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Geotechnical monitoring of railway infrastructure subject to mine subsidence-induced horizontal closure

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Abstract

Surface subsidence produced by longwall mining beneath mainline railways produces numerous technical challenges for the engineering profession, covering inter alia mine subsidence prediction, civil engineering management of the track, electronic remote monitoring of the rail, and management of rail infrastructure — all in the context of maintaining rail safety combined with efficient resource recovery. This is world-leading practice.

Near Tahmoor, NSW, longwall mining is being undertaken at a depth of cover of 440 m and subsidence of the Main Southern Railway of up to 0.9 m has occurred during multi-pass longwall panel retreats.

This paper presents details of the monitoring of structural and geotechnically-based intervention measures to manage track safety without impeding mining operations. The methodology is illustrated by way of a case-history which deals with a structure that is a 100-year-old, inverted horseshoe shape, under-track, brick arch culvert of 4.5 m diameter, with shallow cover to the underside of the rail formation.

The paper discusses the monitoring philosophy, measurement protocols, checks and balances, calibrations, and result interpretations. A particular challenge that will be addressed in the paper is discrimination of seasonal and diurnal effects from the mining-induced creek closure effects.

1 Introduction

All mining methods have a propensity to impact upon the ground surface and therefore the infrastructure upon it. For longwall mining, the impacts involve subsidence related ground tilts and strains that develop as a consequence of the retreating active mining face in time. That is, longwall mining imposes a four-dimensional response in which the first three dimensions are geometrical and the fourth dimension is time.

The impacts of subsidence upon railway infrastructure have been shown to be manageable without disruption to mainline operations. This has not always been thought possible and coal has been left in the ground, at some cost to the economy, by an approach that avoids mining within a 'zone of influence' of infrastructure by leaving a 'barrier pillar'. In the case of Tahmoor Colliery such a pillar would have been at least 400 m wide and continue for the entire footprint of the Main Southern Railway (MSR) over the mine plan (part of which is depicted in Figure 1). Provided an appropriate management plan is in operation, maximising mining of the coal seam/natural resource means:

- Removal of adverse impacts upon mine layout through modification of panel extraction.
- A more uniform subsidence bowl is an outcome.
- Improved recovery of the nation's resource.

- Normal safe mainline operations continue.

Longwall retreats undertaken prior to LW25 were constrained to leave a solid coal barrier beneath the Main Southern Railway. As an example, LW24 left 350 m of solid coal for its full width beneath the MSR (though this is not visible in Figure 1) — representing 290,000 tonnes of lost resource in this one LW panel.

Intervention strategies varying from minimalist to major structural works may be necessary to maintain standard mainline operation requirements for the track while maximising coal extraction. The critical function that goes hand-in-glove with this is appropriate monitoring either to confirm that the decision not to intervene is appropriate or to assess the performance of the chosen intervention strategy. Since the scale of the intervention may vary, each instance requires an appropriate monitoring plan to be devised, implemented and reviewed within the framework of an overall subsidence management plan.

An important part of that plan is the development of actions to be taken should they be deemed necessary during monitoring. Therefore, it is imperative to have confidence in the results from the monitoring. How the passage of several longwall retreats beneath the MSR at Tahmoor, NSW has been managed by Tahmoor Colliery is the subject of this paper.

2 Mining setting

2.1 Tahmoor Colliery and the Main Southern Railway

Tahmoor Colliery is conducting underground coal mining of the Bulli Seam beneath the MSR within the Tahmoor region as depicted in the layout presented in Figure 1. The active mining face is currently near the end of LW28 (north of Tahmoor Township), and has retreated from the southeast to the northwest within each panel, as the mining progresses northwards towards Picton. LW25 to LW28 were mined for retreat distances of the order of 3.5 km long, and 283 m wide (rib-to-rib), with a typical mining interval of 2.1 m. The longwalls, from LW25 onwards, have retreated beneath the MSR at a depth of approximately 430 m below rail formation level under a management plan.

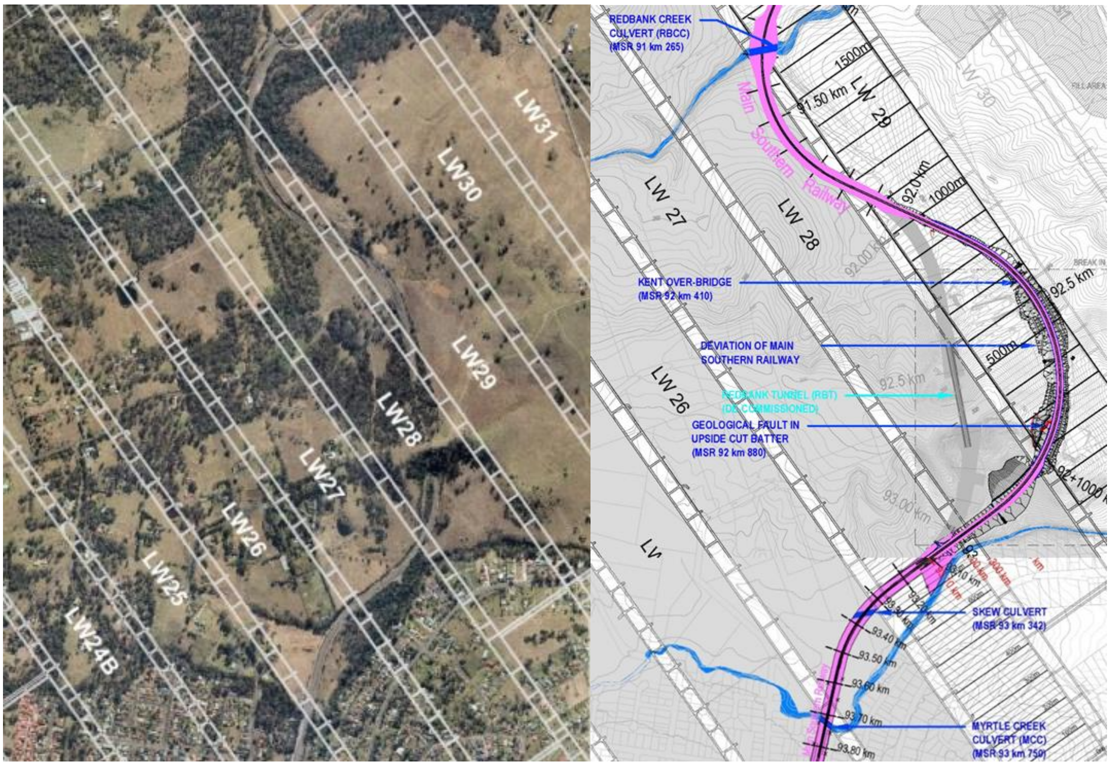


Figure 1 Layout of the underground longwall mining within Tahmoor Colliery (left) and the location of infrastructure elements considered under the Track Safety and

Serviceability Management Plan; MCC is the southernmost infrastructure shown

Myrtle Creek culvert (MCC) is situated above LW25 at a retreat chainage of 1,380 m and is positioned over the gate road between LW25 and LW26. Figure 1 provides an indication of the setting of the mining to the north of Tahmoor, the relative location of the Main Southern Railway across the mine's longwall panels and the position of MCC above the gate road.

2.2 Geological setting of Myrtle Creek culvert

The inferred sub-surface conditions at MCC are shown schematically in Figure 2. At MCC, Myrtle Creek has incised through the uppermost portion of the Triassic-aged Hawkesbury Sandstone formation (NSW Department of Mineral Resources 1999) which outcrops in the creek banks and creek floor, both upstream and downstream of the culvert site. Rocks of the basal member of the Wianamatta Group, the Ashfield Shale, are exposed in the shallow cuttings either side of Myrtle Creek. Remnant portions of the Ashfield Shale subcrop throughout the Tahmoor Township, and around though not at MCC. The Hawkesbury Sandstone is a medium to coarse-grained quartz sandstone, with occasional minor shale and laminite lenses. It comprises massive, bedded and cross-bedded units (massive and sheet facies) with shallow (2° or less) dip towards Sydney.

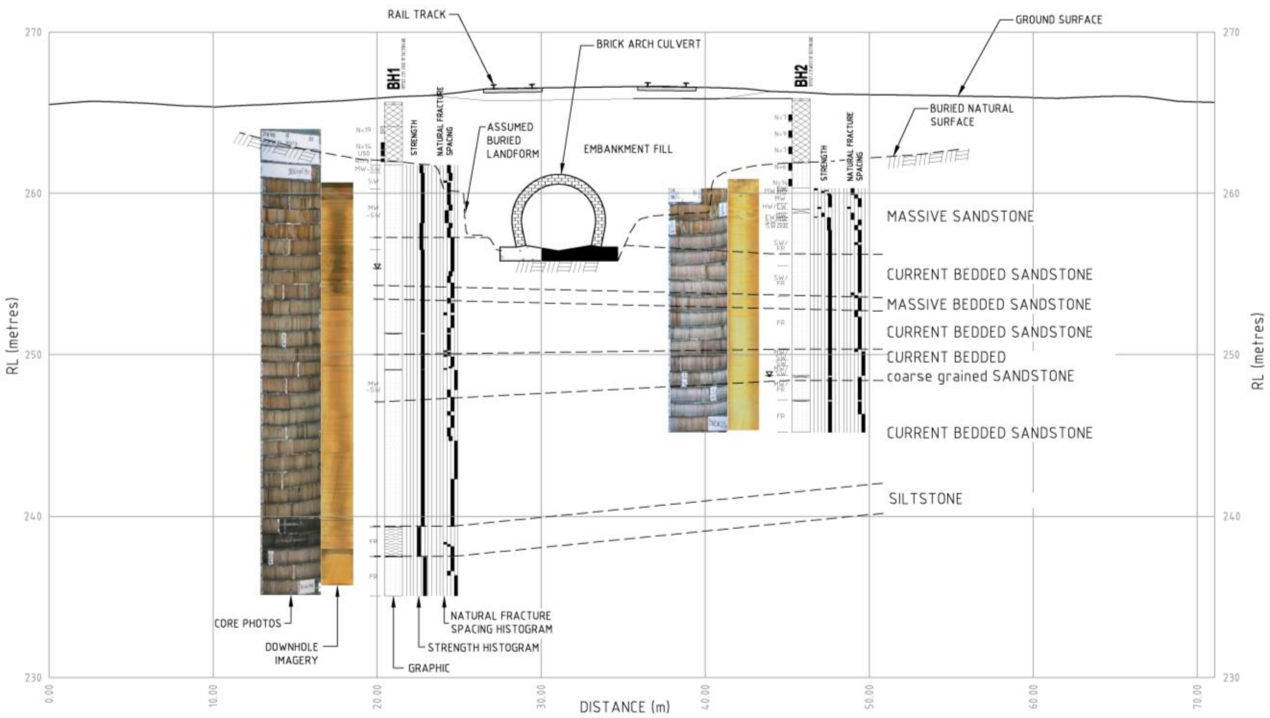


Figure 2 Inferred sub-surface conditions at Myrtle Creek culvert

The predominant rock mass defects in the Hawkesbury Sandstone comprise bedding plane partings, bedding plane seams, cross-bed partings and sub-vertical joints. Bedding planes are typically sub-horizontal and planar to curvi-planar. Cross-beds range in dip angle from 15 to 30 degrees from horizontal. Within the central Sydney Basin, two main orthogonal joint sets are frequently identified with strike directions generally ranging from 0 to 30 degrees and from 100 to 120 degrees (grid), though up to three more joint sets are typically present at any particular site — similar natural defects are expected. The direction of principal stress in the rock mass is expected to be approximately N15°E.

The embankment which supports the railway crossing of Myrtle Creek includes materials from the adjacent cuttings, being Ashfield Shale, together with railway ballast. The fill typically is of 'loose' consistency. The outer skin of the embankment is steep (steeper than 40°) and covered by spilt ballast.

3 Main Southern Line infrastructure at Myrtle creek

The Main Line crosses Myrtle Creek, north of Tahmoor station, upon a filled embankment approximately 10 m high that effectively runs from rim-to-rim of the creek at this location.

3.1 Myrtle Creek culvert

MCC consists of a brick arch culvert that was constructed in the early part of the 20th century (c1917), with an inverted horseshoe shape and consists of five courses of brick on-edge masonry. The brickwork was (and remains) in good condition. The brick arch culvert internally is 4.6 m wide, 4.4 m high and 22 m long. Whilst Standard NSW Railway's drawings from the early part of the 20th century typically depict a floor slab under the brick arch, no meaningful concrete slab is present at MCC with only a variable depth of cyclopean mass concrete detected. An impression of MCC can be obtained by reference to Figure 3.

Figure 3 Myrtle Creek culvert viewed from upstream showing the steel ribs, the reinforced concrete invert lining within the brick arch culvert and under rail steel baulk

Figure 3 shows a view of the culvert prior to intervention and two other views, one showing the internal ribs and the other a view of the track above showing the steel under-track baulk, as described below.

Prior to intervention, a two-dimensional plane strain, soil-structure interaction finite element (FE) analysis was undertaken as an assessment of the response of the brick arch culvert to mining-induced creek closure. This provided input to the structural analysis. The FE analysis was based on the assumption that the predicted creek closure between the rims of the creek line (buried beneath the embankment fill) was accommodated through a response of the rock mass and the fill, and thereby reported onto the culvert.

Steel ribs were designed by John Matheson & Associates as the primary intervention measure. The ribs consist of fabricated arched beams equivalent to 250UC89 installed at 0.6 m centred along the length of the culvert, together with a reinforced concrete partial lining (invert infilled between the ribs). The ribs were installed to provide structural stiffness and strength, whilst the reinforced concrete invert provided additional structural thickness and confinement at the critically stressed lowermost internal 'corner' of the brick arch culvert. The aims of the intervention measures were to hold the form of the culvert and maintain its function as a drainage culvert. This intervention was possible given the culvert was deemed to still fulfil its hydraulic function despite the reduction in diameter caused by the ribs.

Sub-vertical 3.25 m long passive rockbolts were installed through the relatively thin cyclopean mass concrete and into the sandstone bedrock beneath to ameliorate the effects of upsidence. External intervention included steel beam frameworks on the endwall faces and along the wingwalls to maintain their integrity as brickwork units (not shown in Figure 3). To maintain track geometry, and as an additional intervention measure (to act as a back-up in a leading-edge design and analysis environment), a 700 mm deep stiffened steel deck was installed as a baulk beneath the track over MCC.

In accordance with guidelines developed by the regulator (NSW Department of Mineral Resources 2003), the design of the ribs was modelled on 150 mm creek closure, which was a factor of 3 times greater than the 50 mm prediction (Mine Subsidence Engineering Consultants 2008).

3.2 Anticipated response

The anticipated displacement response was closure of the ribs in the horizontal direction with concomitant extension in the vertical direction, expressed by way of uplift of the culvert obvert. The potential failure mechanism did not involve a snap-through buckling collapse mechanism, principally due to a thick walled cylinder analogy. Without intervention measures, whilst considerable over-stressing of the original brickwork was expected, the development of a collapse mechanism was not reflected in modelling. A stiff quazi-composite system (in the sense of a friction contact) was produced by the combined structures after the intervention measures had been installed.

The advantage in reducing displacements through the intervention measures is apparent, particularly when the creek closure is greater than 100 mm, as was the case at MCC.

During longwall operations and the consequent mine subsidence, loads can develop within surface structures as a consequence of displacements driven by complex realigning of strata to accommodate strains involved in creation of the goaf above the extracted panel. As such, the loads reporting to all parts of the rock mass, but in particular to the surface elements, increase (or decrease) only while straining continues. Traditional methods of design involving load factors are challenged by this mechanism. In this case, of a strain-driven system, a load factor is meaningless and recourse is therefore made to factoring strains or rather, displacements, not stresses.

In summary, the response of the brick arch culvert at MCC was strain-driven rather than the conventional stress-driven response, all within a soil-structure interaction scenario. The importance of this is that once the subsidence related creek closure ceases, so too does the impact upon the culvert structure.

4 Instrumentation

4.1 Types of instrument and locations

A necessary part of verification of the design and assessment of the performance of the intervention measures was the implementation of a reasonable, yet effective, monitoring programme.

With a reasonable degree of redundancy, the forms of monitoring employed to identify the response to subsidence of the culvert and the surrounds in both a structural and geotechnical sense, were:

- Sinco Electrolytic (EL) tiltmeter beams were installed at the crown, along most of the length of the culvert to measure the longitudinal tilt of the culvert with effectively continuous readings.
- EL beams were installed radially around four selected ribs, above the spring line of the culvert, to measure straining of the arch, in addition to its lateral tilt with effectively continuous readings.
- Structural monitoring was through continuous readings of strain gauges installed on selected ribs.

- Survey of marks either side of creek upstream, downstream and along rail corridor — frequency as for tape extensometer (see below).
- Tape extensometer readings on ribs 1, 4, 11, 17, 22, 28, 34 and 38 were made between reference marks, focusing on dimensions in the plane of the ribs. These were monthly, reducing to weekly on longwall approach and relaxed to monthly when LW25 retreat had passed MCC; optical survey of the culvert was also undertaken. Eight laser reflectors were located on each of the tape extensometer monitored ribs and were taken monthly until lost due to vandalism.
- In addition, detailed monitoring and expansion switch management of the rails themselves (Pidgeon et al. 2011) was undertaken.
- Downhole inclinometer measurement in two axes to a depth of 30 m below the rail.
- Visual appraisal of brickwork quality, the creek bed and surrounds, and measurement of the opening between the outside flange of the ribs and the culvert brickwork across the obvert intrados — same frequency as for tape extensometer readings.
- Periscopes along baulk to monitor uplift of baulk relative to embankment fill — intermittently.
- Observations of revetment displacements relative to wingwalls — frequency as for tape extensometer readings.
- Tape extensometer reference marks were also established between the wingwalls at both ends of MCC to measure closure effects with the same frequency as above for the ribs.

The location of the tiltmeters, reference marks for the tape extensometer readings and optical survey reflectors installed throughout MCC are presented in Figures 4 and 5.

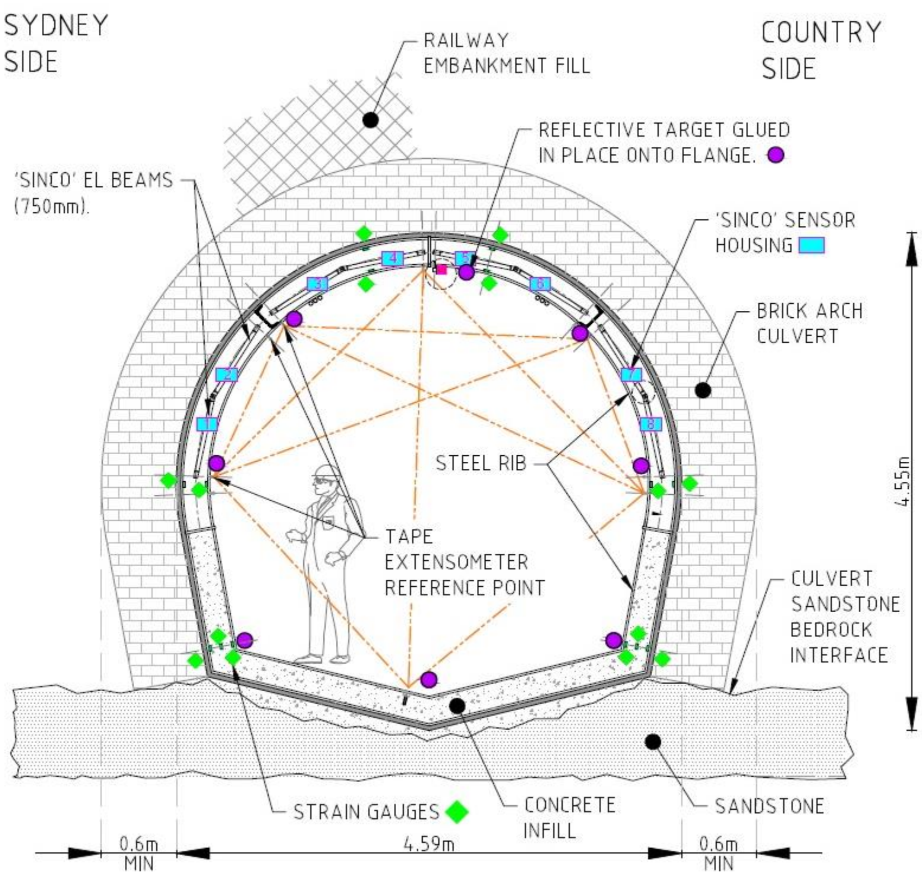


Figure 4 MCC cross-section showing intervention measures and monitoring instrumentation — circumferential and longitudinal EL beams, tape extensometer marks, strain gauges and survey reflectors

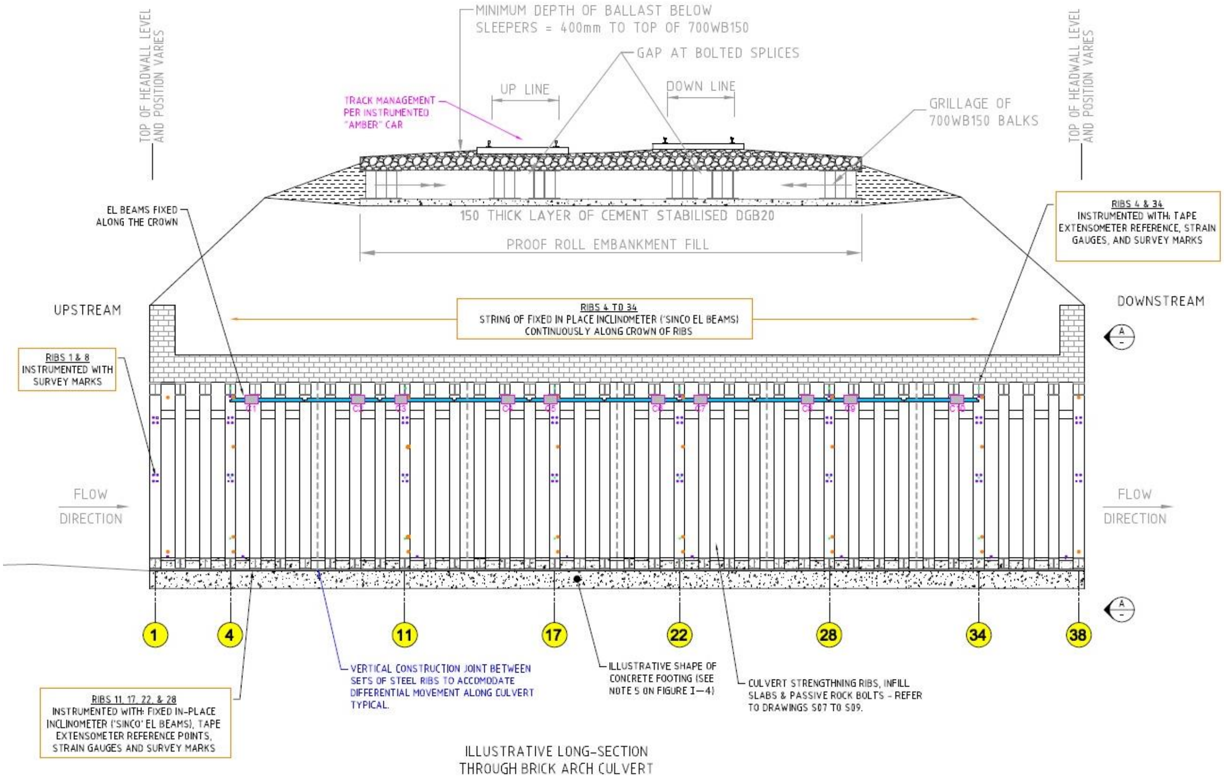


Figure 5 MCC long-section showing intervention measures and monitoring instrumentation — circumferential and longitudinal EL beams, tape extensometer marks and survey reflectors

4.2 Calibration

The instrumentation was calibrated prior to installation for the case of the EL beams and strain gauges. The tape extensometer and downhole inclinometer instruments were subjected to calibration verification during the period of monitoring given the length of time and high duty cycle of the field readings.

In particular, the tape extensometer was subject to internal wear and stretching of the tape index holes. To remove these effects from the readings, an array of reference marks was established in a basement car park in which measurements covering the range of those taken in the field could be made. This also allowed changing tape extensometer instruments if needed, since the new instrument could be calibrated to reproduce the old instrument values for the ‘car park’ marks. The basement carpark was considered a relatively benign environment given the small temperature range recorded and accommodation of temperature variation in this continual re-calibration assessment process.

The expected small changes in dimension in the culvert required a degree of repeatability of the order of 0.1 mm to allow discrimination of the impacts of subsidence from the general noise and systematic effects associated with the normal life cycle of the culvert.

The inclinometer sonde was calibrated in the laboratory at intervals of about 6 months during the monitoring period. As well as the original sonde, a second sonde was also used to obtain a duplicate set of readings down the hole on the same day and a second cable was also purchased. Thus, should an issue arise with the original sonde it was still possible to take readings. It was preferable to employ the same cable on all inclinometers to avoid side by side checking of the depth marks of each cable.

Although not experienced at MCC, having two sondes and cables also ameliorates the situation posed by having a sonde and cable become trapped by the sharp bends associated with rock layers shearing.

An EL beam was also fixed to the concrete floor within an unused stair well and monitored over an extended time to observe any drift in the readings. Temperature at the time of the reading was recorded and the results showed no discernible drift in the readings with time or temperature.

5. Response of MCC to retreat of LW25

5.1 Philosophy of response

In regard to the response of the intervention measures, it became apparent that the culvert produced monitoring results that were initially as predicted, but which then became counter-intuitive and were believed anomalous. The response was investigated and became recognisable as a response of the structure to a seasonal thermally driven environmental influence, upon which subsidence impacts were superimposed (Figure 6). The result was a combination of long duration seasonal responses and higher frequency diurnal responses, e.g. the temperature readings obtained from the instrumentation within MCC in Figure 6. The temperature values clearly demonstrate both the annual response and diurnal high frequency variation, as would intuitively be expected.

It is noted in this interpretation that MCC has been under the influence of the seasonal (essentially sinusoidal) and daily (erratic) environmental influences for the last century (Figure 6). Presumably, this applies to other, if not all, brick arch culverts be they railway or otherwise, e.g. Hull et al. (2012). Noting this, no adverse effects from this history of the culvert as a ‘breathing dragon’ was observed in the brickwork prior to the mining of LW25.

5.2 Geotechnical responses

The response of MCC to the retreat of LW 25 was predominantly as a rigid tube. Three-dimensional survey results for the track demonstrated displacement towards the approaching goaf of LW25, and then reversed to follow the retreat of LW25. The final position of the track was comparable to its initial plan position, notwithstanding the movement during the travelling subsidence wave. During this response of the groundmass, MCC rotated about its long axis towards the goaf of LW25 by 2.0 milli-radians. Little relative twisting along its axis was observed, implying that MCC behaved as a rigid (composite brick and steel) tube. The rigid tube response showed: tilt down towards the approaching goaf; flattening off at about one-third of a panel width retreat past MCC; rebound and recovery to the initial orientation at less than one panel width retreat; continued rebound until retreat achieved three panel widths past MCC; and then a degree of shakedown until the end of LW25 (Figure 6).

The longitudinal tilt reduced the gradient of MCC from its initial 180 mm (upstream end to downstream end) by about 8 mm — viz. 0.4 mm/m over the 22 m culvert length.

The lateral rotation of the body of the culvert is shown in Figure 8 where it achieves a value of 2.0 milli-radians, equivalent to 2.0 mm/m rotation across the horizontal axis of the culvert and a net downward displacement of 8 mm on the country side of the culvert relative to the Sydney side. Some 82% of the final rotation was achieved at a retreat of 1 panel width, and the majority was complete by a 2-panel widths. There is no evidence of seasonal effects upon this rotation and it was related to the travelling subsidence wave above the goaf of LW25, and finally is equal to the locally measured gradient of the subsidence bowl.

The response of the culvert in the cross-sectional plane of the ribs is another matter. It is clear from the response of the ribs that an environmental seasonal response is observed, with higher frequency diurnal responses overprinting the annual seasonal response. Off-set responses to the seasonal response have been assigned to the valley closure influences induced by mine subsidence (see Figure 7 for the interpretation). The interpretation of the combined seasonal, diurnal and subsidence impacts upon the intervention elements is provided within Figure 9 for the vertical and horizontal responses of two ribs (considered illustrative of the measurements obtained) being for Rib 1, which is the westernmost rib (UP-side) and Rib 17 which is near the centre of the culvert length. The readings (with temperature and instrument corrections) are shown as the open circles, whereas the readings adjusted for seasonal correction are depicted with the solid dots.

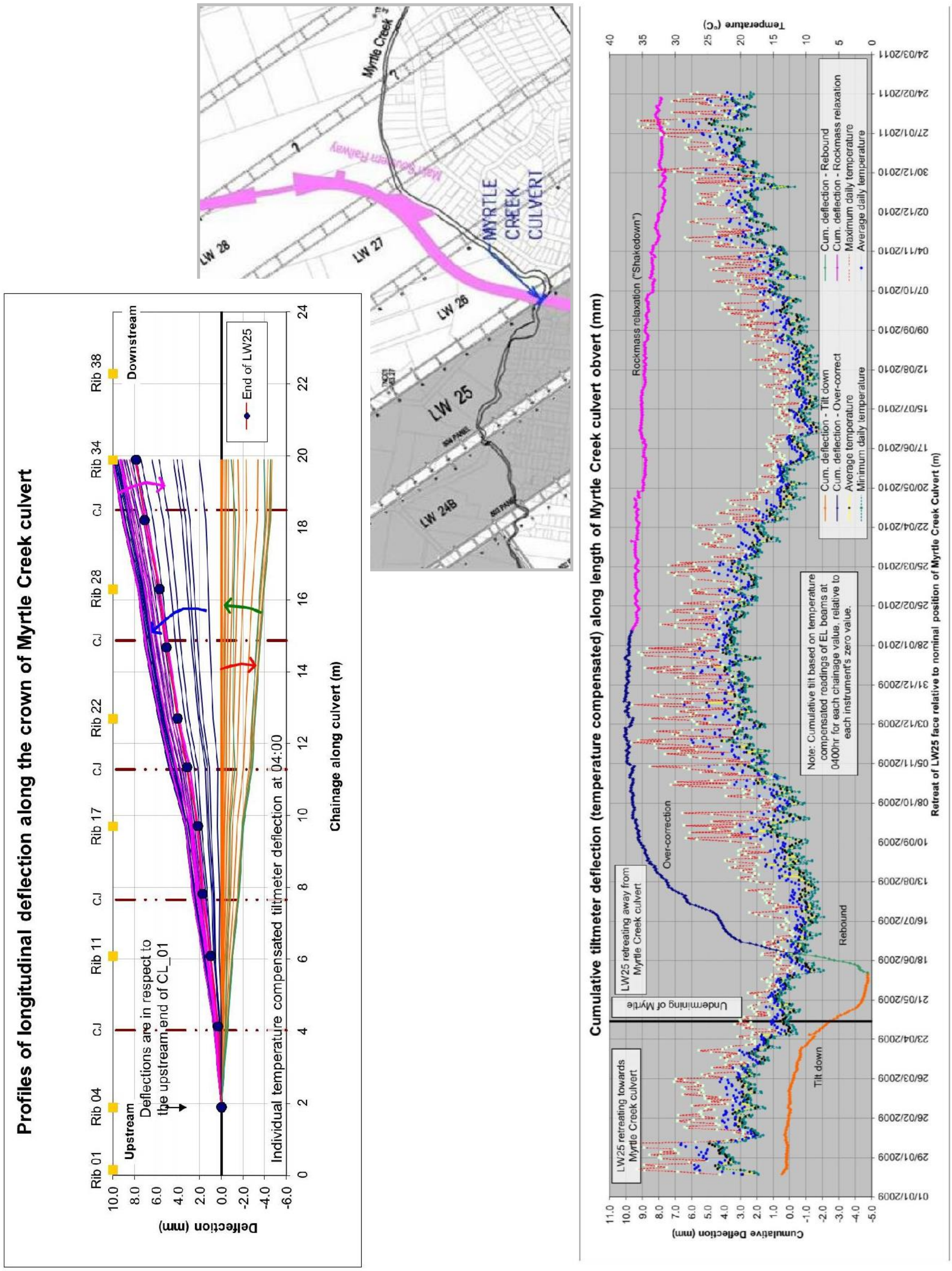


Figure 6 Diagram of position of MCC above gateroad between LW25 & LW26 (top left); track of longitudinal tilt and environmental temperatures within the culvert, both with time (right); and tilt along the culvert tracked with longwall retreat (colour coding matching trace of longitudinal tilt) (bottom left)

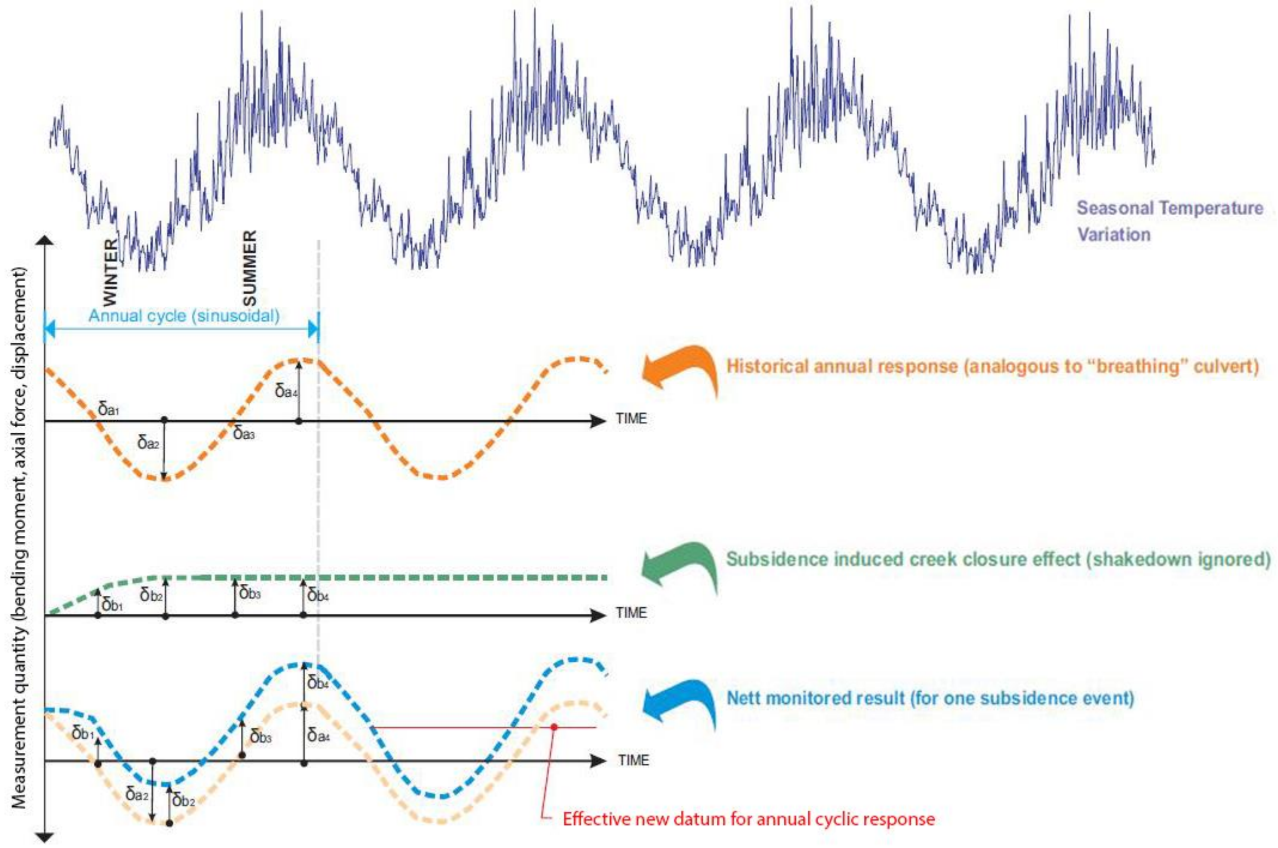
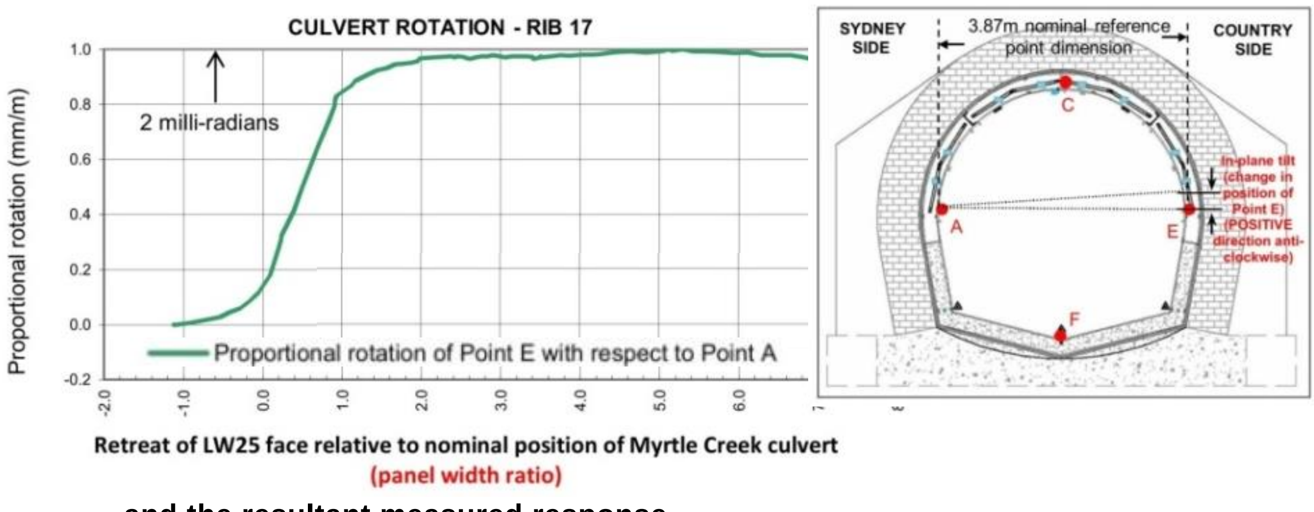


Figure 7 Schematic illustrating the seasonal temperature, the historic annual response of the culvert dimension change, the dimensional change due to creek closure



and the resultant measured response

Figure 8 Lateral rotational response of MCC to retreat of LW25, as illustrated at Rib 17

The challenges associated with the initial interpretation are illustrated with reference to the uncorrected response of Rib 1 in the vertical direction. The early time response is indicative of a reaction by the rib to retreat of LW25, whereas the seasonally compensated readings illustrate that the main response did not occur until the retreat passed MCC by about 2-panel widths. Whilst a similar response is seen for Rib 17, there the compensated responses are suppressed and are considered minor, at most. This demonstrates the 3D nature of the response and that there was little net response in the centre portion of the culvert, as is demonstrated by the reduced response (seasonally adjusted).

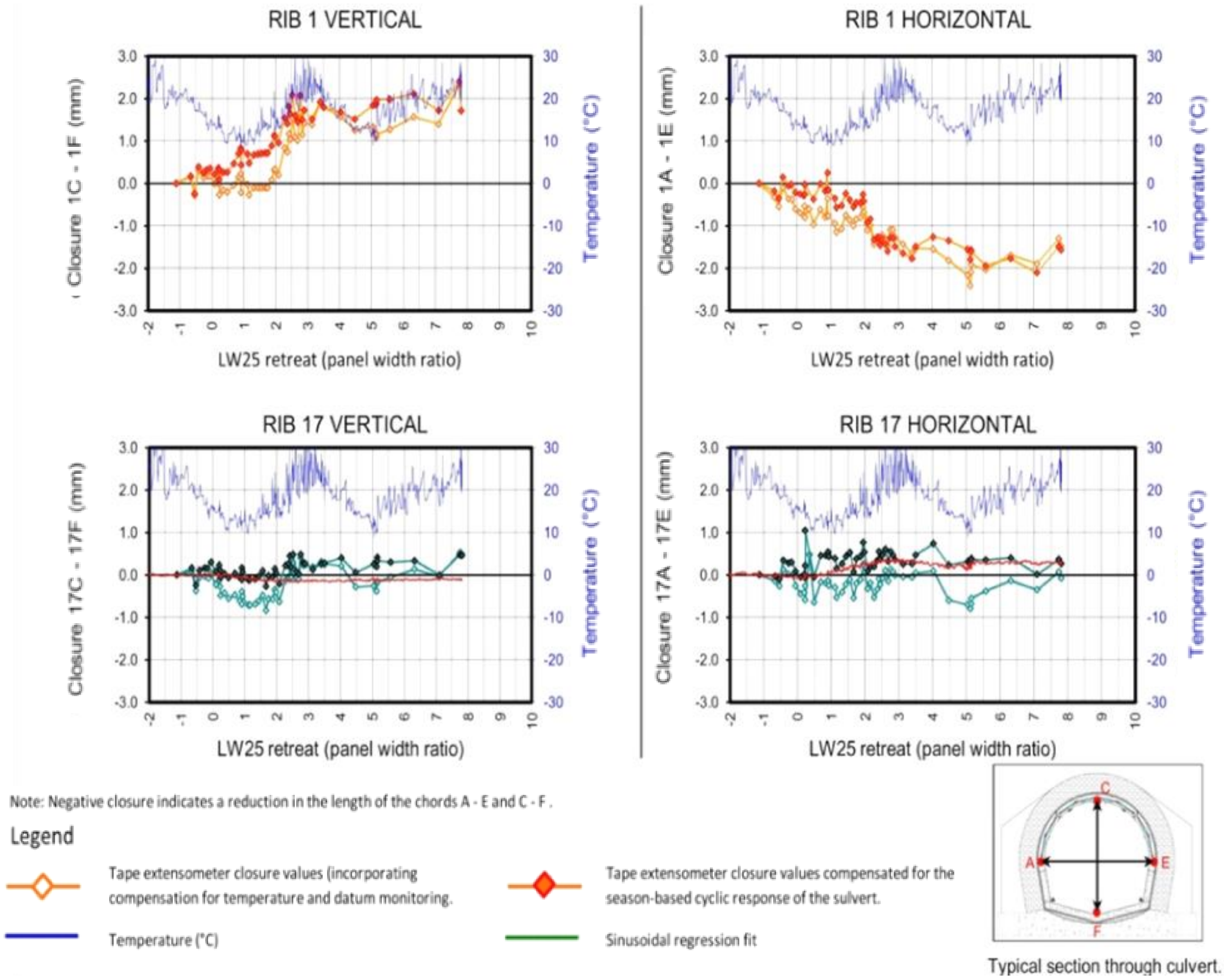


Figure 9 Vertical and horizontal closure response of Ribs 1 and 17 within MCC

An important issue when managing the response of the culvert to creek closure is identification of the subsidence related displacements from the seasonal responses (‘breathing’ of the culvert), which are of similar magnitude, and this becomes a challenge for investigators, miners and regulators in recognition of the response and management of it. The benefit of long lead-time monitoring is important in this regard.

Other responses observed in Figure 9 include:

- The sinusoidal nature of the readings prior to compensation which mimic the seasonal response.
- That a slight lag existed between the seasonal temperature variation and the response of the ribs (attributable to thermal inertia).
- That there remained some minor variation following the seasonal compensation, which is assigned to diurnal influences.
- The westernmost rib, Rib 1, responded with horizontal closure and reciprocal vertical extension, consistent with an arched frame response. The response in the central portion of MCC, as illustrated at Rib 17, was much suppressed.
- A three-dimensional response to creek closure was observed along the body of the culvert, notwithstanding the rigid body rotation that was observed.

Closure measured along the culvert, following seasonal compensation, is given in Table 1. The maximum displacement from the seasonally compensated tape extensometer readings attributed to creek closure was 1.7 mm and the maximum vertical opening was 1.9 mm (both recorded at Rib 1). The closure response along the culvert was variable, with the greatest response at each end and the least within the mid-section.

Table 1 Representative influences along MCC due to creek closure produced by LW25

MCC rib number (from upstream portal)	Incremental displacement of ribs assigned to creek closure (mm)		Maximum incremental rib stresses assigned to influence of creek closure (MPa) [tension +ve, compression -ve]		
	Horizontal	Vertical	Rib invert	Rib spring	Rib obvert
Rib 1	-1.7	1.9	NA	–	–
Rib 4	-0.8	1.4	-42.0	-10.0	-10.2
Rib 11	-0.5	0.8	-38.6	-14.5	-12.6
Rib 17	0.3	0.3	-15.8	-16.6	-7.7
Rib 22	0.4	0	19.7	10.6	14.8
Rib 28	0.5	-0.3	18.2	11.5	10.2
Rib 34	0.2	0.1	-6.6	-12.2	-13.7
Rib 38	-0.9	0.8	–	–	–

5.3 Structural response

The initial structural assessment of MCC was carried out in the context of AS3700 Masonry Structures with self-weight, fill embankment cover earth pressures, rail live load surcharge and non-systematic creek closure pressures (from the geotechnical analysis) applied to the external surface of the brick arch culvert. The brick arch culvert was modelled using Microstran software, with the creek closure strain-induced pressures applied incrementally to the culvert until load eccentricities reached the limits of AS3700; these pressures were consistent with 40 to 50 mm creek closure.

The culvert response predicted by the 2D analysis shows that small differences were expected for MCC with and without intervention measures at 50 mm creek closure. The stiffness of the uncracked masonry structure is significantly greater than that of the steel rib intervention measures. In the uncracked condition, the masonry structure was expected to resist the majority of the closure induced pressures until the stiffness of the masonry structure reduced because of cracking. From this, it was inferred that the behaviour of the brick arch culvert was effectively elastic without significant cracking up to 50 mm of creek closure and that stresses within the steel intervention measures generated by creek closure were unlikely to be significant at this level of closure.

The stress data indicated a strong correlation between measured stress change and diurnal and seasonal temperature variations at MCC. To filter out the 'noise' of the diurnal temperature effects, monthly average stresses were calculated to demonstrate the impact of seasonal temperature variation and the underlying creek closure imposed stress changes.

Back-analysis of the data indicates that valley closure had generally imposed permanent stresses on the structural steel ribs. This was identified as a step-change in stress measured when subsidence impacts were recorded at Myrtle Creek and a year later (which is beyond when changes in vertical subsidence and valley closure had effectively ceased).

By way of example, selected strain gauge measurements recorded at Rib 11 are presented in Figure 10 (refer to Figure 4 for strain gauge locations). The maximum inferred step-change was -42.0 MPa (compressive stress) — see also Table 1, measured at the Sydney-side invert of Rib 4 (14.0% of yield stress) and the maximum step in measured rib tensile stress attributed to creek closure was 19.6 MPa at the Country-side invert of Rib 22 (7% of yield stress). However, the pattern and distribution of stresses was not uniform in all ribs — Ribs 4, 11 and 17 showed a trend to increased compression, and Ribs 22 and 28 toward reduced compression, whilst Rib 34 rebounded toward compression.

The magnitude of the back-calculated step-change in rib stresses was attributed to creek closure and appeared to be generally consistent with the view that, whilst the masonry structure remains uncracked and the structure acts quazi-compositely, the intervention measures attract a limited proportion of the creek closure induced pressures. From analysis of stresses within the ribs within MCC it was concluded:

- Baseline and post mining monitoring has shown that the steel stresses within MCC undergo seasonal variation over time, as do the geotechnical measurements of in-plane rib displacements.
- The additional stress due to valley closure across the culvert can be estimated by measuring the shift in the seasonal responses and was found to be less than 14% of the yield stress of the steel.
- The geotechnical response and structural response are broadly in harmony, though the relationship with apparent creek closure is far from consistent.

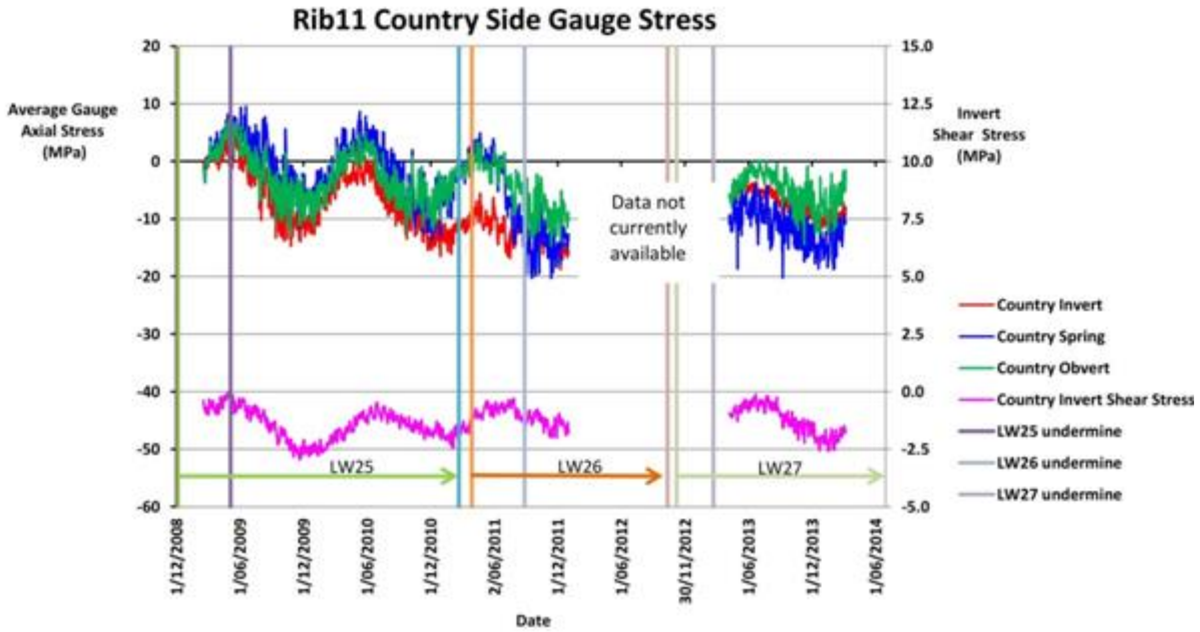


Figure 10 Stresses in Rib 11 in response to the retreat of LW25, LW26 & LW27

5.4 Creek closure

Tracking of creek closure and vertical subsidence through optical survey measurements is presented within Figure 11. The results are presented in terms of displacements versus a non-dimensional retreat in panel widths, with respect to LW25 retreat relative to MCC. The figure shows that:

The closure varied from upstream to downstream sections across Myrtle Creek, and that the closure of the rail track itself was less than both creek closures. This may be attributed to the effect offered by the culvert and embankment themselves; the passive rockbolt reinforcement through the floor of MCC; and the presence of the track baulk.

Vertical subsidence effectively achieved final values by a retreat of two panel widths past MCC, with 80% of the total vertical subsidence at a retreat of 1 panel width.

Creek closure was effectively complete by three panel widths retreat past MCC, with 70% of the closure reported by the survey marks at a retreat of one panel width past MCC.

The development of valley closure movement and vertical subsidence was gradual, as expected.

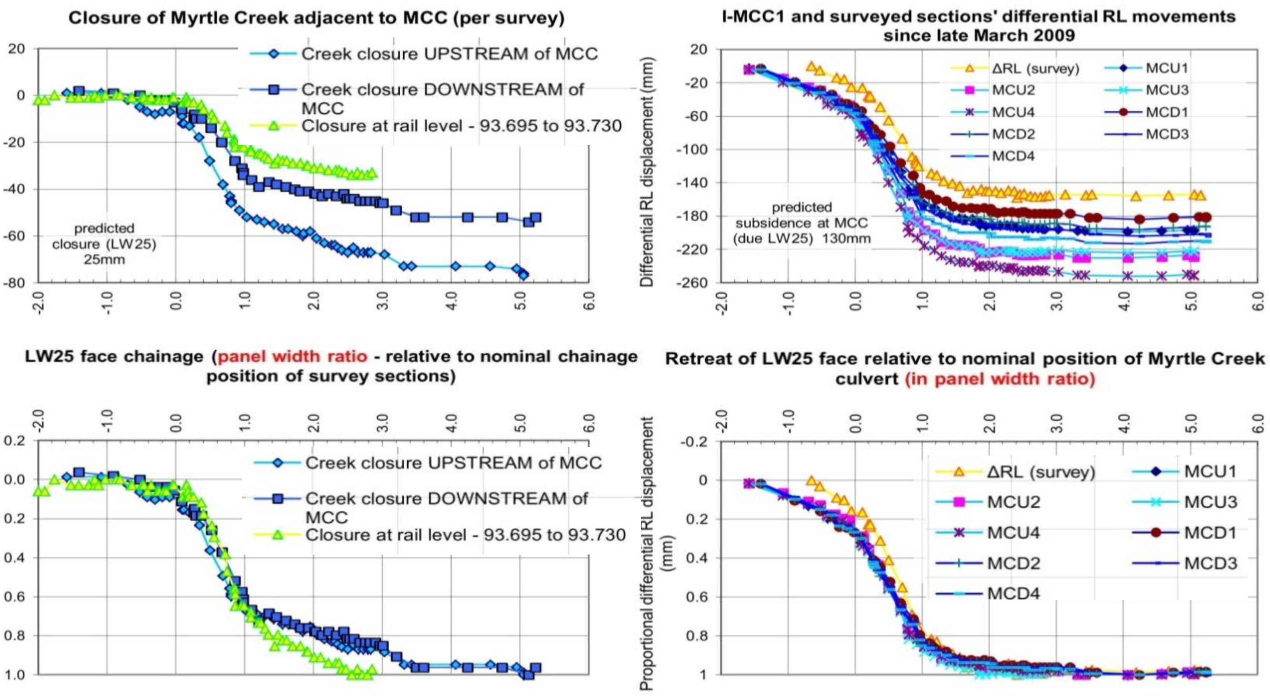


Figure 11 Creek closure and subsidence in proximity of MCC in response to the retreat of LW25

The local displacements and strain field around MCC were plotted to enhance the understanding of the closure response of Myrtle Creek, and the magnitude of closure that may have been reporting to the culvert structure. Whilst the results remain open to a degree of discussion, the evidence presented on Figure 12 is compelling that much of the closure displacements did not report to the culvert. It is inferred that horizontal ground shearing has developed on the upstream monitoring line between survey marks on the southern bank, with less ground shear apparent across the creek downstream of MCC, as observed from shearing of the downhole inclinometer.

This may partially explain the dichotomy between the relatively large apparent closure being inconsistent with the measured structural response of the ribs and the displacement response of the culvert. Aerial photograph interpretation of geological structures noted that lineaments were observed within Myrtle Creek (incidentally with local 90 degree changes in direction immediately downstream).

In terms of shearing of the rock mass due to subsidence, it is noted from Figure 13 that multi-directional shearing was recorded at no less than five horizons throughout the 30 m depth of an inclinometer installed adjacent to MCC — with particularly large deformation at 27 m depth (about 19 m below the adjacent floor of Myrtle Creek).

It was concluded that the strengthened culvert experienced only minor deformation and stress due to the mining of LW25. This may be due to one or a combination of the following reasons.

The overall ground closure across the creek at MCC was relatively small, with greater closure upstream and downstream of MCC, although this is not easily proven.

The creek closure movements appear to have focussed more so within the southern bank of Myrtle Creek than beneath MCC.

If, despite the above, it is assumed that MCC has experienced creek closure of approximately 80 mm, as observed by the upstream monitoring line, the observed impact of valley closure on steel stresses and deformations within the structural steel ribs has been less than expected.

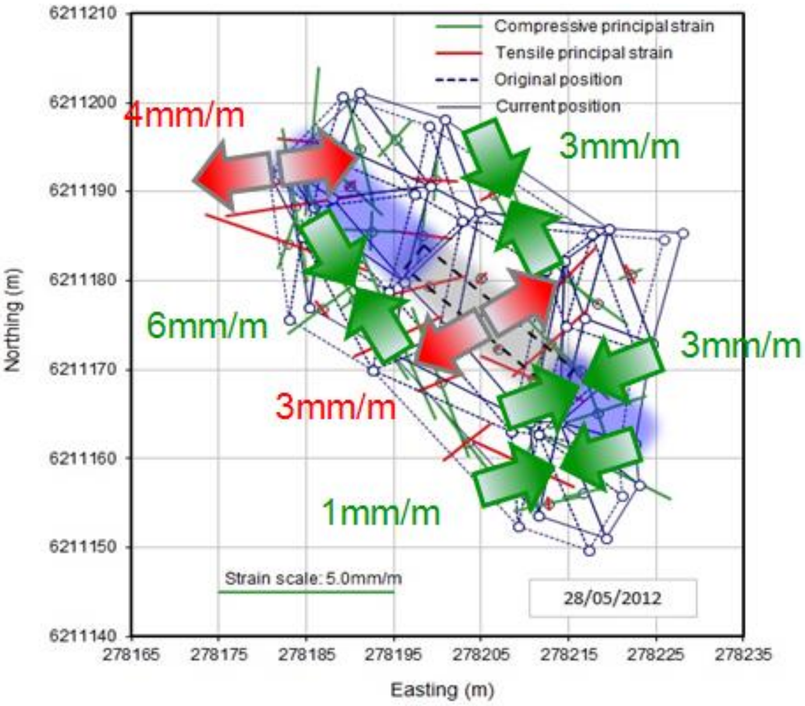


Figure 12 Plan of MCC showing closure movements and inferred controlling geological structure

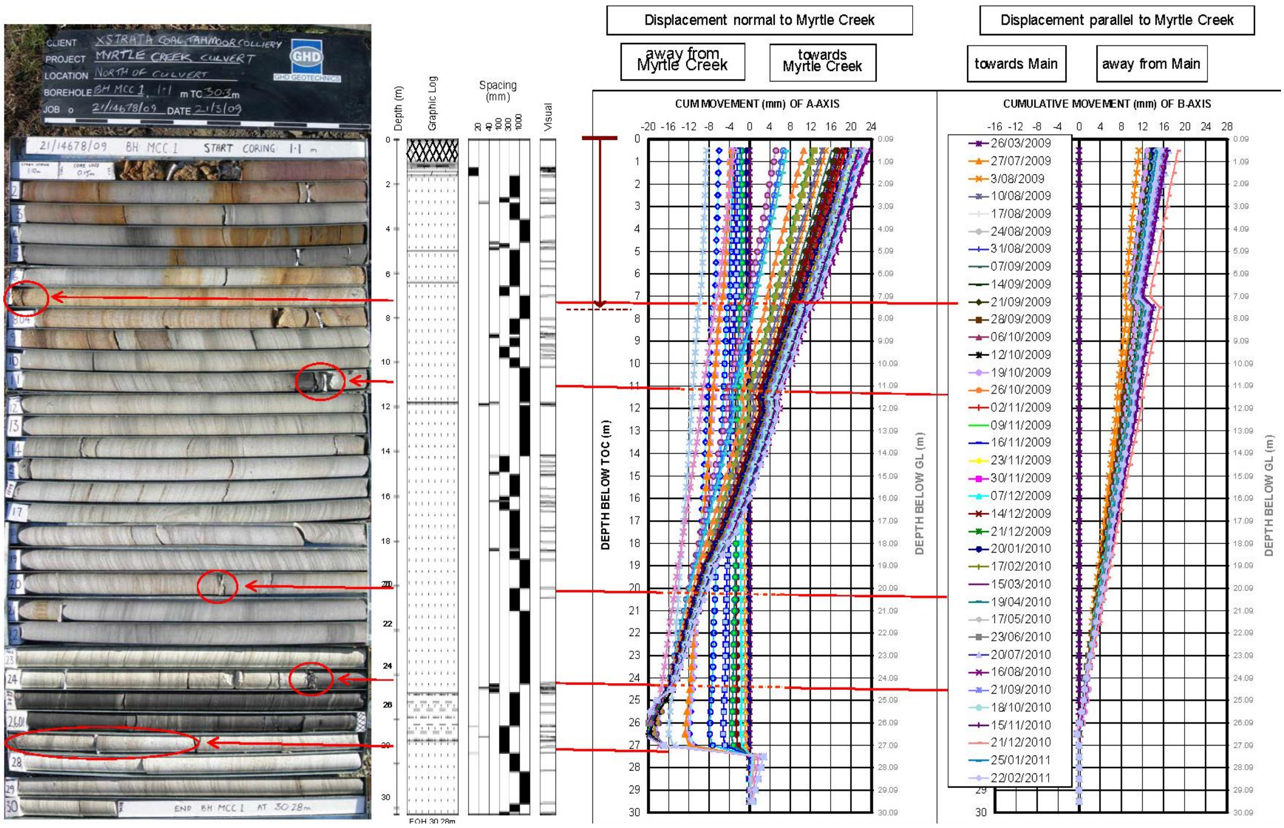


Figure 13 Downhole profile of response to retreat of LW25 by inclinometer installed upstream Sydney-side (northwest) of MCC

In terms of risk management, there is substantial structural capacity remaining in the ribs to withstand additional creek closure movements. Further, the structural capacity of the ribs can be increased by installing horizontal struts, if required. Finally, even if the strengthened culvert were to fail, the potential impact on train operations is mitigated by the structural steel baulk that was installed above MCC.

6 Conclusion

This paper presents the measured response of infrastructure with intervention measures developed to allow safe operation of the Main Southern Rail during the first longwall mining conducted beneath Main Line Rail without restriction upon rail operation or mining activities.

A lengthy monitoring period during multiple passes of longwall panels beneath the culvert, with lead-in monitoring, detected the natural environmental response of the structure.

The culvert has existed for 100 years, responding to environmental influences through cyclic expansion and contraction. The response of the steel ribs, and presumably the brick arch culvert itself, to these environmental influences is recognisable within the monitoring results as both seasonal and higher frequency diurnal responses. Subsidence induced creek closure imposed upon these cyclic events has been identified within the monitoring results. Strengthening of the brick arch culvert at Myrtle Creek was prudent given the results from the monitoring.

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