the necessary dimensions required for modern longwall face equipment. These need, for practical reasons, rectangular roadways which therefore require suitable rockbolt and long tendon support.

Problems associated with face line drivage and support have increased as face headings have become longer, wider and deeper. UK longwall panel widths have increased from typically 250m to 300m with current plans for 350m. This leads to longer standing times and consequent support issues. Wider face headings are required due to the larger face equipment being used. Typical UK roadway widths are 5.0m for gateroads and 6.0m for facelines, but some faces are now being driven as wide as 8.5m. In Germany the range of faceline widths is 6 – 10 m.

The main candidate heading strategies for face lines are one pass, two pass and stress relief. Geotechnical numerical modelling is being used to model these options. The packages being applied are MAP3D, FLAC2D and FLAC3D. Modelling of support geometries, stress re-distributions and likely deformations has been undertaken for two collieries.

The recently driven 8.5m wide faceline at Colliery A was planned to be driven in a single pass. The two previous 8.5m wide facelines in the same area of the colliery had been undertaken successfully. However, conditions on this third faceline proved to be difficult with large roof deformations occurring rapidly. FLAC 2D modelling was undertaken to assist with assessing the option of continuing drivage at 5.2m and then widening to 8.5m and this strategy was implemented. The actual experience of completing the faceline drivage has been assessed and the information used to develop a 3D model to allow improved analysis and design for the next faceline. Back analysis with this model for the last two facelines driven, indicated that the last face line was most probably affected by unusual geotechnical conditions (rock disturbance and/or stress) in the section driven in a single pass. The modelling

confirmed that significant benefit can be derived on the next face drivage (modelled at full width) from the potential to install 8m fully resin encapsulated flexible bolts at the face of the heading. This will also benefit from the larger diameter rockbolts developed for the mine.

At Colliery B, a study of the ground conditions was undertaken for the primary support design of an 8m wide faceline driven in two passes. Here the motive for two passes was improved drivage speed rather than strata control. The FLAC3D model runs simulated the two stage excavation by initially excavating and supporting at normal width, running the model until stability was achieved and then excavating and supporting the additional width. Unlike the situation for Colliery A, this faceline was orientated in the most favourable direction with respect to the direction of maximum horizontal stress. No long tendon reinforcement was included in the model.

The model results for drivage at the initial width, at two alternative lateral stress levels, showed small roof displacements with softening within the bolted height and the bolts well loaded. With the lower lateral stress of 11MPa, widening to 8m had little effect on the roof. With the higher lateral stress of 15MPa, widening resulted in a large increase in roof movement and softening well above the bolted height indicating a need for cable bolting. The actual drivage experience, which was very good, has been assessed and compared with the modelling. Plans at the mine are to drive future face lines across the maximum lateral stress direction and the consequences on support have been considered by modelling and monitoring gate road drivages in this direction. The first face line in this direction has now been completed, again using a two pass strategy. Conditions were more difficult than for the previous face, especially in areas affected by tectonic disturbance and an overlying pillar, but drivage and face widening were completed satisfactorily.

Future work on this project will include assessing further face heading drivage alternatives for colliery A using a narrow initial drivage with the powered supports being installed close behind a small machine (Celtic Miner) taking the second pass.

MRSL’s research is primarily associated with assessing the feasibility of unconventional rock fracture methods within manless, automated excavation schemes, involving the development of a) models of electro-fracture mechanisms, b) a techno-economical understanding of the technology and c) the concept of manless mining in an inertised atmosphere.

After an extensive literature review, as summarised in the last SHMRAB report, the tentative conclusion was drawn that rock fracture requires either a) very high voltage and energy (perhaps 100 kV, 100 kJ) or b) a more moderate energy but a very fast pulse rise-time (say 10 ns). A pulse rise-time this fast is difficult to achieve but is essential if the voltage and energy requirements are to be reduced to manageable values. A technique has been developed that it is hoped will ease this task. Experimental apparatus is being constructed and a patent application is expected to be filed shortly.

Studies also included a detailed theoretical appraisal of rock fracture modes. It is expected that this work, combined with experimental results from the electro-fracture equipment, will allow extrapolation to much larger masses of rock.

To investigate the possibilities of operating in an inert atmosphere, small-scale electro-fracture experiments will be carried out in a nitrogen atmosphere, for which a suitable tank has been constructed from 20 mm Perspex panels, which will allow the fracture events to be captured by a high-speed camera.

MRSL studies also involve the ergonomic assessment of mining machinery, where new design guidelines are being prepared in order to minimise health and safety risks and to improve the operational efficiency and reliability of roadheader operations.

Ergonomics assessments were routinely undertaken on the mining machines used by BCC from the mid 1970's through to the late 1990's. Relevant data and fundamental design principles have been extracted from these assessments to ensure that this fundamental ergonomic data is made available to project partners, particularly those from Eastern Europe. Moreover, the updated set of data sheets has been re-designed and re-structured, to provide the fundamental information necessary to allow:

- Designers to more effectively address ergonomic requirements on new road heading machinery.
- Purchasers to assess the ergonomic suitability of road heading machines
- Producers to identify ergonomic limitations and potential retrofits to reduce risk.

Prediction and Monitoring of Subsidence Hazards above Coal Mines.

RMT, UKCoal and MRSL are project partners and Nottingham University have been subcontracted to develop numerical modelling to improve surface subsidence prediction techniques taking account of geology. This part of the work has been completed with a conclusion that modelling can give much better predictions of maximum subsidence than the SEH where there is unusual geology but currently it cannot predict accurately the shape of the subsidence profile. A database was compiled containing data from nearly 700 subsidence measurements, some of which had been used in developing the SEH with others being more recent and/or from elsewhere worldwide. Analysis of the data has shown the important effect of geology on subsidence and highlighted the need for an alternative approach to the SEH.

RMT's work on this project concerns sub surface subsidence and disturbance of the strata and is particularly involved in studying the circumstances of water inflows into working mines from the surface, seabed, aquifers and old workings and in improving our understanding of how to work longwall panels above old worked areas. This is relevant to current and planned workings at 4 UK mines.

Historic and case study data on water inflows into working longwall panels due to mining induced permeability were obtained and collation and analysis is almost complete. Considerable historic data has been obtained from the UK Northumberland and Durham coalfields, pre 1980. Three major sets of water inflow incidents have occurred in the UK over the last 25 years, and data from these cases in the Selby coalfield, N W Leicestershire coalfield and Northumberland have been gathered.

Work on the problems associated with mining above previous longwall panels has included obtaining data from a number of historic case studies, examination of recent experiences at a colliery currently working the Deep Soft seam above old Parkgate goaf and pillars and analysis of potential problems likely to be encountered in the neighbouring mine which is just commencing workings in this seam. An initial analysis of stress distributions on development and retreat with the current planned layout at the latter mine has been completed using MAP3D. A FLAC 3D model has been developed for analysis of roadway support. Detailed geotechnical measurements from the first mine working the Deep Soft are being made and these will allow back analysis of the previous model predictions for improvement of the model for the latter mine. A particularly important aspect here is how the condition of the strata within the Parkgate subsidence trough is represented in the models and a focus of the work will be to improve this.

A subcontract has been placed with Exeter University to examine alternative modelling packages for application to these problems.

The University of Nottingham contribution to achieving this objective relates to the development of improved tools for predicting the effects of subsidence on the rock matrix itself, using 2D and 3D numerical modelling. The accurate prediction of the final surface subsidence profile caused by any mining activity is essential to help reduce damage to surface structures and to optimise mining method design.

Previous research has been carried out at The University of Nottingham in this complex field (see Reddish 1984, Yao 1992 & Benbia 1995). The current research aimed to draw upon existing knowledge and compare numerically calculated subsidence profiles with measured data. A measured subsidence profile taken from above the Barnsley seam at Naburn in North Yorkshire was obtained from UK Coal. The excavation under investigation was 2.8m thick, 255m wide and 679.5m below the surface. A numerical model was constructed using the commercial finite difference software FLAC v3.4 (Itasca, 1995). A wide range of rock properties have been used and the displacement results compared with the observed surface settlements.

A second case study with recent surface survey data was taken from above the Barnsley seam at Wistow colliery. This excavation was 2.55m thick, 68m wide and 410m below the surface.

The models used have been sophisticated utilising special techniques to simulate the goaf and altering stiffness properties with depth and strain during yield. The general modelling of the situations has been satisfactory with the maximum subsidence of model and monitoring similar, however the measured surface profile is somewhat more narrow than the modelled profiles. Basically its half subsidence points are closer to its centre and its side profiles are steeper. The first case study demonstrated through sensitivity studies that changing input values for strength and stiffness to the models changes subsidence magnitude effectively, however the fundamental shape of the profile changes much less. Only by changing the constitutive model can the shape be seriously altered. Of the constitutive models the strain softening model has the best subsidence profile shape but it is still significantly

wider than the profiles observed. The introduction of anisotropy to the stiffness of the overburden in modelling by others has been shown to be effective for improving subsidence profile shape. However the anisotropy can upset the balance between vertical and horizontal ground movements. A good subsidence fit being at the cost of poor horizontal displacement and strain prediction. The fundamental continuum nature of the FLAC code appears to extend the subsidence laterally with angles of draw significantly wider than generally reported from the field. The introduction of further structure into the rock mass possibly with strong directional weaknesses would appear to be the best approach to improving the modelling further.

The final part of the study presents a database originally initiated by C Shadbolt in 1987 and expanded and updated since by the authors. This database includes subsidence behaviour data from a long history of British mining. It includes all the cases used in the Subsidence Engineers Handbook (1975) plus many more from the NCB archives and records. Much of this data in its raw form is now with the Coal Authority. International data is also included for comparative purposes. The data set includes all the usual key subsidence parameters with the addition of a geological index indicative of the overburden properties. The Subsidence Engineers Handbook presents curves derived from part of this data set. It doesn't however present likely errors or variations from the basic empirical model. This data set allows those errors to be systematically studied, a major advantage if risk approaches are to be adopted.

MRSL's research has three major components – the monitoring of shaft fill material, in order to provide advanced warning of subsidence and consequential risks, field studies including shaft imaging in low visibility conditions, and the adverse effects of mine water pollutants on shaft fill and shaft lining materials, incorporating methods to neutralise these effects.

A review of telemetry and data-logging options for use in an abandoned shaft monitoring system was undertaken, with emphasis placed on the development of cost-effective, low power electronics and radio telemetry. In conjunction with this review, development work was undertaken on a sensor for monitoring the movement of the fill in disused mine shafts, with a view to obtaining advanced warning of surface subsidence. A prototype was constructed using a friction retarder and a magnetic shaft encoder and field trials will commence early in 2009.

Research was carried out relating to Shaft Imaging in Low Visibility Conditions. At present various advanced methods of optical imaging in turbid water are also under investigation. A technical review of ultrasonic imaging techniques was carried out and a field trial, using commercial ultrasonic equipment in an actual mine shaft is planned for 2009.

Long duration testing continued, to evaluate and quantify the effects of the chemical processes associated with mine water pollutants interacting with a range of mine shaft materials. These materials are representative of shaft fill, shaft lining and shaft capping (basalt, cast iron, reconstituted aggregate, steel reinforcement, limestone and concrete). These trials will continue into 2009, allowing for scientific testing and analysis.

In order to research the potential benefits of concrete ‘treatment’, samples were subjected to acidic mine water immersion tests following treatment with readily available water repellent products which can be applied by remote spraying. Work commenced to assess the potential for “flash setting” of a “pumpable grout”, as a low cost solution for rapid strengthening of shaft fill material especially for use in areas where mine shafts are constructed within thick superficial deposits.

Line communications

Researching the Applications of Open Innovative Wireless Technologies

The main objective of this research is to enhance mining operations through the widespread introduction of advanced wireless network technologies, including smart open wireless sensor networks, wireless digital voice communications and wireless position tracking systems. The other UK partner in this project is RMT.

The main activities during the final year of the project involved the completion and testing of a proof-of-concept underground mine tracking system, developed using mesh wireless technology (ZigBee / EmberZNet). The system is a novel method of achieving active tracking, using a coarse or ‘zone’ based approach. It offers a low cost alternative to RFID systems, along with the flexibility of having the potential for additional functionality. In addition to location information of a mobile device attached to a person, vehicle, or plant, it could also be used to collect sensory data e.g. environmental or machinery diagnostics. The system was installed at the Camborne School of Mines (CSM) Test Mine, using an Ethernet backbone to view/operate the tracking system remotely. The latter stages of the test programme involved up to 40 mobile devices (MDs). Three worst case scenarios were examined: high volume of MDs at low speed (group of personnel walking), moderate volume of MDs at high speed (small man-rider / vehicle), and large volume of MDs at high speed (e.g. locomotive). The results demonstrated a robust overall operation of the underground tracking system, exceeding most of the worst case scenarios.

Another aspect of the project was to evaluate the potential application of smart wireless sensors using mesh technology, specifically for improved mine safety monitoring. A prototype system developed during the project was assessed during the final underground testing phase, interfacing the devices to temperature and other environmental monitoring sensors. This demonstrated a novel method of automated sensory data acquisition across a mesh wireless network, offering a range of key benefits in an underground mine due to the scalable, adaptable and self-healing nature of the mesh network.

RMT completed development of the wireless enhanced version of the m-Comm mines rescue communication system which employs a Bluetooth link between a headset worn by the Rescue team member and either a handset clipped to the communications cable or a hub mounted within the cable reel. The prototype system was trialled in a number of locations, including underground, and application made for ATEX approval. Once approval has been received it will be put into production and replace the current system.

This project was completed in June 2008 but the final report has still to be approved and published by the European Commission.

Mine operations

Evaluation and Interpretation of the failure Mechanism of Idler Rollers on Fast Moving Underground Conveying Systems

Following a number of incidents, research work was requested that would provide a scientific understanding of the flammable/explosible materials produced during failure mode of idler rollers.

The aim of the first phase of work was to perform a scientific analysis of Idler roller component materials, including seals, grease, paint and bearing gauge material, in order to determine the fire and explosion properties of the materials during an idler roller bearing failure and assess their potential as an ignition source. The work on this phase will reach a conclusion shortly, at which point tests will be performed on static idler rollers that have been in-service, to determine the practical effect of heating the roller to temperatures seen during bearing failure mode. This will enable differences in the failure mode to be assessed, when using flame retardant (FR) or mineral grease as a bearing lubricant. In addition, methodology will be developed to replicate the frictional heating that is generated during bearing failure, to the point of ignition of the component parts of the idler roller/bearing.

Interpretation and Explanation of Abnormal Defects and Potential Failure Mechanisms of Mine Shaft Conveyance Suspension Equipment

Mining cage suspension gear is frequently taken out of service and thoroughly examined for defects before being used again. Each shaft has a number of complete sets of gear to allow the sets to be used in rotation, allowing inspections to take place with minimal disruption.

The assessment of the gear is performed according to the **Procedure for Examining Cage Suspension Gear at Test Centres,** published by the National Coal Board in 1980 and commonly referred to as the Green Book. This gives guidance on the types of defects acceptable for different positions on a variety of components, and criteria for their withdrawal from service. The Green Book, however, gives little information about the effects of corrosion pits, concentrating mainly on general wear and defects arising in service, and also defects arising from manufacture.

The aim of this project was to improve the guidance for assessing corrosion in these components, in order to better determine their fitness for service.

A number of papers relating to fatigue from corrosion pits have been reviewed. Since the stress intensity threshold for fatigue crack initiation from corrosion pits and sharp cracks were similar under tension, it is reasonable to model pits as sharp cracks.

Several papers included a formula for the calculation of a threshold size of a pit, i.e. the depth at which the rate of crack growth from a pit would exceed the rate of pit growth from corrosion.

Using these formulae for an item of highly stressed suspension gear resulted in a defect depth well below that which could be confidently detected.

A number of boundary element models have been created to evaluate the stress concentration factors arising from hemi-spherical pits and plate materials.

This indicated that pits would have a detrimental effect on the fatigue performance of components even when rounded. It should therefore be assumed that cracks could be present where pitting is found, regardless of shape.

Since it is assumed that any pitting could cause cracking a model based on crack growth rate and inspection intervals was investigated.

By knowing the design strength of the material and assuming a worst case based on the minimum fatigue reserve factor (FRF) allowed by the Design Guide for Cage Suspension Gear, published by the NCB, 1983, a maximum stress range was calculated which was used to predict crack growth rate and fatigue life.

Table 1 Number of cycles to failure

Load	Initial crack size	Number of cycles to failure
FRF 1.3	1 mm	50,000
	2 mm	25,000
FRF 1.6	1 mm	75,000
	2 mm	39,000
FRF 2.0	1 mm	135,000
	2 mm	70,000

If a component was likely to experience more cycles than the predicted fatigue life before the next examination, then a number of options would be available:

- evaluate the FRF for individual components and loading. A table could be produced (e.g. Table 1) to show fatigue life for a range of FRFs.
- shorten inspection interval.
- remove from service.

General Interpretation of Non Destructive Testing (NDT) Tests and Results

This project is a call off contract covering unusual or unexpected NDT results or developments in NDT in the mining industry.

At present deep mining facilities in the UK rely on the Ropescan system for NDT. This system, while accurate, is old and can be subject to breakdown.

The cost to date relate to an on-site evaluation of the Intron NDT system recently purchased by Bridon, as a possible alternative to Ropescan. The system performed satisfactorily and was easy to use.

A further test of the system using HSL's reference rope is at the planning stage, funding to be shared between HSE and Bridon.

Shaft Key Failure at a Potash Mine

This project involved the examination of part of a failed driveshaft and eight failed bolts taken from a winding engine at a potash mine. A large scab of material had broken from the side of a large keyway in the driveshaft, as a result, drive had been lost to the winding mechanism and there had been an un-anticipated descent of a cage during a routine test cycle. It is understood there were no personnel in the cage and nobody was injured as a result of this dangerous occurrence.

The HSL investigation centered on the modes of failure of the driveshaft keyway and the bolts to determine whether other driveshafts in the same drive train needed to be inspected and/or replaced prior to re-commissioning of the winding engine. This response was provided before Christmas 2007. Other work was carried out and completed on the modes of failure and materials of manufacture of the bolts.

The final letter report was issued in July 2008.

Locomotive Brake Shoes for Mines

This project has involved reviewing published material on the use of cast iron brake shoes containing a high level of phosphorus. There is considerable experience and interest in high phosphorus iron shoes for use in conventional rail locomotives, because this material appears to reduce the rate of shoe wear. Some reports also indicate that high phosphorus cast iron has a lower tendancy to generate incendive sparks. Inquiries have revealed that high phosphorus iron is used widely for rail transport outside the UK.

New Mechanisation and Automation of Longwall and Drivage Equipment.

This project has now been underway for 30 months. RMT’s work is focussed on developing improved techniques and tools for designing mechanical cutting drums used in coal mining machinery. This will cover roadheaders, with axial and transverse heads, shearers and continuous miners. This work is being addressed through fundamental numerical modelling of the cutting process using FLAC 3D, analysis of selected case studies and developing an improved software package based upon the software originally developed by British Coal in the 1980s and incorporating a modern user interface. The project is mainly oriented towards improved production performance and reduced costs of cutting rather than Health and Safety.

Improved Extraction Ratios for Deep Coal Mines

This project commenced in June 2008. RMT are the co-ordinator and Nottingham University and UKCoal are partners alongside German and Polish colleagues. The

main aim of the project is to research, identify and develop practical means by which coal recovery ratios in European deep mines can be improved significantly in a safe and efficient manner.

Improved Extraction Ratios for Deep Coal Mines (IMPREX RFCS Project)

The main objective of the IMPREX (IMProved EXtraction) project is to research, identify and develop practical means by which coal recovery ratios in European deep mines can be improved significantly in a safe and efficient manner. The sub-objectives of the individual Work Packages are as follows:

Determine world best practice in the identified mining methods with potential for increasing extraction ratios and, taking the outcome into account, investigate European coal reserves that would benefit from a successful outcome of the project and identify the key constraints which must be overcome, including environmental factors.

Nottingham has the specific tasks to study the application of, and design methodologies for, remote and auger mining systems when used in the following:

- highwall mining
- mining marginal coal from ribsides and pillars.

For this to be achieved there has to be an exchange of experience with international experts.

This task will also include a comparison of attitudes to the target mining methods across European regulatory systems, allowing the identification of major potential constraints.

An appropriate testing programme will be conducted on coal measure rocks from candidate sites to obtain good quality input data to develop the wide range of numerical models and undertake feasibility studies and practical system trials planned for the project. This will include strength and stiffness testing using multistage triaxial testing and possibly in-situ stress measurements. This will require the acquisition of suitable material from actual operational sites both in Europe and possibly further afield.

The key feature of auger and highwall systems is the extraction density, which is normally only limited by stability issues. It is proposed to evaluate the stability issues for this technique by the use of FLAC 2D and 3D numerical modelling systems. This will require data gathered from the review of world-wide mining sites where this technique is applied both as a surface mining tool but also as a system that could be applied underground.

This task will comprise developing a proposal for a field application of an auger system in an underground application based on data gathered in the previous phases of the project. This application may be based on a UK site, but the overall potential applicability and significance to EU mining will be assessed

Initial work has concentrated on defining the state of the art and world best practice in the various mining methods to be examined. These include room and pillar development, pillar extraction, reduced longwall pillar sizes, remnant pillar extraction through short longwalls and auger mining, increased mining height in thick seams and longwall top, coal caving. Safety will be a major issue in these considerations.

Increasing the Efficiency of Roadway Drivages through the Application of Advanced Information, Automation and Maintenance Technologies (IAMTECH)

The aim of the research was to improve the efficiency of roadway drivages, through the use of the latest advances in information and automation technologies, applied to:

- The automation and assessment of operations that are currently performed manually.
- Providing on-line support and expert diagnostics during maintenance activities, and large assembly-disassembly works, using simultaneous video, audio and data transmissions delivered to the point of use.

The final report was finally approved by the EU in late 2008 and a published report should be available from them soon. The major findings of the project were included in last year's SHMRAB report.

Advances in Exploration Methods and Applications

In addition to MRSL, other UK partners involved in this project were UK Coal, Heriot Watt University and Seismic Image Processing. The project sought to enhance mining exploration and planning capability through techniques such as seismic surveying, radio imaging through coal panels, drilling parameter analysis and micro-seismic monitoring. MRSL's research concentrated on determining the factors that have limited the scope of deployment of the 'Radio Imaging System' (RIM) in the UK, and in seeking methods of enhancing the technique.

MRSL's work concluded that the RIM technique cannot be improved by lowering the probe frequency and that it is necessary to use advanced signal processing to improve the readability of the signals at the 'standard' RIM frequency. In the latter part of the project, algorithms were developed which allow the receiver to operate using an extremely narrow bandwidth. Earlier in the project, a technique was devised for maintaining synchronisation with the transmitter, which was the subject of a patent application. Additionally, two novel types of antenna were developed, one based on specialised ceramic tiles which concentrate the electric field; the other on the use of plastic electrodes or foam pads (both using electrically-conductive materials) attached to the rib-side wall. MRSL has filed a patent describing the use of such electrodes.

Restrictions on the zones in which non-approved electrical apparatus may be operated underground meant a departure from the test programme originally envisaged. It is, in fact, questionable whether meaningful results can be obtained in areas remote from the face where the roadways are lined with metal. Nevertheless, equipment was built and submitted for inspection by HSEC Ltd prior to underground

experimentation. Unfortunately, delays caused by changes to the test programme and the construction of this specialised equipment meant that only limited results could be reported under the ADEMA project.

Nevertheless, it is intended that the equipment will be used for ongoing investigative work within the EMTECH (2008) and EMIMSAR (2009) projects, both of which address the topic of emergency communications through rock strata.

The project finished at the end of June 2008 and the final report is due to be submitted by the end of March 2009.

New Mechanisation and Automation of Longwall and Drivage Equipment [NEMAEQ]

The project focuses on the development of full automatic shearer face equipment. This will take into account development of software for the design of cutting tools with a minimum of pick wear and machine down time due to excessive vibrations. Innovative methods of maintenance and planned repair of the machines are also features of the project.

One MRSL research element involves oil contamination monitoring and six commercially available sensors were evaluated on a test rig at Mansfield. The Vaisala MMT318 outperformed all the other sensors in giving expected results under virtually all test conditions. On this basis, the feasibility of producing an ATEX M1-M2 version of the Vaisala MMT318 water-in-oil transducer is being investigated and meetings were held with Eickhoff G.B. and Vaisala to examine engineering specifics. Discussions with Vaisala indicated that it is technically feasible to adapt their existing products to produce an ATEX M1 or M2 certificated water-in-oil transducer.

Further discussions regarding adaptation of the MMT318 or similar water in oil sensor will continue into the next semester. The production of these devices is likely to involve long lead times before any direct industry benefits can be realised. Consequently, an alternative sensor with a monitoring and transmission technology that will facilitate a more immediate implementation strategy is also being investigated. This work is being undertaken in close collaboration with a Polish project partner who has produced a prototype “water presence/level” sensor that is compatible with an existing wireless machine monitoring sensor network.

A software “toolkit” for assessing maintainability and human reliability was developed and preliminary evaluation and testing exercises completed. The three primary tools included in this “toolkit” are:

- **Maintainability assessment** – facilitates maintenance task analysis and the identification of the basic physical machine attributes that will determine its overall maintainability.
- **Violation potential** – used to identify actions that can be taken to reduce the risk of artisans failing to complete maintenance tasks in accordance with the prescribed schedule.
- **Risk perception** – provide comparative estimates of risk used to assess human reliability and identify potential impacts on maintenance standards.

The software tools were updated in line with the findings derived from usability trials, and additional user interface enhancements, combined with a context sensitive ‘Help’ system, added. The resultant software and integrated ‘Help’ system were packaged into a distributable, end-user installable, software product to facilitate distribution of the tools to other project partners. Field trials will be undertaken in collaboration with the other project partners to enable further testing and refinement of the software during the final year of the project.

Improving Mining Transport Reliability [MINTOS]

The project addresses a range of novel approaches to improving the performance, reliability and environmental aspects of operating transport systems underground in deep, extensive coal mines with complex networks. The use of alternative motive power provisions for transport vehicles will be investigated, by examining the potential for using alternative fuels, including fuel cells. The study also encompasses transport logistics and the potential merits of using advanced management information and machine diagnostic systems. In addition, the safety and health aspects of machine fires, exhaust emissions and whole body vibration are included.

As part of this project, MRSL was involved with UK Coal to improve monitoring and control of transport equipment and the underground mine environment by completing the transfer from legacy systems to Wonderware’s InTouch SCADA software. The system is configured with dual redundancy and uses both control and view nodes via a terminal server to sites in the mine.

A major element of MRSL’s part of this project is the development of an on-board engine compartment, cab and wheel-arch fire-fighting system, which can be periodically tested and yet still maintain operational capability. Due to difficulties in accessing the two FSVs intended for this work, tests were undertaken on a ‘mock up’ test vehicle. Nozzles tested were a single hollow cone and two different types of cluster nozzle, all operating at a pressure of 8MPa, with each displaying a characteristic spray pattern. At each of the three nozzle locations, a fire was allowed to burn for 90 seconds and a 3-second water mist blast then applied. Where the fire was not extinguished, a subsequent 3-second blast was applied at 95 seconds. Overall the tests were very successful and further tests were undertaken on an underground diesel engine van.

A prototype fire extinguishing system has now been designed for use with underground FSVs, consisting of a single hollow cone nozzle in each wheel arch and cluster nozzles in the cab and engine compartment. A separate cluster nozzle on a ‘lance’ can be used for ‘external’ fire suppression. For a 10 litre water reservoir, the overall system provides 45 blasts of 3-second duration, with each blast utilising 220cc water.

Enhanced miner-information interaction to improve maintenance and safety with augmented reality technologies and new sensors [EMIMSAR]

The research will develop, implement and demonstrate “Augmented Reality” devices and applications, enhanced marker systems and real-time location systems that will

improve the interaction of mine personnel with computer-stored information and knowledge in several fields of work. The project also involves condition-oriented preventive maintenance, which will be addressed through the development of novel sensors for online monitoring of critical parts of AFC and plough systems.

Study of Shaft Stability Issues at a Potash Mine

Sinking of both the mine shafts at a potash mine – the rock winding shaft and man riding shaft - was carried out during the period 1968-1974. The two shafts are approximately 1150m deep and pass through a 10m thick bed of squeezing rock (Carnallite Marl), close to the bottom of the shafts). The shaft linings installed at the sinking of the shafts suffered severe damage that resulted from the considerable pressure of the surrounding soft rock and upper strata. Neither the original liner nor the subsequent relining adopted by the mine lasted a long time. The first relining of both shafts through the marl zone took place during 1983-1986, and the shafts were again relined through the same zone during 1997-2001.

Cracks appeared in the walls of both shafts after only two or three years and within a decade of their installation they both had to be replaced. Now, after about 10 years of the second relining completion, a third replacement of the liner is required.

A PhD student at the University of Nottingham is conducting a study of the mechanisms that have affected the stability of the shaft linings during the life of the mine through numerical modelling using the finite difference programs FLAC2D/3D. By modelling the shaft's restoration history, this project aims to explain the shafts failure mechanisms, and subsequently to predict the long-term deformation behaviour and stress conditions of the newly designed concrete liner (the 3rd restoration) under severe ground loading in this particular strata zone.

Initially, relevant rock material test data has been collected together, including test data from the University of Newcastle-upon-Tyne (1970s), the Royal School of Mines (RSM) of Imperial College (2000) and Nottingham Centre for Geomechanics (NCG) at the University of Nottingham (2007,2008). Uniaxial and triaxial compressive tests and tensile tests of rock materials from Boulby Mine have been conducted at NCG. Time-dependency tests of rock are still ongoing. Test data from the completed time-dependency tests has been analyzed and compared with that available from other evaporite measures aiming to find an appropriate creep model (Kelvin, Maxwell or Burger) to be used in the future numerical modelling.

The preliminary phase of numerical modelling is nearly completed. It focused on simulating the original concrete liner's stress and closure conditions at the Carnallite Marl level.

- A Plane strain Mohr-Coulomb model in FLAC2D was employed at this stage.
- The finite difference mesh and methodology to model the concrete liner were developed to replicate the closure experienced in the shafts
- The modelling examined the effect of ground stress (hydrostatic or not) and the weakness of the rock zone surrounding the shafts on concrete liner's stress and deformation. A sensitivity study has been conducted, applying

different strength parameters of Marl (Elastic modulus, cohesion, friction angle and tensile strength) and evaluating their influence on concrete liner's stress and deformation conditions.

- Another important aspect under consideration is the influence of point loading on the concrete liner which may lead to severe tension failure of concrete liner at great depth.

The continuing research will concentrate on simulating the shaft concrete liner's restoration history using modelling methods and material parameters concluded from the previous research. The time-dependency tests will be continued to obtain suitable creep mode for future modelling.

Appendix 1 - Members of SHMRAB 2008

Mr I Waugh, HM Chief Inspector of Mines, HSE. (Chairman);
Mr T Spurry, Group Safety Engineer, UK Coal Mining Ltd;
Mr E Morland, Chief Executive, Health and Safety Laboratory;
Dr R Stace, School of Civil Engineering, University of Nottingham;
Mr R Young, President, the British Association of Colliery Management;
Mr D Flack, Chairman, the Federation of Independent Mines;
Dr R Quinlan, Medical Director, RPS Business Healthcare Ltd;
Mr N Greatrex, President, the Union of Democratic Mineworkers;
Mr A Allsop, Union of Democratic Mineworkers;
Mr R Soar, National Association of Colliery Overmen, Deputies and Shotfirers;
Dr P Holmes, British Gypsum Ltd and the Mining Association of the UK;
Mr R A Fenton, Secretary Mining Association of the UK (MAUK);
Mr S Hunter, Cleveland Potash Ltd;
Mr C Daniels, Manager, Hatfield Mine, Powerfuel;
Mr M Padley, Health & Safety Manager, Hatfield Mine, Powerfuel;
Mr D Pascoe, Specific Interventions, Policy Group HSE;
Mr R G Siddall, Past President of the Institution of Mining Engineers;
Dr B Jones, Chief Executive, Mines Rescue Services Ltd;
Mr P Shorthouse, SES Contracting Ltd;
Mr G Huitson, Maltby Colliery Ltd;

Papers to Mr K Stanley, National Union of Mineworkers

Others who contributed to SHMRAB meetings during 2008
Dr R Wharton, HSL, HSE;
Mr S C Bennett, Mines Rescue Service Ltd;
Dr L Kent, Rock Mechanics Technology Ltd;
Mr G Gilmour, HMIM, Technical Secretary to SHMRAB;
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