MANAGING RAIL SAFETY ASSOCIATED WITH LONG WALL MINING UNDER THE TRACK

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Introduction

This paper reviews the impacts on the Main Southern railway from four longwall mining operations, each of which were adjacent to the railway and caused the track to subside up to 75mm with a resulting loss in Stress Free Temperature of up to 8 degrees. The next longwall will pass under the railway, resulting in an incremental subsidence of 600mm and a loss in SFT up to 68 degrees, with weekly changes in SFT up to 50 degrees. With these changes, the risks of track misalignments are extreme, unless we have in place a comprehensive Subsidence Management Plan. This paper addresses the management plans to dissipate the changes in rail stress and to enable the railway to continue to operate without significant speed restrictions.

How Underground Mining Impacts on the Railway

The method of mining underground coal is by longwall advance, or retreat, between underground roadways used for access, ventilation and transportation of the coal. Individual faces are known as panels, and are rectangular in shape, up to 350m in width and up to 1,500 metres in length.

The strata behind the working face is allowed to collapse into the worked out void and this results in subsidence at the surface. Where mining activities occur within the vicinity of the railway, the corridor owner and the coal company along with the mining regulator must manage the detrimental affects on the infrastructure. In NSW the rail corridor owner does not have the right to reserve the coal and prevent mining. The amount of vertical settlement and associated horizontal ground strain is complex combination of issues, involving:

- The thickness and depth of the extraction of the coal seam;
- The width and length of the panel of coal;
- The proximity of other extractions of coal and how they impacted on ground surface;
- Geological criteria, including the dip of the seam, faulting, the presence of valleys.

![Figure 1: Diagrammatical Representation of Ground Movement](image)

Figure 1 above shows how the vertical movement of the surface varies throughout the subsidence basin. The size of the “O” character is used to illustrate the variation in magnitude.

The direction and magnitude of the horizontal movement are also indicated by the length and direction of the lines that pint to the centre of the basin.
**Horizontal Ground Strain**

With more substantial amounts of subsidence, e.g. when a longwall passes under a location, rather than nearby, the horizontal ground strains are often more significant than actual vertical movement. It is usually this ground strain, not necessarily vertical settlement which poses the greatest risk to the safe operation of infrastructure.

Compressive ground strains generally occur in the area above the mining operation and tensile ground strains may occur at the edges of the area of subsidence influence.

The transfer of ground strain through the ballast, the sleepers and fastenings will result in changes in the Stress Free Temperature of the rail. 100% transfer of ground strain of 1mm/m would result in a change of SFT of 87°C for fully restrained rail.

This can be demonstrated by using the formula for calculation of extension free rail when its temperature changes $e = 1000 \times L \times t$

- $e$ = extension in mm
- $L$ = the length of free rail in metres
- $X$ = the coefficient of expansion of rail steel (0.0000115 per °C)
- $t$ = the change in rail temperature.

Hence for a strain of 1 mm/m

$$t = \frac{e}{1000X} = \frac{1}{1000(1)(0.0000115)} = 87°C.$$  

**Ground Strain Transmitted to CWR Track**

The compressive and tensile strains associated with subsidence have an impact on the rail. SFT is lowered by compressive strain “over” the panel, and it is raised by the tensile strain over and beyond the edges of the panel.

Many factors will influence the actual forces developing in the rail including ambient temperature, original SFT, measured SFT and condition of track components.

However, not all ground strain necessarily is transmitted through the formation, ballast and sleepers, resulting in an equivalent change in SFT. The extent of transfer of ground strain to rail strain has been documented in a number of reports and technical papers over the recent years, A recent UK Network Rail document estimates the following relationships between predicted ground strain and the resulting changes in SFT:

<table>
<thead>
<tr>
<th>Predicted Compressive Ground Strains</th>
<th>Estimate of Maximum Strain Values used to Calculate changes in SFT</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 2 mm/m</td>
<td>75%</td>
</tr>
<tr>
<td>1.5 – 2 mm/m</td>
<td>66%</td>
</tr>
<tr>
<td>0.75 – 1.5 mm/m</td>
<td>50%</td>
</tr>
<tr>
<td>&lt; 0.75 mm/m</td>
<td>33%</td>
</tr>
</tbody>
</table>

In 1993, M A Grainger, a mining engineer with British Rail Research Central Services, in Derby, UK, presented a very informative paper to the Institution of Civil Engineers, and he said “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%.”

The Tahmoor project team decided early that in the risk assessments being undertaken in the development of the Rail Management Plan we would conservatively assume 100% of ground strain. Later on during the project, it may be possible to revisit this assumption when sufficient data is available.
Xstrata Tahmoor Colliery

Tahmoor Colliery is located approximately 80 km south west of Sydney, in the township of Tahmoor NSW and is managed and operated by Xstrata. The mine was formerly operated by Centennial Coal up until October 2007. Coal is being extracted from the Bulli Seam of the NSW Southern Coalfields.

Longwalls 22 and 23A

LW22 was extracted in 2005. The longwall extraction length totalled 1,877m. The distance from the longwall face to the railway was 55m. At this distance from the longwall face, the subsidence consultant MSEC were able to predict movement and possible impacts on the rail corridor prior to the extraction.

LW23A was extracted in late 2005 and early 2006. The longwall extraction length totalled 768m. The distance from the longwall face to the railway was 66m.

It should be noted that surveys of ground strain were measured over 20m bays, the final Mine Subsidence Engineering Consultants Report notes: “Although the observed strains are greater than the predicted strains, it is noted that the survey tolerance for measurement of strain distances is ±2 mm, which equates to approximately ±0.1 mm/m. The predicted strains are therefore within survey tolerance of the observed strains.”

The impacts of the subsidence from LW23A extended over the areas previously affected by LW22. MSEC analysis included both the incremental effects of LW22 and LW23A as well as the combined, total effects from both LW22 and LW23A.
Table 1: LW22 & LW23A Subsidence

<table>
<thead>
<tr>
<th>Subsidence Parameter</th>
<th>Predicted</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Movements (LW22 &amp; LW 23A)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum subsidence (mm)</td>
<td>45</td>
<td>48</td>
</tr>
<tr>
<td>Maximum tilt (mm/m)</td>
<td>0.3</td>
<td>0.4</td>
</tr>
<tr>
<td>Maximum tensile strain (mm/m)</td>
<td>&lt; 0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Maximum compressive strain (mm/m)</td>
<td>0.1</td>
<td>0.4</td>
</tr>
<tr>
<td>Incremental Movements (LW22)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum subsidence (mm)</td>
<td>36</td>
<td>12</td>
</tr>
<tr>
<td>Maximum tilt (mm/m)</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Maximum tensile strain (mm/m)</td>
<td>&lt; 0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Maximum compressive strain (mm/m)</td>
<td>&lt; 0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Incremental Movements (LW23A)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum subsidence (mm)</td>
<td>43</td>
<td>39</td>
</tr>
<tr>
<td>Maximum tilt (mm/m)</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Maximum tensile strain (mm/m)</td>
<td>&lt; 0.1</td>
<td>0.3</td>
</tr>
<tr>
<td>Maximum compressive strain (mm/m)</td>
<td>0.1</td>
<td>0.3</td>
</tr>
</tbody>
</table>

LW23A Impacts on Welded Track Stability

During LW22 and LW23A, both the Up and Down Main lines through the site was comprised of 53 kg/m CWR, a mixture of timber sleepers with double-shouldered sleeper plates, dogspikes and rail anchors, as well as variably interspersed steel sleepers with resilient fastenings.

During the mining of LW22 and LW23A, the project did not have in place an active system to directly monitor changes in rail strain from the mining subsidence. The only monitoring in place was the regular ground survey in the rail corridor, with the survey pegs about 10m from the Up Main.

At this stage of the project, it was assumed that 100% of the ground strain would pass directly to the rail. From the ground survey data, we calculated losses in welded track stability, based on the procedures and tables in the current ARTC Standard TEP-09 “Calculation of Welded Track Stability from Filed Information” (RIC C 2443). The ground strain information was used to calculate temperature errors and hence the estimation of loss of welded track stability.

![Strains & Welded Track Stability Losses](image)

Figure 3: LW23A Loss of WTSA
Following the completion of LW23A, the affected track was restressed during a scheduled track closure to restore the design Stress Free Temperature.

**Longwall 24B**

Longwall 24B commenced extraction prior to LW24A, commencing in late 2006. LW24B extraction width was 268m rib-to-rib, with an extraction length of 2,261m. It was separated from adjacent longwalls by coal pillars of 40m in width. The depth of cover to the Bulli Seam was approximately 440m beneath the railway, and the extraction height of the coal seam was approximately 2.0m. MSEC provided detailed predictions of subsidence as shown in the Figure 4.

![Figure 4: LW24B Subsidence](image)

Prior to the commencement of LW24B, extensive Risk Assessments were undertaken and detailed risk management controls were developed, and written into the Tahmoor Colliery Mine Subsidence Management Plan (SMP).

In preparing for the subsidence from LW24B, a series of rail strain gauges and rail temperature sensors was installed, as shown in Figure 5 and listed in Table 2 overleaf.

![Figure 5: LW24B Strain Gauges, Rail Temperature Sensors and Creep Survey Locations](image)
Table 2 - LW24B Sensors

<table>
<thead>
<tr>
<th>Location</th>
<th>Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Down Main</td>
<td>3 Rail Strain Gauges</td>
</tr>
<tr>
<td>Up Main</td>
<td>7 Rail Strain Gauges; 3 Rail Temperature Sensors</td>
</tr>
<tr>
<td>Dummy Rail</td>
<td>1 Rail Strain Gauge; Rail Temperature Sensor</td>
</tr>
</tbody>
</table>

Based on the MSEC predictions, the resulting loss in SFT was calculated at 8.1ºC. This is equivalent to a P2 welded track stability defect.

Given the low risk of track misalignment and loss of SFT it was decided that the monitoring system should be limited in its capacity, and not required to provide comprehensive monitoring of all the subsidence-affected track. Its purpose was to increase our understanding of what happens during the period of active subsidence, and to plan for enhancements for future monitoring systems associated with later longwalls that may have more impact on track integrity.

The strain gauge monitoring system was installed and commissioned in mid 2006, prior to the track being restressed to the design Stress Free Temperature and to enable a base-line of data to be gathered.

During the initial restressing of the rails on the weekend of 2-3 June 2006, the rail strains were sampled at 30 second intervals, to help with subsequent analysis. At this sampling rate a significant amount of information could be found from a Strain/Temperature/Time chart, as in Figure 6. This figure shows that the Up Rail Up Main was cut at 15:29 hours, and the strain went from 211 µe (showing the rail was in tension) to 0 µe (showing no tension or compression). Restressing commenced at 15:39 hours, but was stopped with jack failure. Restressing was finally recommenced at 16:00 hours. In this case, the rail was returned to its original stress free temperature. The strain gauges need to be zeroed at a point of known stress. For this strain gauge zeroing was performed when the rail had been rendered stress free with hammering prior to restressing commencing. All readings for this gauge are based on the zero strain reading as shown in the chart.

This adjustment was undertaken at a low 9 degrees C.

![Figure 6: Re-Stressing on 2 June 2006](image-url)
After the initial restressing, the sampling rate was adjusted to 5 minutes. This sampling rate provided us with adequate data for all subsequent analysis.

A number of issues occurred during the period getting ready for monitoring changes to the SFT during the mining subsidence, including:

- Initial re-stressing was found to be in error, partly due to the low temperatures of initial restressing, partly to creep through anchor points, and partly due to the work processes;
- The removal of a defective rail was not completed with the closure being welded into the track; the two mechanical joints created a degree of difficulty in analysing the data until they were discovered;
- Changes to the temperature measurement processes – see below.

**Tracking SFT Changes**

As the monitoring system was installed to indicate changes to the Stress free Temperature during the period of active subsidence, all of the track and system preparation were ready to do this from the beginning of November.

A typical Strain v Temperature chart at Gauge B-Up is shown in Figure 7. This chart indicates:

- lowest rail temperature at 0600 with the highest strain (and highest tension);
- highest rail temperature at 1515 with the lowest strain (and highest compression);
- SFT approximately 31 degrees, where strain is zero.

![Figure 7: Strains and Temps at Gauge B-Up](image)

Each day the SFT at each gauge was calculated by plotting Strains v Temperature. Where the chart crossed the X-axis, the SFT on that day could be determined.
Figure 8: SFT at Gauge B-Up

As there was some minor variation in the calculated SFT, we used a 3-day rolling average to plot changes in SFT.

Figure 9: SFT on Up Main during LW24B Subsidence

Figure 9, we recorded significantly varying SFT at the gauge A-Up. This gauge was at the Sydney end of the test site, and the area of track has growths of tall trees on both sides of the corridor. The track is in shade for parts of the day. The closest rail temperature gauge was not suitable as a base for determining SFT.

An associated chart tracked changes in SFT during the period of subsidence:
MSEC predicted a drop in SFT of 8.1 degrees, based on 100% transfer of ground strain to rail strain, as well as the predicted subsidence profile. We calculated a lowering of SFT up to 7.0 degrees. Immediately after the period covered by the above charts the rails were adjusted to restore the normal SFT and to minimise losses of welded track stability.

Lessons Learnt from LW24B

A Temperature Measurement

Initially only 2 rail temperature sensors were installed on the running line, and 1 on a piece of dummy rail.

One of the temperature sensors was located near the Thirlmere Way overbridge. This gauge was often in shade and so was not able to be used readily in the calculations of SFT’s.

The other sensor at B-Up was not well located, as the shadow of a tree covered the short area of track for one to two hours every afternoon. It took us a while to find out what was causing the sudden but regular temperature changes!

In early October we installed a second sensor near the Cabinet where no shadow affected the rail. We found a new problem here: the two rails sensors were located on either side of the rail. In the morning, the sensor facing east (Cab-Up) would be “super-heated” by the direct sunlight due to its covering in black tape, in the morning and would show higher temperatures than the average rail temperature. In the afternoon, the sensor at B-Up would also be super-heated, but only until the shadow of a tree covered the track at this location for about an hour. Our solution was to cover each of these sensors by a polystyrene foam block, to minimise the difference in rail temperatures:
Future monitoring systems will have smaller rail temperature sensors imbedded in the centre of the web of the rail.

Future monitoring system will require a greater number of rail temperature sensors more closely spaced to the strain gauges to enable more accurate and consistent calculation of SFT changes.

B Temperatures

Based on the records kept from 2006 to the present, the following statistics are listed:

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest rail temperature</td>
<td>61.7 °C</td>
</tr>
<tr>
<td>Highest difference between rail &amp; ambient temperatures</td>
<td>26.6 °C</td>
</tr>
<tr>
<td>Lowest rail temperature</td>
<td>-3.3 °C</td>
</tr>
<tr>
<td>Highest daily range, rail min temp to rail max temp</td>
<td>47.6 °C</td>
</tr>
</tbody>
</table>

Note: * Ambient temperatures taken at nearest Bureau of Meteorology site at Camden

Longwall 25 Trials

The project team decided that the preferred method of managing changes in rail strain and rail stresses was by an engineered solution rather than by a labour intensive solution to regularly re-adjust the rail during the period of subsidence.

The engineered solution would involve a series of expansion switches and the use of Zero Toe Load clips to enable the rail to move freely relative to the sleepers, or more exactly, to let the ground move without changing the stresses in the rail.

Early in 2008 we installed a set of PRE expansion switches at 94.150km on the Up and Down Main as shown in Figure 13. These expansion switches were of a design which allowed full train speeds only in one direction and required slower speeds in the reverse. They allowed for the rails to each move ± 65mm, and the total "gap" at the expansion switch to expand or contract by ± 130mm. Each switch was separately monitored for rail movement electronically and the "Y Gap" was monitored with daily manual measurements.

The trial in the first half of 2008 at Tahmoor was to see how this design of expansion switch accommodated changes in rail stress and rail strain from thermal changes without the mine induced subsidence’s. The trial also included progressive changes to the fastening system to identify how the track would behave.

The Expansion Switch is illustrated as follows:
Two types of ZTL were used, as the Down Main was constructed with Pandrol e-clips, and the Up Main was constructed with Pandrol FastClips. These fastenings have a space below the clip above the foot of the rail, as shown in Figure 14 and Figure 15 below:

The trial included the following ZTL configurations:

- Nil ZTL’s
- 5m ZTL’s on the approach side;
- 25m ZTL’s on the approach side;
- 50m ZTL’s on the approach side;
- 100m ZTL’s on the approach side;
- 150m ZTL’s on the approach side;
- 150m ZTL’s on the approach side, with various forms of snagging & mid-point anchoring of the rail;
- 75m ZTL’s on both sides of the ES’s.

A new monitoring system incorporating axial bridge strain gauge to measure rail stress, rail temperature transducers and displacement transducers to measure the movement of the switch was installed by BMT-WBM.

At the installation of the Expansion Switches, we had a period without using ZTL clips, and found a stress gradient either side of the Expansion Switch, and also found some movement of the switches with changes in temperature – the rails remained firmly fastened to the sleepers and the sleepers moved in the ballast. The following, Figure 16 shows changes in rail stress on 29 February at 2 hour increases. On this day, temperatures ranged from 10 to 36 degrees, and the rail remained in tension for the period.
Figure 16: Expansion Switch with nil Zero Toe Load Clips

After the installation of 150m of ZTL clips on the Approach side of the track, we found a new stress gradient at the interfaces between zero toe load and full toe load clips, as shown in Figure 17.

Figure 17: 150m ZTL Clips

We were able to show that the Pacific Rail Engineering (PRE) Expansion Switches together with up to 150m of free rail (with zero toe load clips) limited the variation in rail stress to ±10 MPA, suggesting that only friction is involved in restricting rail movement.
LW25 Rail Management Plan

A | Risks

LW25 will involve the longwall mining passing under the rail corridor from mid November 2008. During the period of subsidence, we expect the track to subside 625mm and the rail, if CWR were maintained, would change by 70 degrees.

The development of the Rail Management Plan for LW25 addresses all the relevant track related risks, including:

- Changes in SFT;
- Changes in track geometry – twist, superelevation, horizontal alignment, vertical alignment;
- Design, installation and performance of the Expansion Switches;
- Performance of the monitoring system.

The project has also addressed the possibility that subsidence and ground movements could exceed the predictions for “systematic” subsidence, i.e. normal, regular or conventional subsidence.

B | Managing Risks

During the period of active subsidence the management of risks will include the following:

- Full time on site track certification staff;
- Short call-out maintenance staff;
- Communication links to the control centre at Tahmoor Colliery;
- 24 hour continuous monitoring of rail stresses, expansion switches, as well as culvert stresses;
- All gauges to be alarmed with Blue, Yellow and Red triggers, along with detailed response requirements and communication plans;
- Detailed and regular ground and track survey;
- Regular monitoring of track geometry by recording trolley;
- Web based access to the monitoring system for all relevant people.

Managing Rail Stress

Five sets of a new type of PRE Expansion Switch (10 off) have been installed in each track; these new type expansion switches allow expansion to total 300mm (150mm+/-) and also enable trains to operate at track speed in both directions during their operation. Additional rail stress and temperature gauges and switch position transducers have been installed. The new monitoring system extends past the end of the track predicted to be affected by the longwall.

The current state of the system shows almost no rail stress along the track between 93.585km and 94.425km. Between the expansion switches are anchor points to fully locate each rail which has zero toe load clips up to the expansion switches. Free rail length varies from 60m (from the edge of the anchor point to the expansion switch blade) to 90m.

Figure 18: LW25 Expansion Switches
Rail Stresses along the track with 5 sets of expansion switches and Zero Toe Load clips over 840m of track are shown in Figure 19.

Figure 19 indicates that rail stresses vary in the range ±10 MPa between the Expansion Switches and the mid-section Anchor Points (50 sleepers), and ±20 MPa in the Anchor Points, compared with a stress range in the adjacent fully restrained CWR on the day of the above chart from -30 MPa (compression) to 80 MPa (tension).

Over the period from winter to summer, the stresses in fully restrained CWR at Tahmoor vary from -50 MPa (compression) to 95 MPa (tension). The combination of expansion switches and ZTL clips has been demonstrated to be very effective in dissipating the rail stresses from thermal changes when we have not also experienced mining subsidence. This system is expected to provide the same level of stress dissipation when the longwall mining introduces new conditions on the rail corridor.

Acknowledgements

There are a number of individuals and organisations providing support and advice to Tahmoor Colliery on this project, including:

- GHD
- Taylor Railtrack Pty Limited
- Mining Subsidence Engineering Consultants
- Signal Support Services
- BMT WBM Sydney
- David Christie
- Martinus Rail
- ARTC, in particular Ross Barber, Moss Vale
- Bruce McComas

Conclusion

Tahmoor Colliery is planning to mine under the rail corridor over the next five years with several long wall mining operations. Mining under the rail imposes new risks to rail safety and the Tahmoor Colliery Rail Management Group have in place comprehensive management plans to avoid damage to the rail infrastructure and minimise impacts on rail operations through engineered solutions to, in particular manage severe changes in rail stresses resulting from the mining subsidence. Extensive trials have confirmed that the use of expansion switches and zero toe load clips, combined with a comprehensive inspection, monitoring and response regime have the capacity to safely manage the rail infrastructure when the underground mining will significantly influence the track condition.