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MANAGING ROOF CONTROL PROBLEMS ON A LONGWALL FACE

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ABSTRACT: A proven way of interpreting the shield leg pressure sensor data within each shield load cycle has been developed by the authors and this has been encapsulated into real time and non real time software. A load cycle is the change in support pressure with time from setting the support against the roof to the next release and movement of the support. It is now possible to automatically identify when a shield has too low a set pressure, and when a shield is faulty and/or has an inadequate capacity for the conditions. It has been found that once set conditions deteriorate and shields are set manually it is very common for set pressures to be too low for the conditions, resulting in roof control problems. The software can automatically identify set pressures that are too low which will enable auditing of shield operation and corrections to be made. Up to 10% of shield legs have faults on a typical Australian longwall and these periodically result in localised roof control problems. Faulty support components are automatically identified, enabling timely repairs to be made. On some longwalls the shields become overloaded at the peak of the periodic weighting cycle and the software can identify the difference between a heavily loaded support and one that is overloaded. By minimising the cycle time and making sure that set pressures are adequate in cycles following the overloading event, it is quite possible to successfully mine through an overloading event if the event is correctly identified.

The use of this software has the potential to significantly reduce or even eliminate roof control problems on a longwall face with significant benefits to both productivity and safety. By automatically identifying potential causes of roof control problems and offering solutions, the software has the potential to aid longwall automation. A Beta test version of the real time software has been successfully working at BMA's Broadmeadow Mine for some time and several mines have benefited from expert off-line analyses using the software. The software can also be used to isolate the many interconnected factors affecting roof control on a longwall face, which will enable their quantification and is therefore a powerful research tool.

INTRODUCTION

In recent years, longwall roof supports (shields) have been equipped with pressure sensors and hydraulic leg pressures can be displayed in real time. Despite the vast quantity of monitoring data captured on a daily basis from the majority of modern longwall faces, few geotechnical analyses are undertaken. The collected data are largely unused for roof control or for other purposes such as maintenance. The failure of the industry to make full use of the data from the face has largely been a result of its volume in real time, its level of corruption, and the lack of a methodology for data interpretation in the context of support-strata interaction.

It is now possible to go to a longwall site and, using the software developed by the authors, interpret how the supports are interacting with the strata without any prior monitoring of the longwall and to identify faulty support components. This allows the optimisation of mining strategy in terms of set pressure and maintenance scheduling in order to mitigate or even avoid strata control problems. Issues such as faulty support components have been demonstrated to periodically lead to roof control problems and costly delays at all sites, even those where roof conditions were good. Setting the supports too low for the conditions can also lead to significant roof control problems.

The interpretations and identifications are based on the recognition of characteristic load cycles. A load cycle is the change in support pressure with time from setting the support against the roof to the next release and movement of the support. The recognition of the load cycles depends on accurate delineation of roof support pressure behaviour and extraction of key features such as average pressure throughout the cycle, the number of yield events, the set pressure, the rate of loading in part or all of the cycle and the cycle length. The extensive validation of the capabilities of the software showed that load cycle features were accurately mapped and that they could give a useful interpretation of the mining conditions.

In contrast to the software available prior to the authors' developments, the system uses and cross references all available data to obtain the required accuracy of load cycle definition. The minimum data input requirement is shearer position, DA ram extension and pressure sensor data, but AFC and shearer power draw can also be used to improve the accuracy of interpretation and aid in identification of corrupted signals. Existing software were all found to be incapable of accurate load cycle delineation, which significantly limits their interpretative capabilities. This is not to say that these software packages are not useful, rather that interpretive capabilities based on load cycle analysis cannot be encapsulated into those programs.

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The software developed by the authors of this paper has now been extended from "off-line" to "on-line" as an aid to managing roof control problems as they develop.

LOAD CYCLE ANALYSIS

A number of geotechnical models have been developed that claim to be able to relate how a longwall powered support is interacting with the surrounding strata. The methods include: detached block theory (Wilson, 1975); yielding foundation theory (Smart and Aziz, 1986); empirical nomograph based method (Peng et al, 1987); load cycle analysis (Park et al, 1992; Peng, 1998); neural networks (Chen, 1998); various numerical models (eg Gale, 2001; Klenowski et al, 1992); ground response curves (Medhurst and Reed, 2005). All models in the public domain literature were reviewed by the authors of this paper (Trueman et al, 2005a). It was concluded that the above models, whilst offering important contributions towards understanding support-strata interactions, did not offer effective means of interpreting how supports interacted with the strata. Periodic weighting and time dependency are essential components of any model that attempts to describe shield-strata interaction and none of the above models considers both of these and most do not consider either. Support yielding is also important and is seldom explicitly considered.

A mechanistic consideration of how the support and strata interact indicates that there should be four basic pressure time patterns to be observed that will indicate when a support has: an adequate capacity and appropriate set pressure; adequate capacity and too high a set pressure; inadequate capacity; and too low a set pressure. The concept has been validated and further refined through the back-analysis of more than 700,000 individual load cycles on seven longwall panels located in six seams at five mines and nine geotechnical domains.

Adequate capacity and appropriate set pressure

A load cycle in which near stabilisation of the roof is achieved, without one or more yielding events (Figure 1), indicates that the roof characteristics are such that the set pressure is adequate to 'clamp' the roof in place or to support the roof load without any downward displacement other than that due to the elastic compression of the support. There is an initial rapid increase in support pressure followed by a marked decrease in the rate of pressure increase as the support stabilises the roof. The term 'near stabilisation' is used as full stabilisation (no further convergence) may never occur in a normal cycle time.

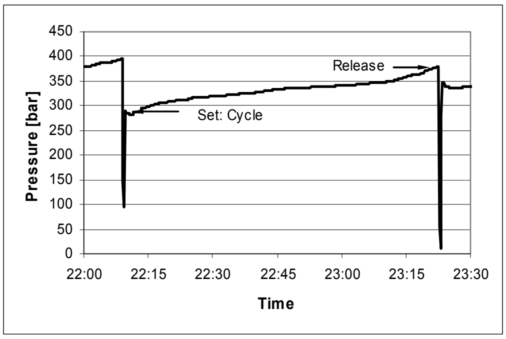


Figure 1 - Pressure *versus* time trend for a typical loading cycle where no yield occurs, indicative of a support of adequate capacity and appropriate set pressure.

Minimal roof deterioration is associated with such pressure-time profiles. There should be minimal, if any, roof control delays and hence production rates may be high.

Time should not play an important role in terms of the support-strata interaction for a support with an adequate capacity and appropriate set pressure. If the load cycle is short then the portion of the pressure time cycle where near stabilisation is occurring will be shorter and will be longer for longer load cycles. Delays in production, for a maintenance shift for example, should not adversely impact on roof control.

Too low a set pressure

Where set pressures are too low for the conditions loading rates are high when compared to situations where the support capacity is adequate and the set pressure is appropriate. The loading rate remains relatively constant throughout the load cycle and the support is unlikely to reach yield. Figure 2 illustrates a typical pressure time chart where set pressure is too low for prevailing conditions; the pressure rise from set to release is relatively constant with little indication of a reduction in the rate of loading. Under such conditions increased loading rates caused by the set pressure being too low for the conditions may result in the unraveling of roof strata. This unraveling results in degradation of the roof conditions such that at the release of the support the roof would not be able to maintain its integrity and would start to break up, leading to difficult set conditions in the next cycle. The difficulty in setting the supports may further exacerbate the problem, as set pressures achieved on the subsequent load cycles would be affected by the poor roof conditions such that achievement of sufficient set pressures may not be possible. The low set pressures and associated rapid roof movement and unraveling of the strata may eventually lead to roof cavities and potential production delays.

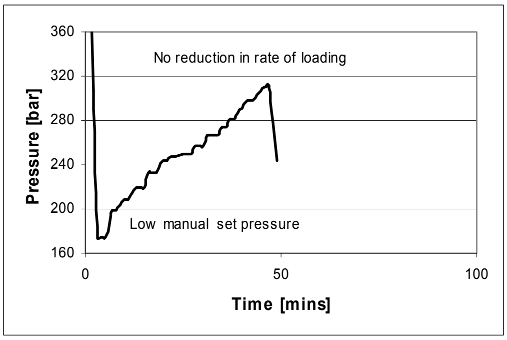


Figure 2 - Typical loading pattern with set pressure too low for the conditions

In the authors' experience too low set pressures usually results where set conditions are poor and operators resort to manual setting of supports. This can be due to soft and fractured immediate roof due to say the presence of faulting or where the longwall has been stopped for a considerable time where the immediate roof is weak. Where supports have been overloaded, as described later, set conditions for subsequent cycles can become difficult.

Extensive back-analyses of longwall sites in Australia carried out with the aid of the software has revealed that once manual setting is resorted to it is quite common for operators to give little consideration to the set pressure. In the authors' experience low sets can often be avoided and are often a result of operator's lack of understanding of the effects that set pressures below a critical value can have on roof control. Even where set conditions are poor it is usually possible to set supports to an adequate set pressure but this can take more effort on the part of the operator. The premature overriding of automatic setting of supports also appears to be an endemic problem on Australian longwalls. Routine auditing of set pressures and when automatic setting is overridden is essential for managing roof control problems on a longwall face and the software described in this paper facilitates this.

In long load cycles the support pressure may reach a level which would normally be adequate for the conditions. However by this time damage to the roof will have already occurred. Minimising the cycle time where set pressures are too low for the conditions leads to less roof degradation. Wherever possible increasing set pressures is the best strategy for minimising roof control problems where set pressures are low. With shields rated at about 100 tonnes per square meter before the shearer takes the next cut, no problems have been observed by the authors of this paper at set pressures of 60% or greater. This equates to an initial support density of 60 tonnes per square meter before the cut. With the same shield rating significant problems have been observed at set pressures below 40% of yield, which equates to 40 tonnes per square meter before the cut. Based upon these observations the authors of this paper would recommend a set pressure equating to a minimum support density of 40 tonnes per square meter before the cut and would consider 60 tonnes per square meter to be better if such set pressures can be practically achieved. If such set pressures are not attainable in the conditions then mining as rapidly as possible will mitigate subsequent roof control problems.

Once roof conditions deteriorate to such an extent that the roof begins to break up the pressure-time signals often become more complex than shown in Figure 2 when set pressures are low. Nevertheless, control of the roof is seldom if at all achieved until set pressures return to acceptable levels, even if remedial action is taken such as grouting the roof. The authors have observed many situations on longwalls where cavities have continued to form after remedial work has been carried out because set pressures have been low in subsequent cycles.

Roof control problems are not inevitable with set pressures below 40 tonnes per square meter because time is a critical factor as previously discussed. If mining is rapid it is quite possible that roof control problems may not develop. At some stage however delays to production will occur and if set pressures are not adequate roof control problems will eventuate.

Inadequate support capacity

When there is no evidence of stabilisation during support yielding, as in Figure 3, the support cannot arrest the roof movement and the support capacity is inadequate for the conditions. Two causes of support overloading have been observed by the authors. One is due to loading transferred from the immediate and/or main roof. The second is a result of one or both supports adjacent to a particular support being faulty and therefore not carrying their rated load. The functioning support is forced to take a higher load in such a case. In such circumstances average loading rates tend to be high.

Based on the experience of the authors, a typical Australian longwall where the supports are not new will have up to 10% of the shield legs faulty at any one time. This is resulting in significant localized roof control problems and production delays. The automatic identification of faults by the software is aimed at achieving rapid repair and a minimization of these problems.

The phenomenon of 'periodic weighting' occurs when the main and/or immediate roof cantilevers over the support. Where competent beds occur in the main and/or immediate roof long cantilevers can form over the support and, as the cantilever lengthens, loads are created which simply cannot be resisted by the support. In such conditions loads just after the cantilever breaks off are usually moderate and can be stabilised, but the load just before the cantilever breaks where periodic weighting intervals are long in physical extent may exceed the support capacity.

The authors have observed effects from thick competent beds whose base was located 50 m from the top of the extraction and the top of which extended to 80 m into the roof at one mine. At another mine the authors identified a thick competent bed as the cause of shield overloading that was located between 65 m and 85 m into the roof. Both mines were extracting a thickness of 4.5 m. This appears to mean that shield loading can be affected by beds located within 20 times the extraction height.

The load cycle characteristic typified by Figure 3 usually only occurs within the high loading portion of the periodic weighting, which normally over 1 to 3 shears. In the low loading portion of a periodic cycle, the cycles, ideally, are similar to those in Figure 1.

When the supports are overloaded, the yielding events lead to significant roof to floor convergence. This convergence increases the probability of roof guttering between the support tip and coal face, making the resetting of the support difficult for the next cycle, and leading to the break up of the immediate roof strata above the supports. Depending on the speed at which mining advances the associated roof degradation can lead to serious roof cavities, resulting in lengthy production delays. The difficulty in resetting the supports may lead to a failure to achieve adequate set pressures for the supports, further compounding the roof control problems. This issue has been discussed above. The combination of roof guttering due to multiple yield events resulting in poor set conditions and low set pressures on subsequent shears is what usually results in roof cavities. Cavity formation therefore generally evolves over two or three load cycles. However, if cycle times are long enough, say where mining has stopped for planned maintenance or an equipment breakdown, roof guttering can deteriorate into cavities within a single load cycle.

Time is a very important parameter in a loading pattern described by Figure 3, irrespective of the cause of the support overloading. If mining proceeds rapidly, the number of yield events and the extent of convergence will be minimised, potentially limiting the extent of guttering between the support tip and face. If mining is rapid enough, it is possible in many situations to get through the interval of support overloading without significant roof control problems. When supports are overloaded it is not appropriate to stop the face for scheduled maintenance, for example. This appears to be an obvious point but the authors have back-analysed problem areas at longwalls using the concepts outlined in this paper where this has happened – simply because operators were unaware that supports were overloaded. After an overloading event, every effort should be made to achieve reasonable set pressure on subsequent cycles under what may be difficult set conditions as described previously. Identifying faulty supports and their timely repair will minimise the possibility of localised roof control problems under all roof conditions.

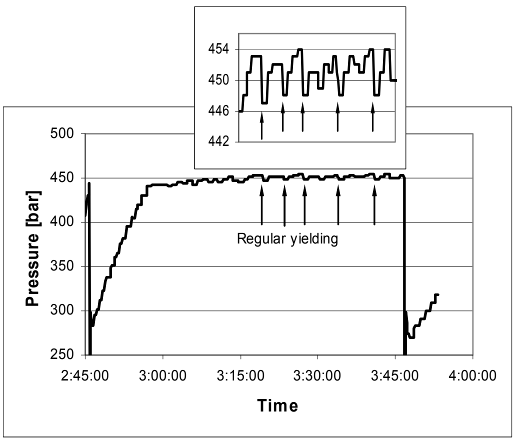


Figure 3 - Support loading for yielding without stabilisation indicating a support with inadequate capacity.

There appears to be a belief in the Australian mining industry that the potential for roof control problems on a longwall face increases with the number of shields that are in yield. This is only partially correct. Through extensive back-analyses at a number of sites the authors of this paper have recognised that it is actually the number of yield cycles that occur in individual support load cycles that influences roof control. If there are less than three yield events in an individual load cycle then roof degradation is seldom observed. In general fretting of the roof between the shield tip and face is observed after about three yield events and as the number of yield events increase this deteriorates into guttering and then cavities. This has been observed where only a small number of shields have been forced into overload because nearby shields were faulty and not able to carry their rated load. On the other hand no roof control problems were observed in a case study where two thirds of the shields on the face were in yield because the number of yield events in the load cycle were less than three in that particular case. Obviously more roof control problems can be expected where a large number of shields are experiencing a large number of yield events.

Because time plays such a critical role in shield-strata interaction it is often not possible to directly equate roof control problems to the causes; be they overlying strata, set pressure or maintenance related. If mining is rapid roof control problems may not develop with faulty shields, where shield set pressures are inadequate or where there are thick competent beds in the roof. But eventually cycle times will be long enough to cause roof control problems where one or more of these factors exist.

Very high set pressures

Set pressures as high as 90% of yield is not uncommon in Australian mines when automatic set is engaged and there appears to be a belief that this leads to improved roof control. The authors of this paper have never observed any problems relating to set pressures when shields are set to at least 60% of yield for shields with a support density of 100 tonnes per square meter or greater before the cut. In general the authors also have not seen any roof control problems relating to high set pressures. In some situations shields have drifted into yield but in the absence of thick competent beds in the immediate or main roof the shields usually have undergone only a single yield event and no degradation to the roof was observed. However, there are situations where very high set pressures may contribute to poorer roof conditions.

Where periodic weighting is high enough to result in periodic shield overload it may be better for set pressures to be nearer 60 % of yield than 90% (with shields of support density of 100 tonnes per square meter or above). This relates to the effect of time. If the support is set to 60% of yield then it will take much longer to get to the first yield event and for the same cycle time there will be fewer yields. Fewer yields will result in less convergence and subsequent roof degradation and it will be easier to mine through the periods of support overload. If a shield periodically has an inadequate capacity for the conditions the authors have seen no evidence that very high setting loads will stabilise the roof. The belief that very high set pressures are beneficial may have arisen when support capacities were less and set pressures close to the yield value were necessary for the set pressure to be adequate.

Panel width, extraction height and seam depth

A number of authors have concluded the need for a greater powered support capacity with increasing panel width, extraction height and depth (eg Medhurst and Reed, 2005; Frith and Creech, 1997). Nevertheless the impact of these factors on support loading is still debated. For example Barczak (2006) challenged the need for increased shield capacity in higher extraction height longwalls. The authors of this paper have also analysed a number of relatively shallow longwalls where support overload was occurring even with relatively high capacity shields. Shield loading is a complex interaction between: shield capacity and set pressure, the composition of the main and immediate roof, the presence or absence of leaking legs, extraction height, cycle time, panel width and seam depth. It has proven very difficult to isolate all these factors. The software developed by the authors that encapsulate their load cycle analysis theories now allows a rapid identification of the causes of shield loading and should facilitate a much better understanding and quantification of the different factors.

One of the factors affecting shield loading that is seldom mentioned is the effect of time. Where longwalls mine wide panels and/or thick seams this inevitably means that individual load cycles are greater than for thinner seams and narrower panels.

This will therefore lead to greater potential for roof control problems to develop at times when set pressures are inadequate, in the vicinity of faulty supports and in situations where periodic shield overload occurs. Auditing set pressures and timely repair of faults will therefore have a larger positive impact on roof control in wider panels and higher extraction heights. That is not to say that auditing set pressures and identifying leaking legs are not important for all extraction heights and panel widths.

Where shields are overloaded at or near the peak of the periodic weighting cycle, the longer cycle times associated with an increase in panel width and/or extraction height may lead to more roof control problems. The merits of increased panel width may of course offset the potential for increased roof control problems in such conditions. Nevertheless, when assessing panel width it would appear wise to understand the potential for periodic shield overload. Recognising such events will also increase in importance with an increase in panel width.

SHIELD CAPACITY

Over the last 20 years hydraulic support capacities have increased significantly. For example, in 1984 the average support capacity in the US was about 450 tonnes and the maximum was about 730 tonnes (Barczak , 2006). By 2005 the average was about 800 tonnes and the maximum was 1160 tonnes. The greater canopy areas to accommodate one web back and wider supports means that support densities have not increased as much however. Most current longwall mines in Australia had a support density in the region of 100 tonnes per square meter before the cut until recently. The newer supports tend to be rated at about 115 tonnes per square meter and Moranbah North have on order 1750 tonne capacity supports with a support density of 140 tonnes per square meter. The technology is there to significantly increase support capacities still further, the current limitation apparently being the ability of the OEMs to test the supports. If the demand for higher capacity supports is there then that limitation will be overcome, but at a price.

Whilst it is true that roof control on a longwall face has improved over the years it is debatable what role support capacity alone has played in this and if further increases in capacity will lead to further improvements. Using the new concepts of load cycle analysis encapsulated in software it is now possible to answer those questions. For the first time it is now possible to rapidly differentiate between causes of roof control problems that relate to poor operation of the support, maintenance problems or those relating to strata-support interaction.

SOFTWARE DEVELOPMENTS

The commercial software being used to manipulate the pressure data that existed prior to the developments described in this paper were found to be deficient in the type of load cycle analysis proposed herein, simply because the necessary concepts for load cycle analysis had not been developed at the time of their release. Analyses of this software (Trueman et al, 2005a) concluded that they were incapable of achieving accurate load cycle delineation. Neither had they any capability for extracting the critical load cycle features essential for interpreting how supports were interacting with the roof strata or differentiating between accurate and corrupt signals. This is not to say that the software packages are not useful, merely that the potentially powerful concepts relating to load cycle analysis noted above cannot be incorporated into these programs.

Existing software used only the pressure signals. The authors' new code uses the pressure signals, DA ram and shearer positions as a minimum. Extensive manual verification of events on the longwall identified by the code has shown that the cycle identification algorithms have a very low error rate and are able to correctly reject corrupt sensor data (Trueman et al 2005b). At present, the accuracy of the code is unmatched. Other signals such as AFC and shearer power draw can be used to further increase the accuracy of load cycle identification when they are available. The code is capable of negotiating signal drop-out, which has been found to be a problem on many longwall faces, and is able to accurately track the spatial position of the face in terms of metres of retreat.

Additional algorithms were developed to extract the critical load cycle features that are essential for interpreting support-strata interaction. The following features are extracted from the accurately determined load cycle for every support leg on the face:

- map of the time weighted average pressure (TWAP)
- map of yield events
- map of the set pressures lower than a user defined threshold
- map of cycle times (time from set to release)
- map of loading rate in parts of the load cycle
- identification of when posi-set has been activated
- map of support legs not carrying their full rated load due to faults associated with yield or check valves
- map of noisy pressure sensor signals that indicate incipient sensor failure.

Extracting such features accurately is not a simple matter given the noisiness of the signals and the degree of signal corruption or loss experienced on many longwalls. Figure 3 provides a good example of the degree of difficulty in isolating yield events from the pressure signals. Elements of the code that detect such features must be very carefully designed and tested to ensure that they identify the sought-after events while rejecting pressure variations that do not represent a yield. Identifying every load cycle on every shield is likewise not a simple task.

In the first instance an "off-line" version of the code was developed in order to validate the load cycle analysis concepts and demonstrate the interpretive capabilities of the software.

Validation of load cycle analysis concepts

To use the load cycle characteristics described above with confidence as an analysis tool, they had first to be validated. It had to be shown that the characteristic pressure-time profiles described above do indeed exist in real mining conditions and the anticipated roof control conditions associated with each do in fact occur. A comprehensive assessment of the load cycle analysis concept at a range of specifically selected longwall mines allowed for such a verification process. Validation revealed excellent correlation between the roof control conditions predicted to be associated with each cycle type and the actual roof control conditions.

The research relied upon analysis of support loading cycles for every support across the face over a total advance at all the mines in excess of 2 km. Approximately 700,000 loading cycles were analysed. This analysis was made possible by development of the new software described above.

Analysis of spatial roof support loading patterns "off-line"

In addition to permitting the validation of the load cycle concepts developed by the authors, the new software has been used to assess support strata interaction, allowing rapid adaptation of mining strategies and set pressures for optimal roof control and maintenance scheduling. The current capabilities of the software are illustrated from an example. Data that was made available on support loading at Mine A between the 10th July and 7th August 2005 was run through the software. An interpretation of the support-strata interaction for this period was made using the outputs generated by the software.

The data are presented as maps in which the x-axis is the leg number counting from the left (tailgate end) of the longwall face which is on the left hand side of the diagrams. The y-axis is the shear number in the direction of mining and is therefore proportional to mining advance.

The plotted value is the value of the variable of interest and it is usually coded by colour. Figure 4 is the TWAP (bar) for the period analysed; the plot has been converted to monochrome for printing. The monochrome printing unfortunately makes the interpretation of the support strata interaction difficult, which is not the case with the colour coded maps.

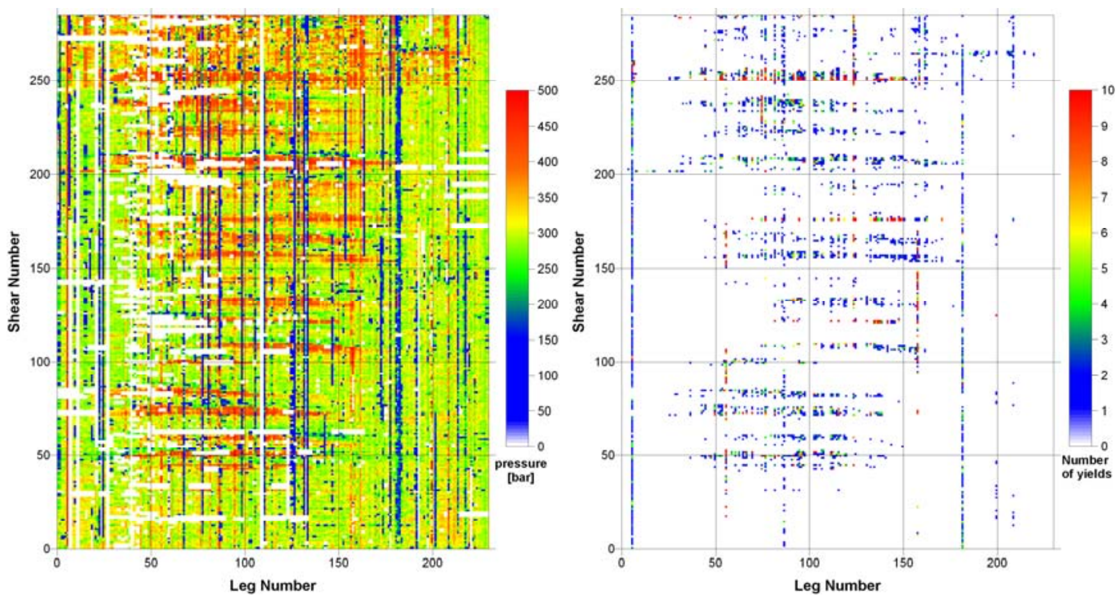


Figure 4 - TWAP (left) and number of yield events for July 10th- August 7th inclusive.

The white regions in the TWAP plot indicate the regions where the sensor signals from the face were absent or so badly corrupted that no useful information could be extracted. The predominant cause of the white regions (>95%) is the simple absence of sensor signals.

The overloading of supports is indicated by the supports going into yield and continuing to yield without stabilisation throughout the support cycle. The number of yield events in a loading cycle is a good indicator of the intensity of overloading when cycles are all of similar time duration. Supports that have undergone yield events are also identified in the right hand plot of Figure 4. Some supports have had more than 10 yield events within the cycle.

Multiple yield cycles correspond to supports that continued to yield throughout the cycle and were therefore overloaded; i.e. they had inadequate capacity for the conditions. The number of yield events is influenced by the cycle time in addition to the intensity of loading, indicating that time is a critical component in assessing support-strata interaction on a longwall. The yielding patterns generally coincide with the high TWAP regions on Figure 4. In terms of strata support interaction there is a very big difference, however, between a heavily loaded support and an overloaded support. Assessing that the support is overloaded is not possible from TWAP alone.

The left of Figure 5 is a map of supports showing the set pressures lower than a user defined threshold and the right maps the cycle time for the shear. In this case, we have chosen 40% of yield as the threshold. This image is intended to reveal the regions of the face in which set pressure is regarded as being too low for the conditions. The reason for the low set pressure may be that the set pressure could not be achieved due to roof damage and debris on the canopy under positive set regulation or that the overriding of positive set for the face and the use of manual setting for the face did not achieve the usual set pressures. Low set pressures often follow regions where supports have been heavily loaded, particularly if cycle times are long during periods of overloading. However, in some cases adequate set pressures can be achieved with extra effort and care. The software can be used to audit shield operation and allows Engineers to give

feedback and guidance to operators. Prior to the development of the software this could only be done by very time consuming and tedious checking of the pressure-time record.

The multiple yield and low set pressure maps also show up faulty supports. For example at about leg 185 the leg is shown to be yielding every load cycle (refer to multiple yield map, Figure 4). An adjacent leg is shown to have a very low set pressure on every load cycle (low set map, Figure 5) indicating a fault. Minor roof control problems were encountered in this area of the face from time to time, particularly during long cycle times and towards the peak of the periodic weighting. However, a separate algorithm has been developed to automatically delineate faulty legs.

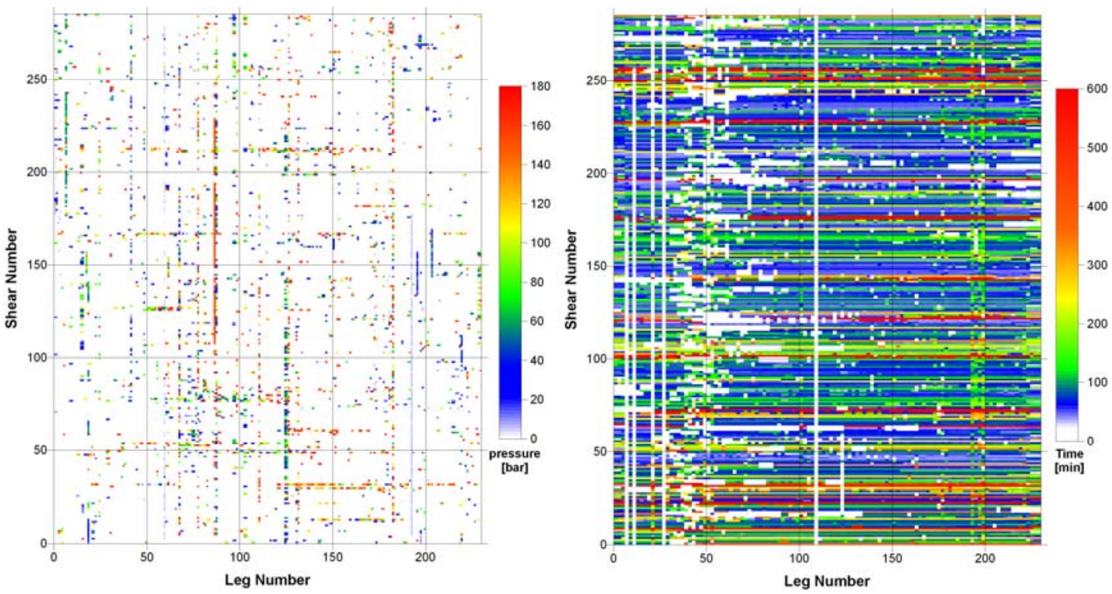


Figure 5 - Supports having a set pressure below 180 bar (left) and cycle time (set to release) for the supports (right).

The four images were used to deduce much of the support-strata interaction throughout the region where analyses were carried out. Feedback from mine personnel indicated that an accurate assessment of what had happened on the longwall face during the period of analysis could be made from these maps.

After mining about 45 shears periodic weighting can be observed on the TWAP and yield maps. There was some evidence of minor overloading of supports and in some cases low set pressures immediately following periods of high periodic weighting up to shear 210. Roof control problems with relatively minor delays were reported by the mine after these periods of support overloading. From about shear 210, the intensity of the periodic weighting started to increase. Overloading of a number of supports occurred in an approximately 3 hour cycle at around shear 210. There is evidence of low set pressures on both the TWAP and low set pressure maps after mining through this period of heavy weighting. Production delays due to roof control issues were reported by the mine.

Another relatively heavy loading occurred at around shear 242 where again a number of supports can be observed to be overloaded on the multiple yield map. Mining continued rapidly through this weighting event. A scattering of supports were observed to have too low a set pressure after this but far fewer than for the previous weighting event. Time was used effectively to negotiate successfully through this weighting event and achieving adequate set pressures in subsequent cycles also aided roof control.

A further weighting event where a number of supports became overloaded occurred around shear 256. There were two relatively long cycles of about 7 hours duration each during this weighting. It would be anticipated that cycles with a duration of about 7 hours could result in roof control problems when supports are so heavily loaded. Long cycles and data loss can be observed from about shear 260. Significant production delays were reported by the mine due to roof control problems.

Additionally, 29 legs on the face were identified by the software as having faulty yield or check valves during the period of analysis. Localised roof control problems were reported to occur periodically in the vicinity of some of these supports. More roof control problems were observed in the vicinity of these supports close to the peak of the periodic weighting and where cycle times were long.

The ability to identify supports that were being periodically overloaded rather than just heavily loaded, the identification of faulty legs and the set pressures being achieved for every load cycle, gave considerable insight to the mine staff as to the causes of the strata control problems that they had been experiencing and we were able to suggest mining strategies
to mitigate the problems. Subsequently, when it was observed that support loading was intense, every effort was made to mine as quickly as possible, thus minimising the number of yield events and the amount of convergence. Every effort was also made to ensure adequate set pressures were maintained during subsequent shears during or after an overloading event. In this way the mine was able to subsequently successfully negotiate several overloading events, whereas previously significant delays to production had been experienced due to roof cavities. Identification of faulty support components reduced the incidence of localised roof control problems.

Although the "off-line" version of the code was useful in identifying the causes of roof control problems and understanding how to mitigate or avoid them, the real interest for the mine was an "on-line" version where analysis is possible in near real time. It is difficult from observations alone to differentiate between heavy loading and overloading, which supports have too low a set pressure for the conditions and which supports are faulty. For that reason the code was further developed in order to provide the required real time response.

Real time analysis

The switch to real time analysis from the off-line work that was done previously posed new challenges. The code that carries out the data analysis has been repackaged into libraries whose interface must be exposed to the graphical user interface (GUI) that the operator will use to configure the system and monitor the analysis results. The system relies on a server delivering data, principally from the longwall face computer, to a database server. A database application fetches blocks of data on a regular basis and passes them to the analysis routines which process the new information. The GUI also displays various forms of live data.

In one sense, the events on the longwall take place slowly; a longwall having one hundred supports is about 200 meters long and, depending on the thickness of the seam, cutting a web of coal requires somewhat less than one hour, if all goes well. However, the longwall is a busy place given that there are 200 cylinders to monitor and within which to maintain pressure and the actions of pushing the AFC or pulling up the support should be done as quickly as possible. It does not take many seconds to push the AFC and releasing, pulling and resetting the support can take place in a matter of seconds. To ensure that all events taking place on the longwall are logged as they happen a logging cycle every 20 seconds or faster is required. Joy and DBT longwalls have different methods of logging. The resulting flow of data, in addition to the control signals needed to keep the wall operating, is substantial, but manageable.

A schematic of the online system is shown in Figure 6. Data is collected from the face via a server that is provided by the longwall manufacturer. The data is stored in a database server, which is queried periodically by the GUI. Once sufficient new data are available for an analysis, the new set is sent to the 'analysis engine' for processing. On completion, a new result set is passed back to the graphical user interface for display in the familiar formats described above. The results are archived in the database for later retrieval.

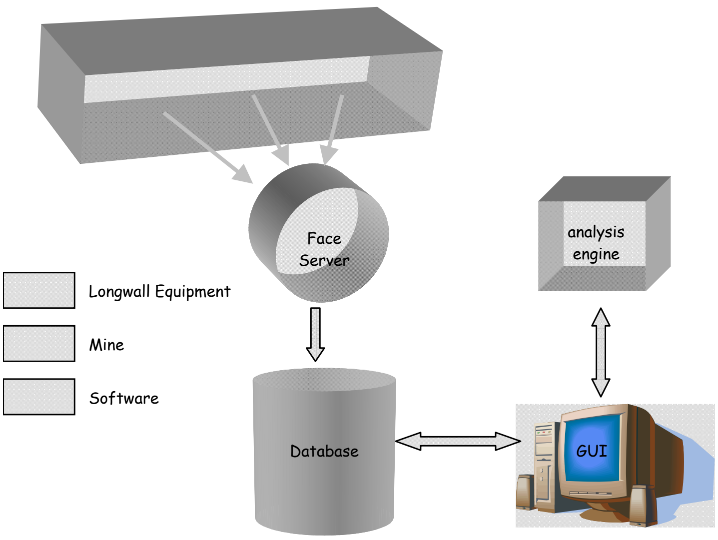


Figure 6 - On-line software schematic

The manner of presentation of the data to the longwall operators in real time follows the format that we found to be successful in our off-line code, with additions. Figure 7 is a screen dump of the control panel, showing TWAP and in the top right hand corner a map of the instantaneous pressures. Colour is used as a third dimension, as with our off-line code. All the different map types can be called up and historical data can also be presented. The instantaneous pressure map is a new development over the off-line code and gets over the problem of the fact that the analysed data is at least one shear behind because a load cycle needs to end before it can be analysed. This limitation is being addressed and with further developments analyses will be possible within the current shear before it ends. The method of presentation of the instantaneous pressures is shown in such a way that it is easy to interpret what is occurring on all supports across the face at a glance. The sloping blue lines for example are releases for the next load cycle. The cursor can be placed at any point on any of the maps and actual data, such as the pressure, are shown.

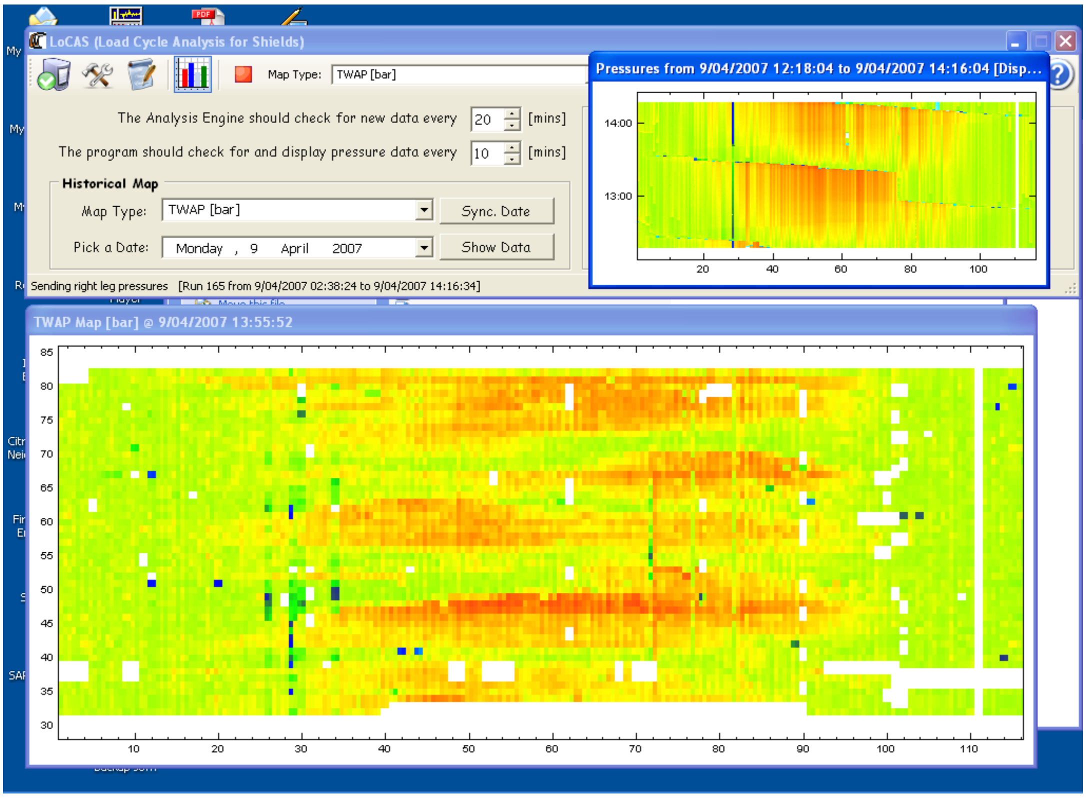


Figure 7 - Control panel, in this case showing TWAP on the main screen and instantaneous pressures top right

The system also displays a vertical colour scale which permits the translation of the colours to numerical values of the variable being displayed. In general, low values of a variable are cool colours with the higher values shown in hot colours. For example, pressures above about 400 bar will be a hot orange or red and high numbers of yield events will also be red. Once a user is familiar with the standard colour scales for each type of display, the colour bar can be turned off.

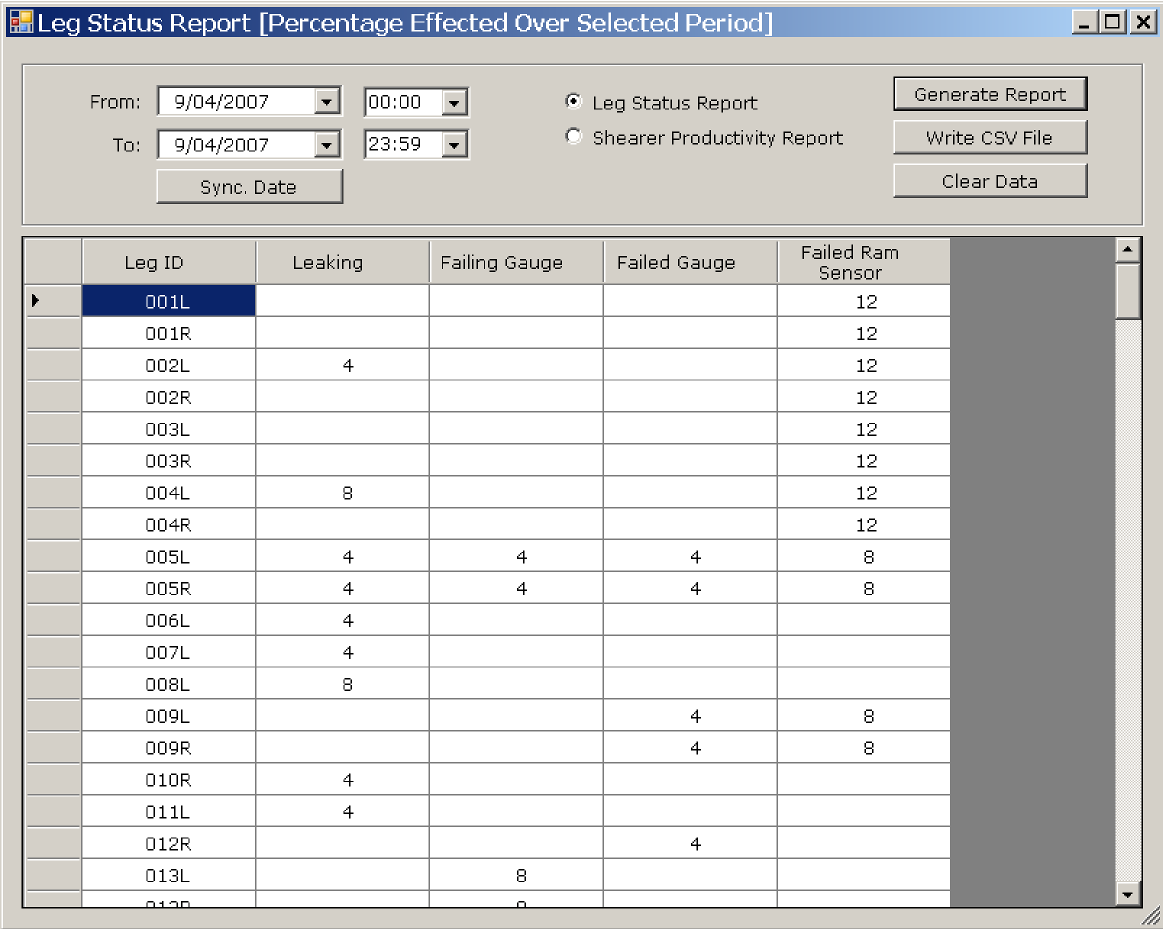
A report is generated of the percentage of time during a user defined period that identified problems (leaking leg, failing gauge, failed gauge, failed ram sensor) occurred; Figure 8.

A shearer production breakdown report is also generated for each shear (start and end time, duration of shear, percentage of total time productive, time cutting, flitting and parked); Figure 9.

Further developments are occurring to move from a Beta test version to a full release version of the software and extend its functionality so that it can be used on any longwall and analysis can be carried out in the current shear without waiting for it to be completed.

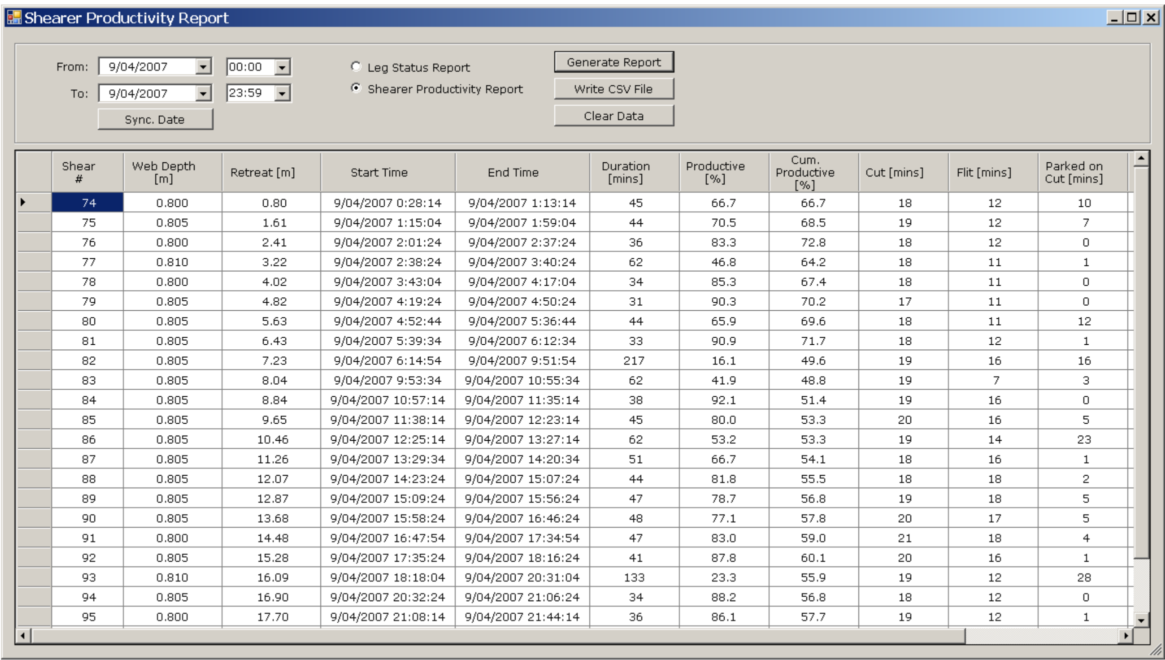
CONCLUSIONS

A load cycle characteristic concept has been developed aimed at quantifying longwall shield-strata interaction and has been encapsulated into off-line and on-line software. The concept has been validated by extensive analysis of about 700,000 support load cycles covering more than 2 km of mining advance at five different mines. The load cycle analysis concepts are a major breakthrough in understanding the interaction between a longwall shield and the surrounding strata. Before these concepts were developed the pressure signals were largely unused, simply because of a poor understanding of what they meant in terms of support-strata interaction or for that matter the integrity of the support. The encapsulation of the concepts into software enables a rapid evaluation of the causes of



Leg ID	Leaking	Failing Gauge	Failed Gauge	Failed Ram Sensor
001L				12
001R				12
002L	4			12
002R				12
003L				12
003R				12
004L	8			12
004R				12
005L	4	4	4	8
005R	4	4	4	8
006L	4			
007L	4			
008L	8			
009L			4	8
009R			4	8
010R	4			
011L	4			
012R			4	
013L		8		

Figure 8 - Report on potential faults on individual legs



Shear #	Web Depth [m]	Retreat [m]	Start Time	End Time	Duration [mins]	Productive [%]	Cum. Productive [%]	Cut [mins]	Flit [mins]	Parked on Cut [mins]
74	0.800	0.80	9/04/2007 0:28:14	9/04/2007 1:13:14	45	66.7	66.7	18	12	10
75	0.805	1.61	9/04/2007 1:15:04	9/04/2007 1:59:04	44	70.5	68.5	19	12	7
76	0.800	2.41	9/04/2007 2:01:24	9/04/2007 2:37:24	36	83.3	72.8	18	12	0
77	0.810	3.22	9/04/2007 2:38:24	9/04/2007 3:40:24	62	46.8	64.2	18	11	1
78	0.800	4.02	9/04/2007 3:43:04	9/04/2007 4:17:04	34	85.3	67.4	18	11	0
79	0.805	4.82	9/04/2007 4:19:24	9/04/2007 4:50:24	31	90.3	70.2	17	11	0
80	0.805	5.63	9/04/2007 4:52:44	9/04/2007 5:36:44	44	65.9	69.6	18	11	12
81	0.805	6.43	9/04/2007 5:39:34	9/04/2007 6:12:34	33	90.9	71.7	18	12	1
82	0.805	7.23	9/04/2007 6:14:54	9/04/2007 9:51:54	217	16.1	49.6	19	16	16
83	0.805	8.04	9/04/2007 9:53:34	9/04/2007 10:55:34	62	41.9	48.8	19	7	3
84	0.805	8.84	9/04/2007 10:57:14	9/04/2007 11:35:14	38	92.1	51.4	19	16	0
85	0.805	9.65	9/04/2007 11:38:14	9/04/2007 12:23:14	45	80.0	53.3	20	16	5
86	0.805	10.46	9/04/2007 12:25:14	9/04/2007 13:27:14	62	53.2	53.3	19	14	23
87	0.805	11.26	9/04/2007 13:29:34	9/04/2007 14:20:34	51	66.7	54.1	18	16	1
88	0.805	12.07	9/04/2007 14:23:24	9/04/2007 15:07:24	44	81.8	55.5	18	18	2
89	0.805	12.87	9/04/2007 15:09:24	9/04/2007 15:56:24	47	78.7	56.8	19	18	5
90	0.805	13.68	9/04/2007 15:58:24	9/04/2007 16:46:24	48	77.1	57.8	20	17	5
91	0.800	14.48	9/04/2007 16:47:54	9/04/2007 17:34:54	47	83.0	59.0	21	18	4
92	0.805	15.28	9/04/2007 17:35:24	9/04/2007 18:16:24	41	87.8	60.1	20	16	1
93	0.810	16.09	9/04/2007 18:18:04	9/04/2007 20:31:04	133	23.3	55.9	19	12	28
94	0.805	16.90	9/04/2007 20:32:24	9/04/2007 21:06:24	34	88.2	56.8	18	12	0
95	0.800	17.70	9/04/2007 21:08:14	9/04/2007 21:44:14	36	86.1	57.7	19	12	1

Figure 9 - Screen dump of shearer production report

roof control problems on a longwall face. The work has the potential to significantly reduce roof control problems on a longwall coal face by influencing:

- Shield design;
- Shield operation;
- Maintenance scheduling; and
- Panel layout and design.

Geotechnical model development would not have been possible without extensive and detailed analysis of support loading cycles (load-time curves between the setting of a support against the roof and release of the support immediately prior to its advance). Analysis was made possible through development of a new computer code that accepts the data stream from the longwall face (leg pressures, shearer position, DA ram position and equipment power draw) and accurately extracts loading cycles. This new code has proved far more accurate for load cycle identification than existing codes and also enables the critical load cycle features to be extracted that are essential for the accurate interpretation of support-strata interaction, the audit of shield operation and identification of faulty support components. The software has been extended from off-line to on-line in order to provide a real time response to changing strata conditions on a longwall. A Beta test version has been running successfully at BMA's Broadmeadow mine for several months. The functionality of the code is being extended.

Shield loading is a complex interaction between: shield capacity and set pressure, the composition of the main and immediate roof, the presence or absence of leaking legs, extraction height, cycle time, panel width and seam depth. It has proven very difficult to isolate all these factors. The software developed by the authors that encapsulate their load cycle analysis theories now allows a rapid identification of the causes of shield loading and should facilitate a much better understanding and quantification of the different factors and is therefore a potentially powerful research tool.

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