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ABSTRACT

The Phalen Colliery in the Sydney Coalfield is extracting the 2.6 m thick Phalen Seam by the panel and pillar longwall retreat method. Abandoned workings occur in the Harbour Seam 140 m above and overlie the Phalen Colliery. Parts of these workings are flooded, and pose a number of questions relating to the safety of operations in the Phalen Colliery. In order to answer some of these questions, the Cape Breton Development Corporation re-entered an abandoned non-flooded roadway in the Harbour Seam directly above a retreat panel in the Phalen Seam to allow the deployment of instrumentation to monitor interaction effects.

Fifteen monitoring sites, each 4.5 m apart, were installed in the 5 East Top Level after it had been re-enteed and made safe. Each monitoring station included a vibrating wire strain gauge piezometer and a potentiometric extensometer. The piezometers were attached to rock bolts anchored into the floor and were connected by a flexible standpipe to a constant head apparatus. Variations in hydraulic head due to subsidence were monitored to determine subsidence. The extensometer units were mounted on rock bolts anchored into the floor of the roadway beneath the ribside and monitored ground strains. The instrumentation was capable of remote reading in the event that access to the site was restricted after installation.

This paper describes the instrumentation, the installation programme, and some preliminary results.

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Keywords
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INTRODUCTION

Background

Until recently the Cape Breton Development Corporation (CBDC) produced coal from three mines in the Sydney Coalfield, which extends northeast under the Gulf of St. Lawrence from the east coast of Cape Breton Island. At present, coal is produced from two mines, Prince and Phalen Collieries. The Phalen Colliery extracts coal from the Phalen Seam offshore of New Waterford in the central part of the coalfield. Longwall panel and pillar retreat mining is practised, with in-seam gateroads supported by rock bolts. Abandoned and flooded mines flank the present workings in the Phalen Seam.

Until November 1992, the Lingan Colliery was working the Harbour Seam, which lies 138 m above the Phalen Seam. Workings in the Harbour and Phalen Seams were concurrent, but in different areas.

In November 1992, the 5 East Panel at Phalen Colliery was retreating towards the main access deeps of the mine. In doing so it had undermined flooded workings in the Harbour Seam to the east of the overlying Lingan Colliery. As the 5 East faceline began to undermine an abandoned and sealed panel in the Lingan Colliery 138 m above, a flow of water was detected from behind a fire seal on the abandoned panel. A major inflow of water followed, eventually causing the closure of the Lingan Mine, with the loss of about 700 jobs.

From observations of water levels in adjacent abandoned mines and from water chemistry analyses, it was eventually determined that the most likely source of this water was the adjacent abandoned and flooded workings. The mechanism by which the water made its way through a 350 m wide solid inter-colliery pillar between the adjacent flooded workings and Lingan Colliery is still not known for certain. It has been suggested that bed separation at or above the Harbour Seam horizon, caused by longwall workings in the Phalen Seam, may have provided the hydraulic connection.

Interaction Monitoring Programme

The potential effect of Phalen Seam workings at the Harbour Seam horizon, and concern over the potential for the flow of water into the Phalen Seam workings from flooded workings above became a major concern to CBDC. Also at stake was the significant loss of revenues that would result from restricting the extracted height in the Phalen Seam to reduce tensile strains at the flooded Harbour horizon.

CBDC enlisted the assistance of the CANMET Cape Breton Coal Research Laboratory (CBCRL) in Sydney, N.S., to investigate the effects of the extraction of the Phalen Seam at the

Harbour Seam horizon. An ideal monitoring opportunity was offered by the extraction of the 1 Centre Panel at Phalen Colliery, which lay directly beneath the abandoned and sealed 5 East Top Level in Lingan Colliery (fig. 1). However, by this time Lingan Colliery had ceased operation and was being allowed to flood. Water pressures monitored behind fire seals outbye 5 East Top Level were still indicating high water levels, although flow rates into the Lingan Mine appeared to be stable at about 1500 igpm. It was by no means certain that the programme could be completed, but CBDC undertook to plan the rehabilitation of the 5 East Top Level, with careful monitoring of the conditions in the abandoned district and the water situation in the panels above it.

CBCRL undertook to fund a contract for the design, construction and installation of the instrumentation in 5 East Top Level. Jacques, Whitford and Associates Limited (JWA), of Dartmouth, Nova Scotia were retained by the Canadian Federal Department of Supply and Services to provide the following services to CBCRL:

1. Design of a suitable monitoring programme to accurately measure strains, subsidence and bed separation at or near the Harbour horizon during the mining of the 1 Centre Longwall, in the Phalen Seam, 138 m below.
2. Fabrication of the entire instrumentation set up, including the purchase of instrumentation and all conduit and connections.
3. Installation of the instrumentation set up from the critical areas of monitoring to a remote base at No. 4 Slope, Lingan Colliery.

These tasks were undertaken in close consultation with CBCRL staff, including significant input from them on the selected instrumentation design.

inbye the seals was the subject of much conjecture. Careful plans were made to re-open the district, including continuous gas monitoring and monitoring of the water pressures on the outbye seals. The plans were submitted to the Coal Mine Safety Commission for approval, which was granted in mid-January of 1993, and work commenced on the programme soon after that.

In order to re-enter the district, access drifts to the top and bottom level seals had to be re-supported and made safe. Ventilation regulators and doors had to be erected or modified to provide ventilation. This work took several weeks to complete. When the ventilation system was ready, crews using hand tools drove into the coal on the low side of the concrete fire seals on the top and bottom levels. The last coal was removed by colliery rescue men under oxygen allowing air to enter and escape from the district. The top level seal was breached first, followed by the bottom level seal.

Gas levels in the return airway were carefully monitored over the next few days. Ventilation regulators were constantly adjusted to allow more and more air to flush the district, all the while keeping the return air methane concentrations at less than 2%. In addition to methane detectors connected to the mine-wide environmental monitoring system, carbon monoxide detectors were installed and regular gas sampling undertaken to monitor any evidence of spontaneous heating in the re-ventilated waste.

After about two weeks, methane concentrations in the district were low enough to allow access, and the top level was examined to a distance of about 700 m inbye the seal, well past the planned instrumentation site location. It was discovered that the level was in remarkably good condition, with no need for additional support.

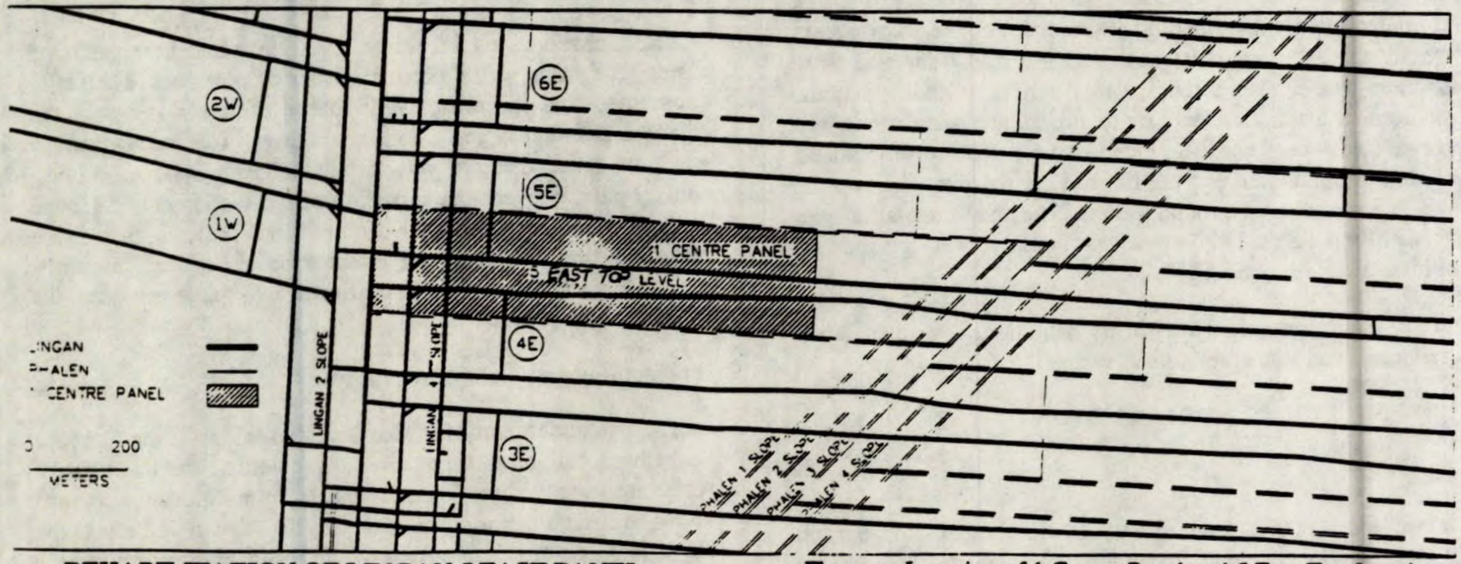


Figure I : Location of 1 Centre Panel and 5 East Top Level

REHABILITATION OF LINGAN 5 EAST PANEL

Re-entry

The 5 East Panel at Lingan Colliery had been abandoned and sealed since 1983. Considerable quantities of methane were known to exist behind the seals, and the condition of the levels

Safety Equipment

Intercom speakers, connected directly to the colliery control room, were established at regular intervals along the level to a point about 400 m inbye the seal. Additional methane monitoring equipment was installed at the inbye end of the monitoring section, including a visual warning of methane levels. Although the statutory methane concentration at which men must be withdrawn from the mine is 2% under the Canadian Labour Code, it was decided that a slightly lower limit would allow more warning of gas surges caused by barometric pressure variations. Alarm limits on the methane monitors were thus set at 1.8%. In addition, Oxy-60 self-rescuers were stationed at three locations in the level and outbye the fire seal. With this equipment in place, work on the instrumentation sites was allowed to proceed.

Monitoring Site Selection

The installation of monitoring instrumentation in an area likely to be subject to intense deformation presented some potential problems regarding the long-term stability of the site during and after undermining. Although room and pillar workings at Lingan Colliery were still open after undermining in the Phalen Seam, the uneven stress distribution around a gateroad with a solid coal pillar on one side and caved waste on the other side lead to some speculation as to the potential for total collapse of the gateroad at some stage of the undermining. This was one reason for the provision of data-logging capability for the instrumentation, and also for some of the design features described later.

CBCRL had conducted a survey of roadway heights and widths in 5 East Top Level as part of a coalfield wide pillar stability survey in 1983. Examination of the data from this survey and gateroad conditions on re-entry resulted in the selection of the instrumentation site between arch 225 and 295. Roadway conditions deteriorated soon after arch 300 in the level.

A supervised inspection of the 5 East Top Level to a point well beyond the position of the 1 Centre faceline below was conducted on Friday, March 5th 1993. During the survey, gateroad heights were collected at locations coincident with the first survey in 1983, and notes taken regarding the condition of the roadway. Figure 2 compares the results of the two gateroad surveys. Time-related deformation in the ten-year interval between surveys was negligible. Major reductions in gateroad height noted in 1983 were found to be the result of floor heave, much of which had been bottom brushed in 1980/81. On re-entry into the district it was initially assumed that the floor heave was the result of the undermining of the level by the 1 Centre Face. On closer examination it was discovered that the zone of floor heave appeared to correspond with a marked reduction in the width of the rib pillar between 5 East Top Level and the adjacent 4 East Panel. The pillar width between these two panels, also shown on fig. 2, decreases from 60 m at the start of the 5 East Panel to about 35 m at the narrowest point. Little or no floor heave was observed adjacent to pillar widths greater than 40 m. The pillar width at the instrumentation site is about 50 m.

Figure 3 compares vertical convergence with pillar width for material and coal roads in the Lingan Mine based on data collected during the pillar stability survey in 1983 (1). It indicates that vertical convergence increases rapidly for pillar widths less than 40 m, and that there is no decrease in convergence for pillar widths in excess of about 45 m. Based on these results, it was felt that the site selection and instrumentation design was valid, and that the site would probably be protected from major floor heave and disruption of instrumentation by the barrier pillar.

The final location of the site was approximately 356 m east of No. 4 Slope extending for a length of 70 m along the high side of the level between arches 225 and 295. Figure 4 shows the general location of the monitoring area in the 5 East Top Level.

INSTRUMENTATION DESIGN

Design Constraints

The design of the instrumentation package to monitor the interaction effects posed several problems. Firstly, the possibility that access to the instrumentation sites would be prevented had to be considered. Secondly, the time window for the whole installation and monitoring process was expected to be very short, a matter of six to eight weeks; any equipment used had to be available on short notice and already approved for use in the coalfield. The third constraint was the level of available funding.

Three potential events threatened access to the instrumentation in the level, and the outcome of the investigation:

1. Any indication that the re-ventilation of the gob was causing spontaneous heating would result in abandonment of the instrumentation and re-sealing of the panel.
2. Any re-occurrence of significant quantities of water in the outbye panels, or any significant increase in the water pressure on the monitor, seals would prevent access into the mine below the 1 East Panel.
3. Significant ground movements resulting in unsafe conditions in the level would prevent further access.

The importance of the monitoring programme to CBDC, combined with the risks to the programme presented above, resulted in the adoption of an instrumentation plan that included conventional survey leveling and electronic distance measurements (EDM) to floor mounted benchmarks in the level, and direct monitoring of subsidence and ground strain by carefully selected instrumentation. The importance of the programme also lead to the requirement that the instrumentation be rugged and reliable, and provide considerable redundancy in the data. The instrumentation plan included capability for manual reading at the site, manual reading at a safe location outbye the fire seals, and data logging from the same location.

Having decided upon a strategy to ensure that data could be collected under the most adverse of circumstances, a number of possible instrumentation designs were investigated.

The original recommendation for interaction monitoring suggested remotely monitored tilt meters. This was based on an assumption that it would not be possible to maintain the instrumentation site for access. With access to the site planned

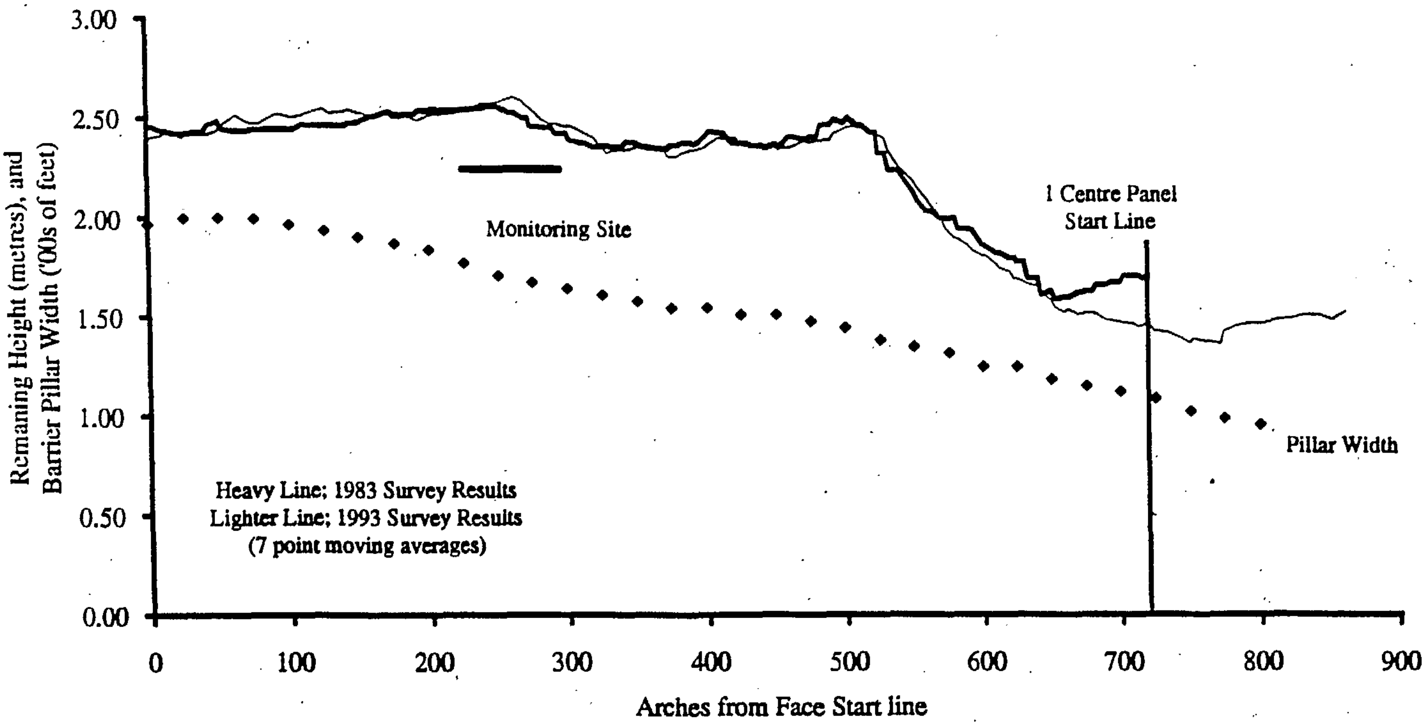


Figure 2: Gateroad deformation survey results.

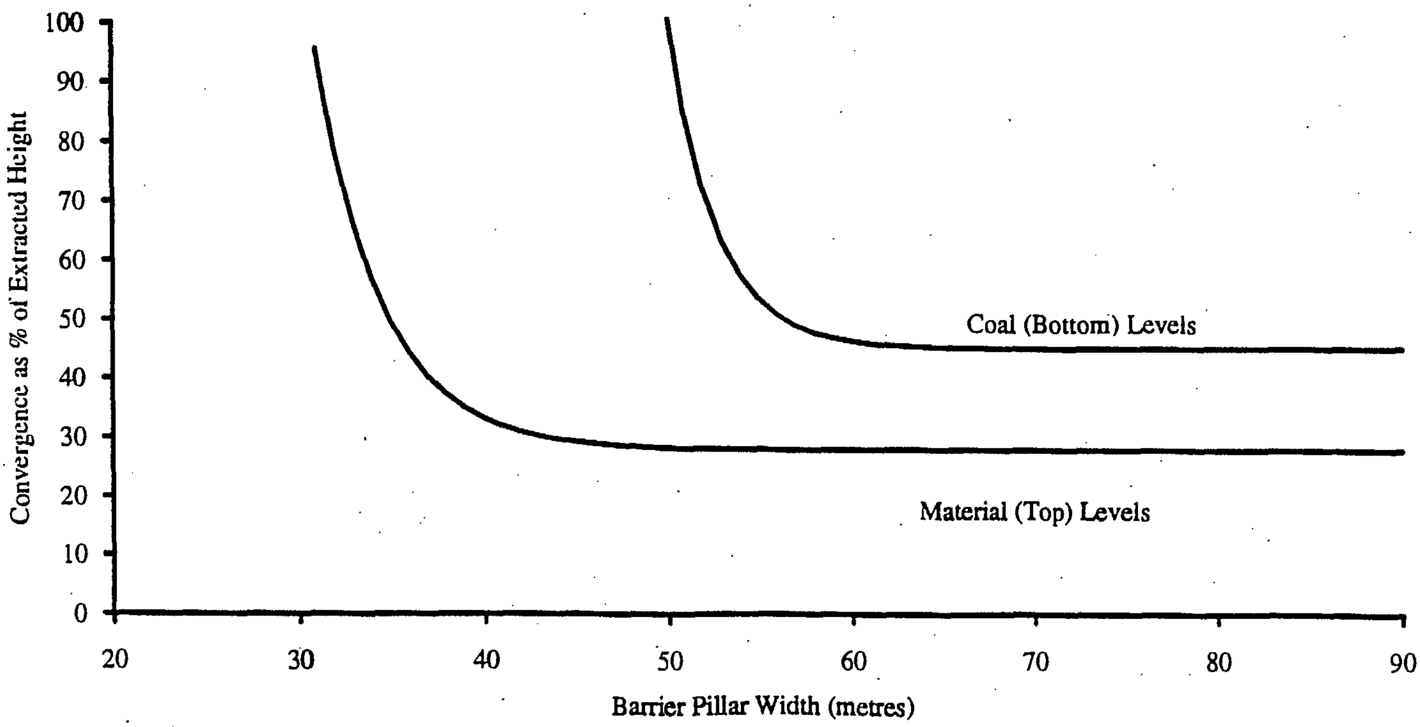


Figure 3: Development of convergence, Lingan Colliery (after (1))

for the entire monitoring period, more conventional monitoring approaches could be considered. However, it soon became apparent that the level of funding available was not sufficient to install the preferred instrumentation, and that the programme had to be re-assessed. After reviewing a number of design alternatives, consultations between JWA and CBCRL staff determined the final instrumentation plan as described below.

System Design

Ultimately, a simpler equipment configuration was selected comprising the following components:

- Survey benchmarks in the form of rock bolts anchored in the floor of the level,
- Vibrating wire strain gauge (VWSG) piezometers, installed in a constant head standpipe, to monitor subsidence, and
- Specially mounted electrical resistance extensometers to monitor strain.

A complete description of all aspects of the instrumentation design, shop drawings of the mounting assemblies, and technical specifications and calibration parameters for the equipment used is reported by CANMET (2)

The number of instrumentation stations that were deployed was determined by the capacity of the data-logger to be installed by CBCRL. Thirty-two channels were available, 16 VWSG channels, and 16 thermistor (resistance) channels. One VWSG and one thermistor channel were required for the piezometer located in the constant head device, and another thermistor channel was required to monitor temperature at the site. The remaining 14 thermistor resistance channels were set up to monitor extensometers. The completed instrumentation site comprised 15 piezometers and 14 extensometers inbye, with the inbye temperature recorded at one station. The last pair of channels recorded an outbye piezometer and thermistor in the constant head device.

Survey Benchmarks

Survey benchmarks were established at regular intervals along the level from the face start line to a position 80 m inbye the monitoring section. The benchmarks consisted of standard 2.4 m x 22 mm rebar rock bolts. They were installed in 2.0 m deep holes drilled within 1 m of the high side of the level, angled at 30° to the high side. The bolts were secured in the hole by one capsule of slow set rock bolting resin, and stabilized with wooden wedges. The wedges maintained the bolts in position during surveying, but would allow any ground movement to occur without disturbing the bolts.

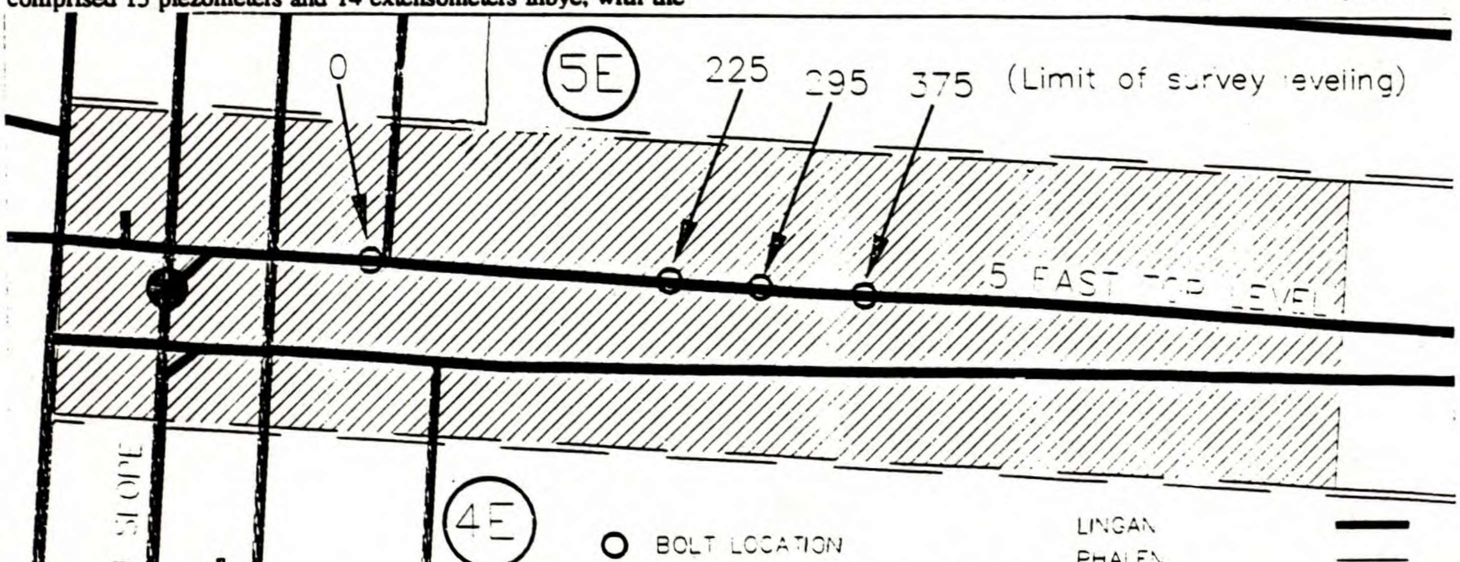
Over the length of the monitoring section, pairs of bolts were installed, the second bolt being placed about 0.3 to 0.5 m from the first, towards the centre of the level. These bolts were installed in the same way, but in 1.5 m holes, leaving about 0.8 m of bolt protruding from the ground, to which the instruments would later be attached.

A benchmark was installed at every fifth arch along the level. The distance between each benchmark was approximately 4.5 m. This is considerably less than the maximum distance between survey stations during subsidence monitoring recommended by the NCB SEH (3), which is 1/20th of the vertical distance to the workings, or in this case 7 m.

Direct Subsidence Monitoring

Direct subsidence monitoring from a remote location presented a unique problem. The solution adopted was to deploy

Figure 4: Monitoring site location, Lingan 5 East Top Level.



VWSG piezometers attached to rock bolts grouted into the floor of the level, and to connect them to a standpipe in which the water level was maintained at a constant elevation at the outbye end. Subsidence at the piezometer location would result in an increase in the hydraulic head, which could be detected by the piezometer.

Geokon VWSG piezometers, Model No. 4500HL-25, were obtained for use in the monitoring programme. They were the only units approved for use in underground mines in the Sydney Coalfield. The selected pressure range was from 0 to 25 psi, and the units included a thermistor for temperature measurement. The accuracy of the units is 0.1% of full scale, which is equivalent to about 3.3 mm of vertical movement. Total subsidence of about 1.8 m was anticipated at the monitoring site, based on a 2.6 m extraction and a subsidence factor of 0.7 at a super-critical width/depth ratio.

The piezometer instrumentation assemblies were pre-assembled at the JWA office in Dartmouth. They included a fitting from the throat of the piezometer to a threaded 38 mm hose mender, which in turn was fastened to a 3 m length of 38 mm PVC suction hose with a spiral plastic reinforcement. Stainless steel hose clamps were used to secure the PVC pipe, and teflon thread sealant was used on all threaded fittings to ensure water tightness.

Individual assemblies were taken into the mine after calibration, and attached to rock bolts using cable ties. The 38 mm PVC hose was then cut to length and connected to the leg of a 'T' piece in the main water line, described below.

Direct Strain Monitoring

Considerable time was spent devising a method of directly monitoring ground strains. The principal problem was that both tensile and compressive strains were expected, which required of the instrument a two-way measuring capability. It was eventually decided to use the Ground Movement Monitor (GMM) manufactured by Frema R&D Services, which was already approved for use in underground mines in the Sydney Coalfield, mounted in a specially designed, spring loaded assembly.

The GMM has a usable range of about 100 mm, and a linear variable resistance between 0 and 19 kΩ. Based on a measurement resolution of 10Ω, the direct strain resolution of the unit is theoretically 0.05 mm over a 4.5 m bay length, or about 0.01 mm/m. Tensile strains of the order of 8 mm/m were anticipated at the monitoring site.

The mounting consisted of two plates between which ran the GMM unit on a PVC rod and a spring obtained from a local hardware store. Attached to the spring was a threaded rod. One plate was fastened by a ring to a rock bolt set in the floor of the level, and was secured with cable wraps. The other plate had two holes spaced to ensure that movement of the spring and the GMM were along parallel axes. The plunger of the GMM was secured through one hole in the plate, and the threaded rod ran through the other. Attached to the end of the threaded rod was a length of aeronautical grade stainless steel cable.

When the cable was stretched out to an adjacent rock bolt in the floor of the level, the spring extended, maintaining the cable and the instrument assembly in a horizontal position. After the cable was made fast at the other end, the GMM could be set by sliding the plunger. When the correct initial position had been reached, nuts on the threaded rod were tightened to secure the plate in permanent position (fig. 5).

This arrangement allowed the GMM to respond to both tensile and compressive ground strains, and gave a wide initial setting range, depending on the tension required in the spring to maintain the unit in a horizontal position. The GMM instrumentation assemblies were pre-assembled at the JWA office in Dartmouth and transported underground prior to installation.

Remote Monitoring Location

A remote monitoring location was established on No. 4 Slope at the junction with the drift to 5 East Top Level in case access to the instrumentation became impossible. Electrical cables and a 76 mm water supply line extended from the monitoring site to No. 4 Slope at 5 Top East Level to permit remote reading of the instrumentation. CBCRL installed a 32 channel intrinsically safe data-logger, developed in-house from commercially available components, at the remote reading station, allowing readings to be taken at 30 minute (programmable) intervals. The instrumentation could also be read manually.

Standard mine-use communication cable was used between the monitoring site and the remote monitoring location. Each cable contained six individually insulated, double wrapped and grounded, pairs of 18 gauge braided copper wire and a common ground. Six cables were run from the remote monitoring location on No. 4 Slope to the instrumentation site. The electrical cables were hung along the level in the same manner as the waterline, passing through unused pipe work at each stopping.

Each cable handled the data from three monitoring sites. The inbye end of each cable was cut to length at the mid-point of each triplet, and both ends were stripped and each pair exposed prior to connecting to the instrument cables and the outbye panel.

The main waterline connecting the individual piezometers to the constant head device was 76 mm diameter PVC suction hose with a spiral plastic reinforcement. Purchased in 30 m lengths, it was first laid out along the level, then each section was connected with black iron hose menders. Four stainless steel hose clamps were used at each connection to secure the hose to the hose menders. The completed hose was hung with rope from the high side of the arch above the floor of the level.

At the monitoring site, the hose was cut opposite each piezometer location and a black iron 'T' inserted into the line. Each arm of the 'T' piece consisted of a hose mender threaded at one end, coupled into one arm of a standard black iron 76 mm three-way connector. Into the leg of the connector was inserted a reduction piece to a 36 mm hose mender end. Once again, connections were secured with stainless steel hose clamps. Teflon paste was used on all threaded connections.

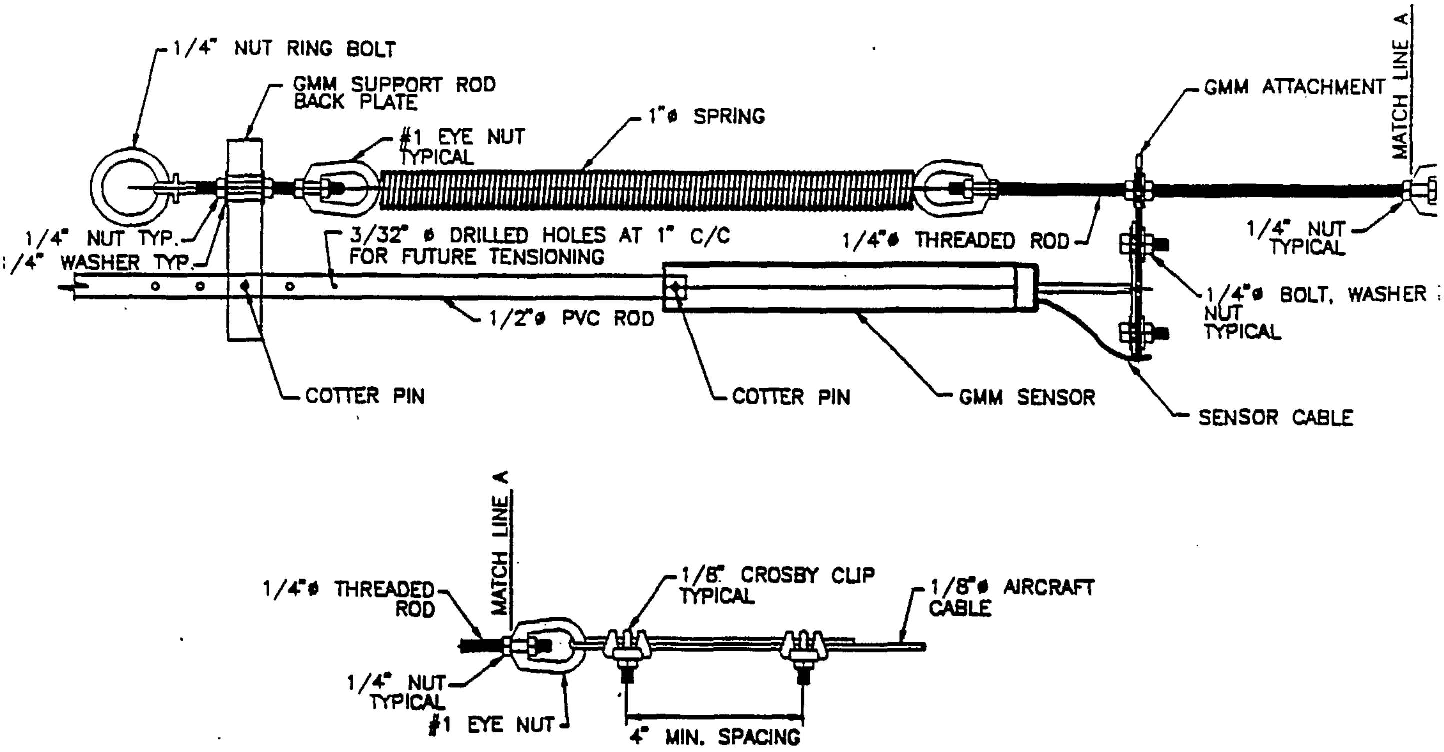


Figure 5: Details of GMM extensometer assembly.

Design Approval

The complete instrumentation and monitoring package was submitted to the Coal Mine Safety Commission for approval, along with details of methane and carbon monoxide monitoring stations, communication plans and the locations of the OXY-60 self-rescuers. The selection of previously certified and approved monitoring equipment and the location of the data-logger in fresh air in No. 4 Slope ensured rapid approval and a timely start to the construction and installation phases.

Prior to the purchase, fabrication and assembly of the components, the system design and cost estimates developed by JWA were reviewed and approved by CBCRL.

UNDERGROUND INSTALLATION

Installation of the monitoring system was carried out between February 22 and 26, 1993 inclusive. An overview of the daily activities are provided in the summary below.

Installation Sequence and Operations

Installation of the GMM and VWSG piezometer instrumentation was undertaken by JWA staff, with assistance from a number of CBDC employees and from CBCRL. Union fitters were made available by CBDC to assist with the mechanical components, and union electricians supervised the electrical installations to ensure compliance with local practise. A mine examiner was available in the level to monitor methane levels and general safety.

Electrical cables and a portion of the 76 mm PVC main waterline were run from the instrumentation site to the top of 5 East Top Level drift at No. 4 Slope prior to the arrival of JWA staff. A summary of the sequence of activities carried out during the installation period, which extended over five days, is listed below.

- Transport of the instrumentation assemblies, pipe fittings, tools and materials underground to 5 Top East Level.
- Installation of the 76 mm PVC main waterline from 4 Slope to the instrumentation site.
- Identification, splicing and preparation of electrical cables prior to instrument and data-logger installation.
- Installation of the instrumentation assemblies, and connection of electrical and waterline fittings.
- Transportation and mounting of the data-logger and the constant head device for the main waterline at the 5 East Top Level and 4 Slope intersection.
- The 76 mm main waterline was filled with water, and any leaks repaired.
- Calibration and system checkout of instrumentation, followed by final set-up of the GMM units.

On completion of the installation work, the positions of the floor pins, and the positions of the instruments on the pins, were measured and recorded. A detailed electrical wiring plan was assembled from notes made during the installation process to make any later trouble-shooting easier, and photographs were taken of the instrumentation site.

Installation Problems

There were no significant problems encountered during the installation of the monitoring system. Slight problems were encountered while filling the 76 mm main waterline.

Numerous undulations in the flexible line occurred where it was suspended from the arches in the level. Air became trapped in the peaks of these undulations, preventing water from flowing through the line. The problem was resolved by screwing #8 wood screws into the waterline and then removing them to allow the air to escape. The resulting leaks were simply repaired by replacing the wood screws. At some locations the leaks persisted after the wood screws were replaced. These leaks were sealed either by placing a mastic rubber pad over the leak, secured in place by a wood screw and washer, or by wrapping the leak with duct tape, then electrical tape.

Field Modifications

Two minor field modifications were made to the instrumentation system. The first consisted of replacing the proposed threaded end-cap at the inbye end of the 76 mm water main with a valve. The reason for the change was to permit the release of air trapped in the pipeline as it filled.

The second modification was arrived at when it was discovered that the water supply to the standpipe was straight out of the overflow from behind the flooded 2 East fire seal. The water contained considerable quantities of sediment, most of which would hopefully be retained in the header tank above the constant head device. However, it was decided to include aquarium fibreglass water filter material in the pipe fitting assembly between the piezometer and the 38 mm hose connection. The purpose of the filter material was to prevent any suspended material in the water supply from blocking the 6.4 mm diameter piezometer inlet.

System Checkout

Following the completion of the instrumentation installation, all systems were operating and there were no apparent problems which would result in failure of any or all of the instrument assemblies. The final stage of the installation procedure prior to handing the system over to CBCRL was the field calibration of the instrumentation, as described below.

CALIBRATION AND TESTING

Prior to installation underground, both the GMM's and the piezometers were tested and calibrated in the laboratory. Additional calibrations were carried out on the instruments in place. The calibration results are provided in the following sections.

GMM Extensometers

Laboratory Calibration

Although it was known the GMM's would require re-calibration underground following their installation to compensate for the increased resistance due to the 450 m main transmission cable, the laboratory calibration was carried out prior to assembly of the mountings to ensure that the units were functioning properly.

A prototype GMM assembly was set up at the JWA office in Dartmouth and monitored over an eight day period to check on the stability of the assembly and to determine the effect on the readings of disturbances to the cable. In operation, such disturbances might arise from accidental contact by survey staff, or as a result of rocks falling from behind the arch lagging. In either event, the data can be adjusted to eliminate the effect. The extended period of monitoring proved that the assemblies were stable, and that steps in the data due to disturbances could be eliminated during the data reduction process.

Field Calibration

Field calibration of the GMM assemblies was conducted just prior to making final adjustments. Calibrated blocks were inserted between the GMM and the plunger plate and the resistance of the unit measured. The calibration curves for each unit were different, but provided a reliable and accurate calibration and accurate derivation of strains at each location.

VWSG Piezometers

Laboratory Calibration

The piezometer assemblies were calibrated in the laboratory by filling the 38 mm hose in four increments, and recording the height of water in the tube and the reading given by a Geokon GK-403 readout unit. The measured pressure readings for each unit were consistent with the actual pressure head of water in the hose column in all cases.

Field Testing

Two sets of field readings were taken from each of the 16 piezometers following their installation underground and prior to filling the 76 mm waterline. The field readings were taken to check the operation of the piezometers and ensure the electrical system was operating properly. The first set of readings were taken on February 24 at the instrumentation site prior to the connection of the 38 mm waterlines into the main 76 mm waterline. The second set of field readings were taken on February 25th at the data-logger location after the system had been connected but before the 76 mm line was filled. On both occasions the piezometers were functioning correctly.

MONITORING

Data-logger

On hand-over of the monitoring system, CBCRL installed their recently developed intrinsically safe data-logger at the remote measuring point to allow continuous reading of the instruments (4). The data-logger employed was a Campbell Scientific Inc. CR10QM, configured with an AVW1QM vibrating wire interface, an AM416QM multiplexer and an SM192QM data storage module. All of these units have MSHA approvals, but CBCRL, in conjunction with the Canadian Explosive Atmospheres Laboratory (CEAL), had to redesign the multiplexer and have it modified before it could be certified as intrinsically safe (I.S.) for use in Canadian mines. The power supply was a Baytec Industries I.S. power pack (CEAL Certificate No. 834).

All of the above components were housed in an EMAC 5 fibreglass enclosure, and mounted in a 1.2 m x 1.2 m x 0.4 m steel box for security. The hand-held CR10KDQM (MSHA and CEAL approved) keypad is used to programme the unit on-site.

Instrumentation Monitoring

Survey leveling began immediately after the bolts were installed. CBDC surveyors began weekly surveys using conventional leveling and electronic distance measuring (EDM) techniques. The first two surveys, which took place on February 15 and 22, 1993, included all the bolts to obtain baseline readings. Subsequent surveys were restricted to the last 26 bolts until movement was noticed, after which an additional 10 stations were monitored each week to keep pace with the face advance in the seam below.

Monitoring of the electronic equipment began on Friday, February 25, 1993. After some minor problems with the programming of the data-logger were overcome, the following monitoring routine was established:

- The data-logger was programmed to take a reading every 30 minutes.
- Each Monday morning, CBCRL visited the data-logger to check the battery level and to down-load the previous weeks readings. The visits coincided with those of the surveyors, reducing the load on the limited resources of the colliery for supervision by a mine examiner.
- Manual readings of the electronic equipment was undertaken at the same time to provide a check on the performance of the data-logger.
- Later during the course of the programme, one of the VWSG piezometers showed signs of malfunction. At this point, manual readings at the monitoring point were initiated on a weekly basis.

RESULTS

At the time of writing this paper (May 1993), the 1 Centre longwall had undermined the 5 East Top Level to a point corresponding approximately to the inbye extent of the monitoring stations (bolt 295). The following results therefore represent only the very first stages of subsidence development. Full details of the interaction between the two workings will be published on completion of the field monitoring programme.

Survey Leveling

As indicated above, monitoring results to date show only the first stages of the development of the traveling profile. Figure 6 shows a comparison of the results of survey leveling for three benchmarks at the inbye end of the roadway. At the time of the last survey, the coalface was beneath bolt 295. Bolt 375 is therefore about 70 m over the waste, and Bolt 225 is about 60 m in front of the faceline.

Subsidence

Examples of the raw data from piezometers located at the beginning (bolt 225), middle (bolt 265) and end (bolt 295) of the monitoring site are shown in fig. 7. All the recovered data is shown for the first twenty days The remainder of the graph shows one reading per day. The response of the piezometers to the changes in barometric pressure is evident. During later analyses, data from the piezometer located in the constant head device at the remote monitoring location will be used to correct for these variations.

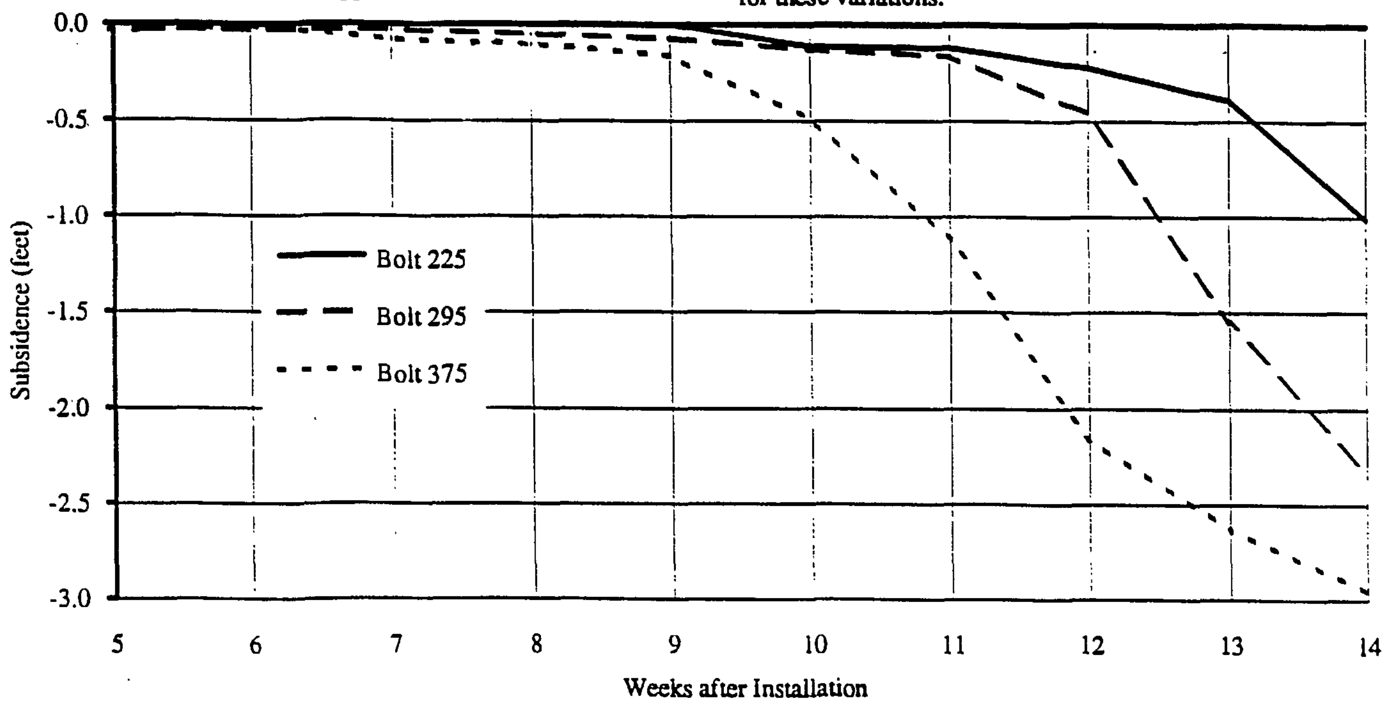


Figure 6: Development of subsidence at survey benchmarks.

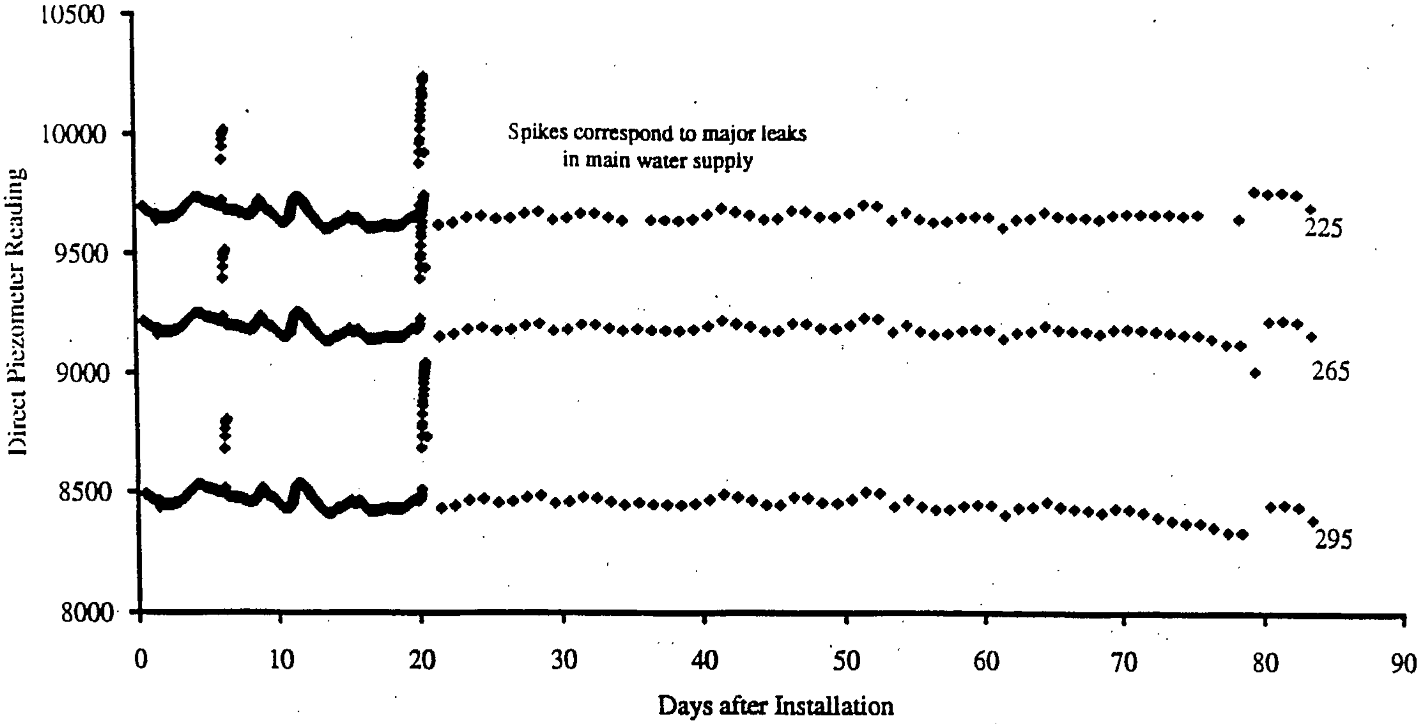


Figure 7: Data from piezometers on bolts 295, 265, and 225.

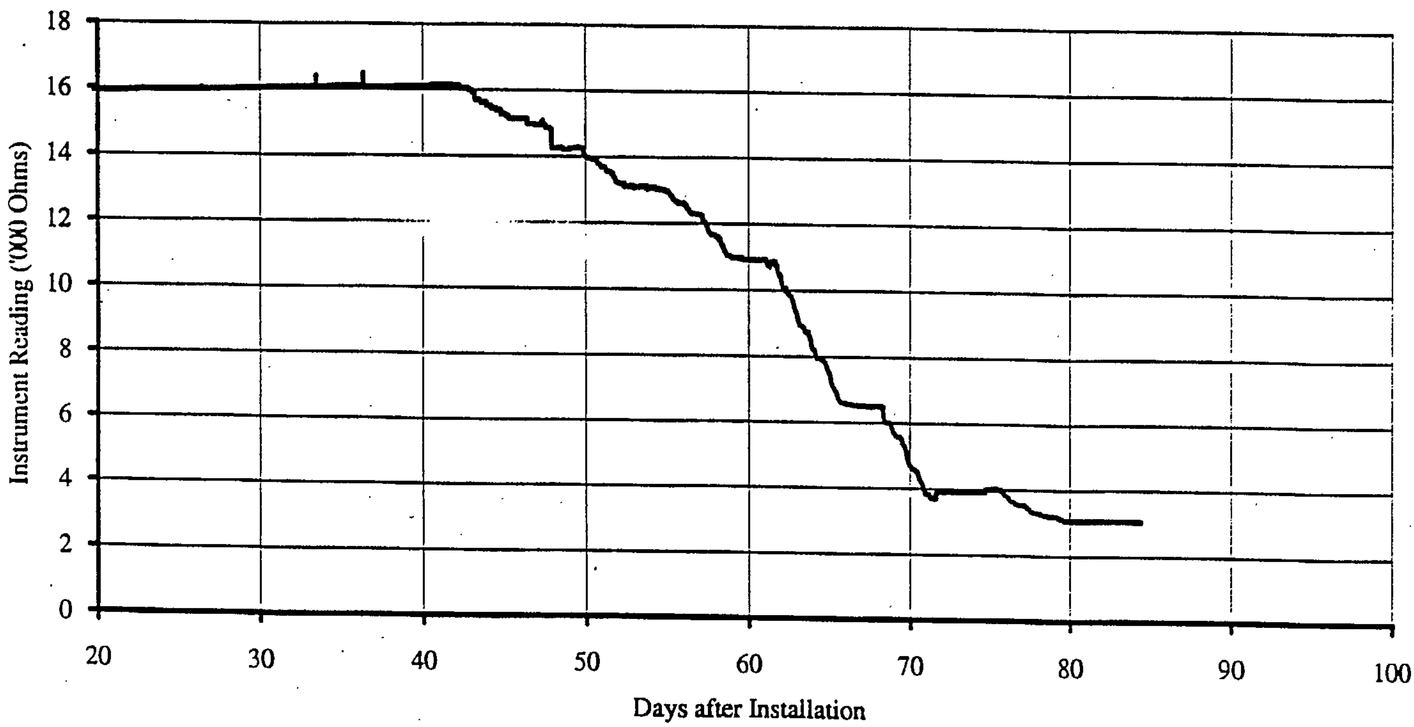


Figure 8: GMM results, bolt 290 to 295.

A general decrease in recorded frequency can be seen in the data for bolts 265 and 295, which corresponds to an increase in hydraulic head as subsidence occurs. The piezometer at bolt 225 appears unaffected by subsidence at this time. The spikes in the record correspond to periods of water loss in the main waterline due to leaks, which were subsequently repaired. The higher values obtained over the last five days or so also correspond to a partial emptying of the waterline.

Strain

Raw data from the GMM extensometer between bolts 290 and 295 is illustrated in fig. 8. The reading changes as tensile strain develops in the ground between the two pins.

Discussion

Although the data presented above is raw data collected during the early stages of the programme, it indicates that the instrumentation is functioning as intended. Data reduction and analysis promises to be a time consuming process. At present the data set consists of about 150,000 data items. However, on completion of the programme, the monitoring stations will have developed fifteen individual subsidence profiles and fourteen individual strain profiles. Survey leveling will produce an additional 60 to 70 subsidence profiles for correlation. This information will be invaluable in the assessment of interaction effects in the coalfield, and could lead to a significant increase in the life of the Phalen Colliery.

CONCLUSIONS

The temporal, fiscal, and instrument approval constraints that surrounded this problem have been successfully overcome, and the data that is being obtained is of very high quality. The benefit to CBDC in terms of understanding interaction effects between the Harbour and Phalen Seams will be considerable. The successful completion of the programme and publication of the results will represent a considerable technical and research achievement.

In this case, it has been possible to maintain access to the instrumentation site during and after undermining. However, the novel monitoring methods have shown their utility, and with minor modifications are applicable to other locations where conditions may be more difficult.

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REFERENCES

1. Majdi, A., Hassani, F.P., and Cain, P. The Influence of Design Parameters on Tunnel Closure in the Sydney Coalfield." Energy, Mines and Resources, Canada, CANMET Coal Research Laboratories Division Report ERP/CRL 86-116(OP)

2. CANMET. Development of a Monitoring System for the Lingan Colliery. Final Report by Jacques Whitford Environment Limited, Dartmouth, N.S., on DSS File No. 02SQ.23440-2-9253, March 31, 1993.

3. NCB. The Subsidence Engineers Handbook. Published by the National Coal Board, Bretby, U.K.

4. Corbett, G. An Intrinsically Safe Vibrating Wire Geotechnical Datalogger Developed for the Sydney Coalfield. Energy, Mines and Resources, Canada, CANMET Mining Research Laboratories Division Report (In Preparation).