Longwall Mining Susidence Effects on Rail Track Structure

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Abstract
South Blackwater Coal Limited began operation of a new longwall mine, Kenmare, in late 1996. The longwall panels run roughly perpendicular to the main rail link to the mine and pass beneath it. Since the track would be affected by subsidence, a 2.6km diversion parallel to the original line was built by Queensland Rail and funded by South Blackwater Coal. The main problems caused by subsidence are changes of rail stress within the subsidence zone which can lead to rail buckling. A monitoring programme including measurements of rail strain and time-lapse video recording was conducted to measure the response of the track structure. The results show that the track-ground interaction was substantially different from previous experience and that the overhead power lines were relatively unaffected by the subsidence.

Key Words: longwall mining, subsidence, rail track, power lines, monitoring

Introduction
Longwall mining began at South Blackwater Coal Limited's Kenmare mine in late 1996. Longwall mining is becoming increasingly common in Central Queensland (CQ). This is a cause for concern for owners and operators of infrastructure since subsidence effects can be severe. To avoid buckling, continuous welded rail lines are pretensioned before being welded. This pretension prevents them from developing a compressive stress due to thermal expansion and hence buckling. Lateral ground movements due to mine subsidence can reduce or reverse this prestress and lead to buckling. Predictions carried out for South Blackwater Coal Limited (SBCL) indicated that vertical subsidence of around 2m and lateral ground strains of around 20mm/m would occur (Wardle & McNab, 1993). The coal seam is approximately 130m below ground at the Kenmare mine. Because SBCL could not afford to lose coal transport out of the mine for any significant period, they were willing to fund a 2.6km diversion line parallel to the existing link. This then allowed traffic to be switched to the diversion while subsidence damage to the main line was repaired and vice versa.

Because of the geology, the subsidence effects in CQ coalfields are significantly worse than those recorded elsewhere in the literature. A report on mining in the Illawarra region quoted lateral strains of 0.8-1.2 mm/m with a vertical subsidence of 850mm. Similarly, subsidence affecting railway track near Newcastle, NSW, showed vertical subsidence of 350mm and a loss of stress-free temperature of 70°C (Widders 1993). This would correspond to a strain of 820 microstrain or .82mm/m. Grainger (1993) reported similar experience from the UK, predicting ground strains of the order of 2mm/m and vertical subsidence of 900mm. Grainger also states that

"Research has shown that, on average, 80% of ground strain associated with mining is transmitted to the continuous-welded rail and that extreme values can reach 100%."
This would clearly have been a major problem at Kenmare as strains of 20mm/m are well above those required to cause yield of the rail. As confirmation that the Kenmare predictions were reasonable, experience at the Gordonstone mine reported vertical subsidence of 1.9m and lateral movements of up to 600mm (Gibson, 1995). 600mm of movement is consistent with the lateral strain predictions made for SBCL.

In the cases referred to above it has been found that the most significant effects are those caused by changes in rail stress due to lateral ground movement. Bending stresses due to vertical movement have been found to be much less important (Grainger 1993, Widders 1993). In both the UK and NSW cases, it was possible for the operators to deal with the subsidence problem by introducing speed restrictions and taking temporary track possessions to carry out retensioning and hence maintain the stress free temperature.

Because Queensland Rail expect subsidence to be a continuing problem in the CQ region, they funded Central Queensland University to carry out a monitoring project on the first section of track to be affected.

Preliminary Modelling

To confirm the likely effects of the subsidence on the track structure, a finite element model of the track structure was created. This was carried out by modelling the track structure as a standard beam on elastic foundation (BOEF) using STRAND 6.1. A 250m section of track was modelled. Each sleeper/rail connection was modelled as a spring, and the rail was modelled as a continuous beam spanning across these spring connections. The model therefore comprised around 700 nodes and a similar number of elements. A representative value of track modulus was assumed from the Railways of Australia Review of Track Design Procedures (Tew, Marich and Mutton 1991) and the appropriate values of rail area and stiffness given by QR were used. Various loading and node displacements were applied to the model to investigate the likely behaviour of the track. The results were as follows:

- The track could be expected to follow the ground profile following subsidence and not to become suspended at any point.
- As found in previous studies, longitudinal stresses due to ground movement were likely to be much more significant than bending stresses
- Effects of ground strain on the track structure would be heavily dependent on the degree of slip between rail and sleepers, sleepers and ballast and ballast and formation.

Instrumentation

On the basis of the modelling, it was decided to use an array of strain gauges along the length of the subsidence zone to monitor changes in axial strain. The strain gauges used were 10mm foil resistance gauges nominally compensated for thermal strain in the rail. That is, they should give zero apparent strain reading on an unrestrained piece of steel during thermal expansion. K-type thermocouples were used to measure rail temperature and temperature inside the hut during the course of the project. A summary of the gauge positions are given in the table below.
<table>
<thead>
<tr>
<th>Chainage from CL</th>
<th>Gauge Type</th>
<th>Gauge Location</th>
<th>West or East Rail</th>
</tr>
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<tbody>
<tr>
<td>80m S</td>
<td>linear</td>
<td>NA</td>
<td>W</td>
</tr>
<tr>
<td>57.5m S</td>
<td>linear</td>
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<td>W</td>
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<tr>
<td>3m N</td>
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<td>Lower Flange</td>
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<tr>
<td>3m N</td>
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<tr>
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<td>linear</td>
<td>NA</td>
<td>E</td>
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<tr>
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<td>linear</td>
<td>NA</td>
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</tr>
<tr>
<td>210.5m N</td>
<td>linear</td>
<td>NA</td>
<td>W</td>
</tr>
</tbody>
</table>

**Table 1 - Strain Gauge Locations**

ETRS Pty Ltd were contracted to install the strain gauges on the rail, and all data was logged to a Schlumberger Orion data logger hired from ETRS. The logger has the capability to drive strain gauges down long line lengths which was considered to be a cheaper and simpler solution than installing signal conditioning adjacent to the strain gauges. The logger was installed within a portable site hut and powered by a diesel generator with a 40 gallon fuel tank.

A time lapse video camera was also set up on the roof of the site hut to gain a visual record of the subsidence. The camera recorded a short burst of video every 45 seconds which gave a tape where 30 seconds of tape time was equivalent to one hour of real time.

A plan of the strain gauge positions in relation to the line and the longwall panel is shown in Figure 1.
Figure 1 - Plan of Instrumentation Positions on Rail Line

As ever with remote field monitoring programmes, success would have been impossible without the support of local staff on the ground. SBCL and their contractors provided day-to-day support by keeping the generator running, checking the logger was still running and restarting the video camera after power failures.

The main problem associated with the monitoring installation was the generator, which suffered frequent breakdowns. However, enough baseline data was recorded, and the equipment functioned satisfactorily during the crucial period where the bulk of the subsidence occurred. A secondary problem was that due to various operational problems with the longwall machine and the geology, the subsidence was delayed by about two months. This caused some concern about the continued health of the monitoring equipment and instruments. Despite this, the strain gauges performed excellently and there were only minor problems with the thermocouples. The video camera fared less well having by the end of the project been locked in a metal box in the tropical sun for around three months. Although the video is usable, some editing work is required to generate good quality video from the final tapes.

Visual Observations
The time lapse video tape records the progress of the subsidence wave beneath the rail line. Probably the most interesting points from this video are that the overhead power line displays relatively little movement as the subsidence wave progresses. This is in line with the experience seen at Gordonstone mine referred to earlier (Gibson, 1995). The rails buckled close to the centreline. This buckling can be seen occurring on the
video, and can also be seen to have disappeared overnight when the sun rises in the morning.

Visual inspections of the formation and track were also taken as the subsidence progressed. When visiting the site, there was a slightly eerie noise of the stones in the ballast gradually creeping as the ground moved! Major tension cracking was seen at the extremities of the subsidence zone, some cracks being up to 100mm in width. Ground heave was visible near the centreline of the longwall panel. As far as effects on the track structure, there had clearly been significant movement between the various elements of the track structure. The sleepers had dragged by up to 300mm in many places, particularly in the zones of high ground strain over the edges of the panels, around 50-80m either side of the centreline. In some places, the rail had also slipped relative to the sleeper. The rail had buckled close to the centreline, but somewhat asymmetrically in that the worst buckling had occurred from 0-20m south of the centreline. A large tension crack ran diagonally across the rail line at 40-50m south of the centreline. This may be because the embankment met with the existing ground at that point which may have been a plane of weakness to initiate the crack.

**Subsidence Measurements**

Surveys of the ground subsidence were carried out by both SBCL and QR. The SBCL measurements were EDM co-ordinate measurements of pegs on cross lines running broadly perpendicular to the longwall mainline, the most relevant cross line being adjacent to the original rail line. Queensland Rail took levels on the rail line itself as well as at lines at offsets of 2.5m and 7.5m either side.

The subsidence wave passed beneath the track in the two weeks 15-27 September 1997. Before this, there had been some minor subsidence effects as the longwall machine progressed slowly towards the rail line. The results of the subsidence measurements show that the predictions carried out for SBCL were uncannily good. Measured vertical subsidence was almost exactly 2m, essentially as predicted. The only slightly difference was that the subsidence zone was somewhat less wide than predicted. An SBCL plot of the measured subsidence is shown in Figure 2.
Figure 2 - Measured Subsidence at the Rail Line

Because of the patterns of cracking in the formation, the plots of lateral ground strain are messier than those of vertical subsidence. However, the peak measurements of strain are approximately 20mm tensile and 15mm compressive. Once again these are very close to those predicted. An SBCL plot of the measured ground strains is shown in Figure 3. These are plotted along a cross line parallel to the rail line and from North to South.

Figure 3 - Measured Lateral Ground Strain
Strain Measurements

Since at the time of writing it is only a matter of a month since the monitoring equipment was removed, analysis of the data is still going on. However, some trends and conclusions have already been gained from the data. A plot of the strain measurements at a succession of positions along the rail is shown in Figures 3, 4 and 5. The straight line portions are due to loss of power at various times, and the large excursion from days 55 to 63 was due to a spike when power was reconnected to the logger after a generator failure. The relationships between the strains are clearer when overlaid in colour on the same plot which is unfortunately not possible in this paper. In each case the strains are apparent strains as recorded and have not been corrected for the effects of temperature. However, the trends in baseline strain are clear.

![Figure 3 - Strains 3m North of Centreline](image)

![Figure 4 - Strains 80m North of Centreline](image)

![Figure 5 - Strains 161m North of Centreline](image)

Figure 3 shows the strain 3m north of the centreline of the longwall panel. As can be seen, there is a gradual decline in base strain until about day 65. This decline in strain is a mixture of thermal changes and the slow progress of the longwall panel, although a deeper analysis is needed to separate these effects. The peak base strain is around 400 microstrain compressive, occurring around 75 days after the start of monitoring. This corresponds to a date of 18 September 1997. Comparing this with the measured ground strain at the same point shows that it is around 4% of the ground strain rather than the 80-100% figures quoted in the literature. The plot also suggests that as a
result of thermal movement and creep the rail has managed to redistribute the strain even while the ground strain is increasing.

Figure 4 shows the strain 80m north of the centreline of the longwall panel. This shows the same gradual decline in base strain, with a slight increase in base strain after 75 days as the subsidence wave passes through. Looking at Figure 2 shows that this gauge fell into the zone where the ground strains were at their tensile maximum, of the order of 20000 microstrain. The increase in base rail strain is perhaps of the order of 100 microstrain, indicating that only 0.5% of the ground strain was transferred to the rail. The strains from the gauge at 75m north of the centreline are very similar. This would imply that the rail has been stiff enough to span across the zone of tensile ground strain and distribute these strains hence reducing their effect. This would correspond with the sleeper movement referred to above.

Figure 5 shows the strain 161m north of the centreline. This is essentially beyond the zone of influence of the subsidence and it can be seen that the base strain is reasonably constant until day 75 when there is an increase in the base strain level. This is a consequence of the rail line sagging into the depression caused by the subsidence and the tensile ground strains developed at about 80m north of the centreline being transferred via the sleepers.

Conclusions
The most important conclusion from this work is that the strain transfer between ground and rail is much smaller than that recorded in previous literature. Transfers of around 4% occurred rather than the 80-100% which has been quoted elsewhere. A second conclusion is that the stiffness of the rail indicates that through relaying the track it may be possible to avoid the construction of expensive diversion lines to cope with the subsidence. The overhead power lines survived the subsidence reasonably well.

Acknowledgments
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References
Gibson, BStC. The Effects of Ground Subsidence from Longwall Coal Mining on Pole Type Overhead Power Lines, pp177-191, Vol 15, No 2, June 1995, *Journal of Electrical and Electronics Engineering Australia - IEAust & IREE Society*


Abstract: Dynamic ground movements associated with a moving longwall face were monitored in different mining and geological environments in four collieries in New South Wales. The face advance rate varied between 4.1 and 7.2 m/day and the average depth between 115 and 474 m. The subsidence development curves differed significantly indicating the dependence of subsidence development rate on the rate of extraction. In order to validate the dependence, subsidence development was monitored over two longwall panels under similar mining depth and geological conditions in the Newcastle Coalfield of New South Wales. The rate of extraction operated to influence subsidence development. A faster rate resulted in less severe ground movements. The dynamic movements were approximately 40% to 100% of total movements over the edges of longwall panels and were large enough to cause surface damage. They occurred over an area where post-mining movements were considered insignificant. The magnitude of the residual subsidence varied from 10% of the total subsidence near the edges of extraction to less than five over most of the panel.

Keywords: Longwall mining, panel subsidence, dynamic profile, ground movements, rate of extraction.

Introduction

A typical subsidence profile over the caving and of a longwall panel is shown in Figure 1. The profile may be in an extracted panel which exceeds a distance of at least the mine depth (H) to the right after the moving end. This maximum distance, usually referred to as the point of mining influence (P), permits the development of the subsidence and the subsidence profile represents the active subsidence associated with a period of constant height. The profile moves forward with the moving face until it reaches the end of the panel. When the face stops at the end of the panel, the subsidence profile above the edge of the panel will be the dynamic profile. The dynamic profile shows the edge changes with time to the final subsidence profile when all the residual subsidence has taken place. The difference between the final profile and the dynamic profile is the residual subsidence. In panel extraction by the longwall method, it may take 6 to 12 months for final subsidence to occur after the completion of mining. The dynamic subsidence profile is also accompanied by a dynamic strain profile as shown in Figure 1.

While dynamic deformation over the edges of an extraction panel may increase after the completion of mining to reach its final value, the deformation over a mining face is transient and may decrease to insignificant levels after the moving face passes. For example, in theory, the surface above the future face of a coalface extraction panel will only subside without experiencing significant deformations after the final state of