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MANAGEMENT OF MINE SUBSIDENCE IMPACT UPON MAINLINE RAILWAY INFRASTRUCTURE – THE FLIRTATION OF LW25 WITH THE BRICK ARCH CULVERT AT MYRTLE CREEK, TAHMOOR

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ABSTRACT

Longwall mining within the Bulli Seam has been conducted beneath the Main Southern Railway (Sydney – Melbourne). The railway track subsided 0.6m during Longwall LW25, and the same again during LW26 (though at a different location). Whilst limited mining has been permitted previously under Main Railway Lines, for the first time longwall mining has been conducted beneath a Main Line without constraint to the rail traffic and without constraint upon the mining. This paper presents the response of a 4.6m diameter inverted horseshoe shaped brick arch culvert, supporting the line.

Keywords: mine subsidence, longwall, coal, infrastructure, brick arch culvert, management

1. INTRODUCTION

Xstrata Coal, Tahmoor Colliery, continue to conduct underground longwall coal mining of the Bulli Seam at depth below the township of Tahmoor and its environs. Mining of Longwall 25 (LW25) was successfully completed (21 February 2011) to the north-west of the Tahmoor township, with the planned footprints of LW26, LW27 and LW28 to extract coal further to the north.

2. MAIN SOUTHERN LINE INFRASTRUCTURE AT MYRTLE CREEK

LW25 retreated a total of 3592m, was 283m wide (rib-to-rib), and the mining interval was typically 2.1m, at a depth of approximately 430m beneath the Main Southern Railway line. Myrtle Creek culvert (MCC), situated at LW25 retreat chainage 1380m, is over the gate road between LW25 and LW26.

Figure 1 provides the setting of the mining to the north of Tahmoor, the location of the Main Southern Railway across the mine's longwall panels and the position of MCC. Myrtle Creek incised through the overlying Wianamatta Group that underlies much of Tahmoor. The Mittagong formation and/or the uppermost portion of the Triassic-aged Hawkesbury Sandstone formation (DMR 1999) outcrop in the creek banks and floor, 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.

The Main Line crosses Myrtle Creek upon a filled embankment approximately 10m high that essentially runs from rim-to-rim of the creek at this location. The embankment includes Ashfield Shale materials from the adjacent cuttings, together with railway ballast. The fill is typically "loose". The outer skin of the embankment is steep (steeper than 40^{o}) and covered by ballast spilt from the track.

MCC consists of a brick arch culvert, constructed in the early part of last century (c1917) as an inverted horseshoe consisting of 5 courses of brick-on-edge masonry, the brickwork of which is in good condition. The culvert is 4.6m wide, 4.4m metres high and 22m long. Standard NSW Railway's drawings from the era typically depict a floor slab under the brick arch, though no meaningful concrete slab is present at MCC - with only a variable depth of cyclopean mass concrete detected. The same drawings suggest that this brick arch culvert has buried external buttresses, and whilst anticipated these have not been proven at MCC. An impression of MCC can be obtained by reference to Figure 2.

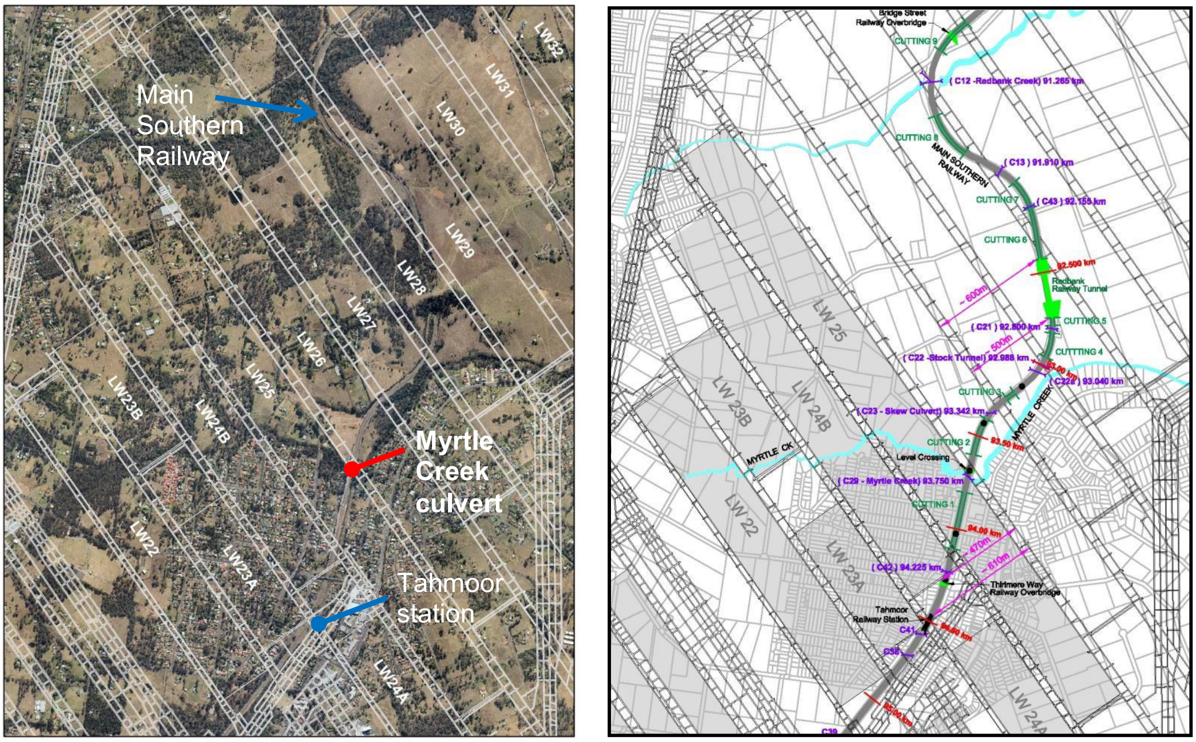


Figure 1: Mining Area Tahmoor Colliery: orthophoto (left) and cadastral information (right).

Figure 2: Myrtle Creek culvert viewed from upstream showing the steel ribs and reinforced concrete invert lining within the brick arch culvert beneath the Main Southern Railway (as indicated by the under-track baulk steelwork and fencing at the crest of the embankment).

2.1 Predicted subsidence impact

Creek closure was identified as the critical design condition for the brick arch culvert. Closure magnitudes were estimated by Mine Subsidence Engineering Consultants (MSEC) – being a cumulative closure of 20mm after LW25, 35mm after LW26, and 42mm post LW27 (MSEC, 2008). The primary intervention measure comprises steel ribs designed by John Matheson & Associates as fabricated arched beams equivalent to 250UC89, installed at 0.6m centres along the length of the culvert, together with a reinforced concrete invert between the ribs. The aims of the intervention measures were to maintain the form of the culvert and its function as a drainage culvert. In accordance with guidelines developed by the regulator (DMR, 2003), the design of the ribs was modelled on 150mm creek closure, which was a factor of 3 times greater than the nominal 50mm prediction.

Passive rockbolts 3.25m long were installed through the relatively thin cyclopean mass concrete and into the sandstone bedrock beneath to ameliorate the effects of upsidence. To maintain track geometry, and as an additional (back-up) intervention measure, a 600mm deep stiffened steel deck was installed as a baulk beneath the track over MCC.

2.2 Anticipated response

The important feature in the understanding of the response of MCC to mining induced creek closure is recognition that the response was strain-driven rather than the conventional concept of stress-driven response in a soil-structure interaction scenario. The mine subsidence mechanics at ground surface level are strain-driven involving complex realigning of strata to accommodate creation of the longwall goaf. Traditional methods of design involving load factors are challenged by this mechanism - load factors are meaningless and recourse is therefore made to factoring strains, not stresses.

The potential failure mechanism did not involve a snap-through buckling collapse mechanism, principally as a consequence of a thick walled cylinder analogy. The 2-D analysis-based rib closures for MCC with creek closure of 150mm were: 25mm vertical and 65mm horizontal without intervention: and 5mm vertical and 40mm horizontal with intervention - demonstrating the advantage of the intervention measures.

2.3 Instrumentation

A necessary part of verification of the design and assessment of the performance of the intervention measures was a reasonable, yet effective, monitoring programme. The instrumentation includes: electrolytic tiltmeters at the crown along the culvert; tiltmeters installed radially around the arch of 4 selected ribs; tape extensometer measurements both within the plane of 8 ribs and also between adjacent instrumented ribs, thereby providing a 3-D coverage; optical survey of the culvert using laser reflectors located upon each of the monitored ribs; and strain gauges installed upon 6 steel ribs for structural monitoring - see Leventhal et al (2011) for more details.

3. RESPONSE OF MYRTLE CREEK CULVERT TO RETREAT OF LW25

It became apparent that the monitoring results in the plane of the ribs were a response of the structure to a seasonal, thermally driven, environmental influence, upon which subsidence impacts were superimposed. This is discussed in the companion paper (see Hull et al, 2012). It is noted that MCC has been under the influence of seasonal and diurnal environmental influences for the last century.

3.1 Geotechnical responses

Three-dimensional survey demonstrated that the track moved towards the approaching goaf of LW25, and then reversed to follow the retreat of the mining face. During this response of the groundmass, with MCC located above the maingate between LW25 and the (then) future LW26, MCC rotated transversely towards the goaf of LW25 by 2.0 milli-radians, with little relative twisting along its axis, implying that MCC behaved as a rigid (brickwork) tube with minor torsion. Monitoring of longitudinal tilt showed: tilt down towards the approaching goaf initially; flattening off when the retreating mining face was about one third of a panel width past MCC; rebound and recovery to the initial long tilt orientation at less than one panel width retreat; continued rebound until retreat achieved 3 panel widths past MCC; and then a degree of shakedown until the end of LW25. The longitudinal tilt reduced the gradient of MCC from its initial 180mm (over its 22m length) by about 8mm – viz: 0.4mm/m.

The in-plane rotation of the body of the culvert during LW25 achieved a final value of 2.0 milli-radians, which is equivalent to 2.0mm/m rotation across the width of the culvert (and a downward displacement of 8mm on the country side of the culvert relative to the Sydney side). Relative to longwall retreat, 80% of the final rotation was achieved at a retreat of one LW25 panel width, and the majority of the rotation was complete by 2 panel widths. There is no evidence of seasonal effects upon the rotation. The rotational response was related to the development of the travelling wave of the subsidence bowl above the goaf of LW25, and the final rotation was equivalent to the local measured gradient of the subsidence bowl - as would intuitively be expected. The rotation effectively recovered during retreat of LW26 to its initial (pre-mining) situation, with minor remnant torsion along the culvert barrel.

Normalised creek closure and vertical subsidence responses are presented in Figure 3, showing that:

- Whilst the closure varied from upstream to downstream sections across Myrtle Creek in absolute magnitude, the relative response development was consistent about MCC.
- Vertical subsidence effectively achieved final values at a retreat of 2 panel widths passed MCC, with 80% of the total vertical subsidence at a retreat of 1 panel width.
- Creek closure was effectively complete by 3 panel widths retreat passed MCC, with 70% of the closure reported by the survey marks at a retreat of 1 panel width passed MCC.
- The development of valley closure and vertical subsidence was gradual, as expected.

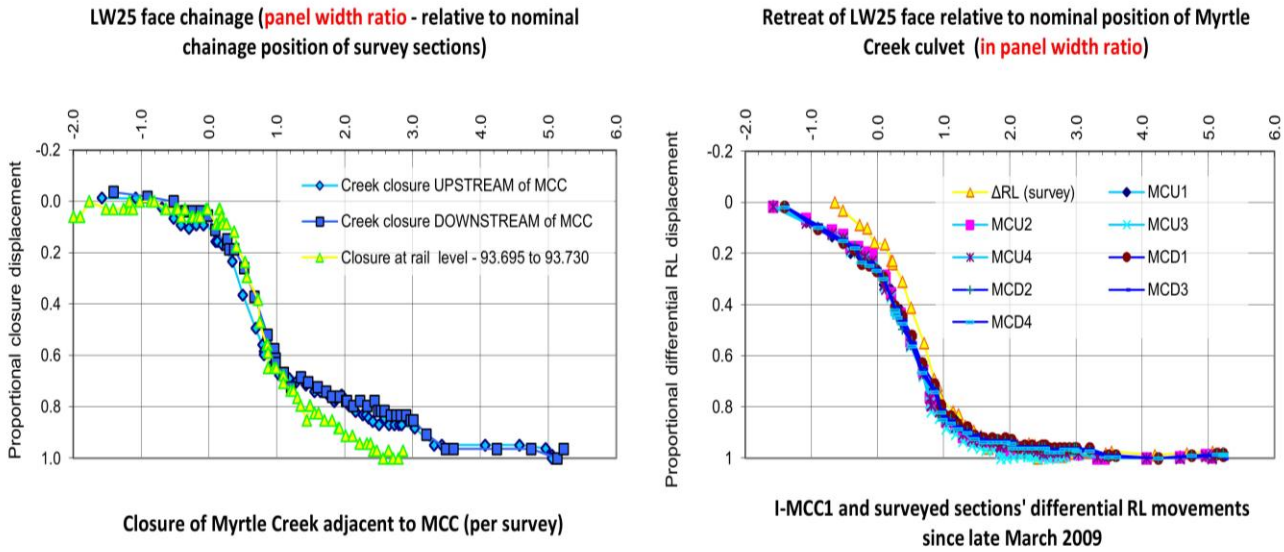


Figure 3: Creek closure and vertical subsidence at MCC in response to the retreat of LW25.

The question that arises is “what was the magnitude of closure that was imposed upon the brick arch culvert with its intervention measures relative to the rim-to-rim closure?” This question is raised in the context of: the predicted creek closures made in advance of mining; how the creek responded to the closure; the response of the culvert to the closure that reported to it, particularly in regard to the regulator expectations; and the remaining capacity within the composite brick arch and steel rib structure to withstand the effects to be produced by the retreat of LW26 passed MCC.

The local displacements around MCC were re-plotted in a strain format to enhance the understanding of the creek closure response, and the proportion reporting to the culvert. Whilst survey monitoring provides the magnitude and direction of displacements of the ground surface as mining progresses, this method estimates the magnitude and directions of lateral principal strains within the rockmass. The principal strain analysis used the perturbations within a displacement field of the final position relative to initial position of survey marks (ie displacement vectors). Using Mohr’s circle of strain, the vectors on three corners of triangles of survey marks were used to determine the major and minor principal strains at the centroid. The minor and major principal strains represent the intercepts on the compression/tension strain axis (x-axis) of the two-dimensional representation given by the Mohr’s circle of strain (the y-axis being shear strain). Whilst the magnitudes of the displacements of the ground (or more correctly, the survey pegs) are similar, perturbations in magnitude and direction occur that set up strains between the displaced survey points. Principal strain tensors for abutting triangles were accumulated to depict the strain field. Within Figure 4, displacements are indicated, albeit at exaggerated scale, through reference to the initial position (dashed linework) relative to the final position (solid linework).

With reference to Figure 4, it is noted that: the tensile strain change field has a direction representing extension towards the retreating face of LW26 (to the north-west); a tensile strain field in Dec 2011 existed along either side of the culvert (shaded) and sub-parallel to the culvert axis, up to 4.5mm/m (4500 με); there is a clear concentration of lateral creek closure compressive principal strain about the creekline at each end of the culvert, with compressive strain magnitudes up to 4mm/m (4000 με).

In recognition of a survey tolerance of +3mm, the perceived accuracy of the principal strain values is of the order of +0.05mm/m strain (50 με). It is believed that this accuracy does not detract from the trends established within Figure 4. Stress change estimates within the rockmass as a result of the strain changes may be of the order of 8MPa given a reasonable estimate for rockmass bulk modulus.

Whilst the results remain open to a degree of discussion, the evidence presented on Figure 4 is compelling that much of the creek closure displacements did not report to the culvert. This may explain the dichotomy of the relatively large apparent creek 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 lineaments were observed adjacent to, and probably controlling, Myrtle Creek. The presence of shearing within the rockmass on the country-side bank is postulated, though the dip direction is currently unclear.

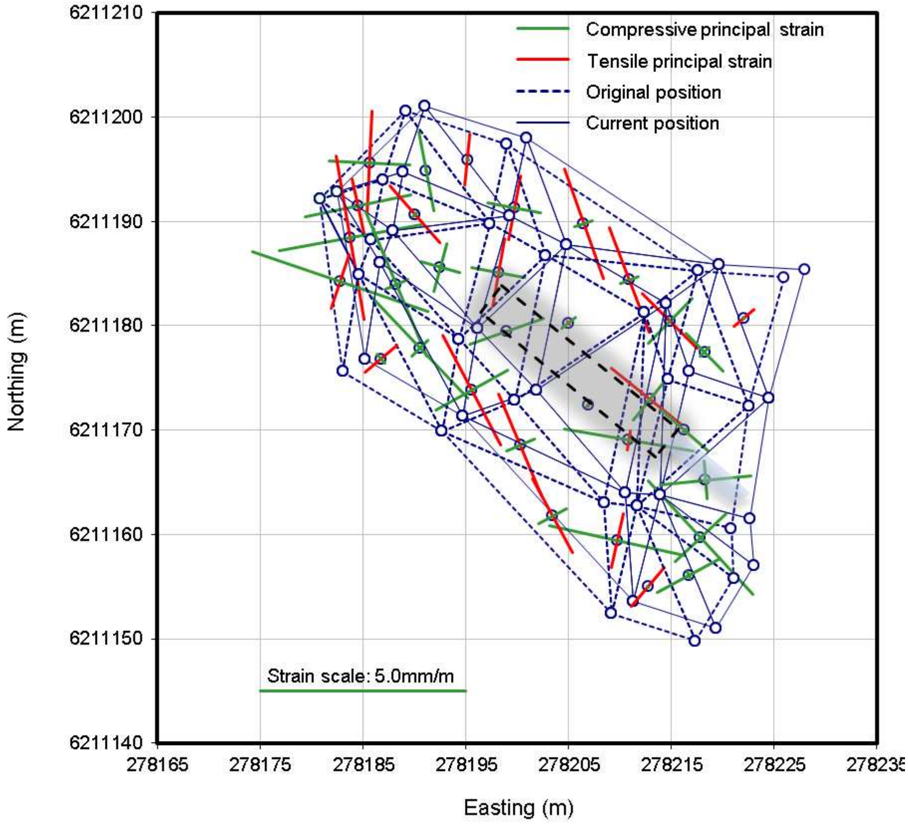
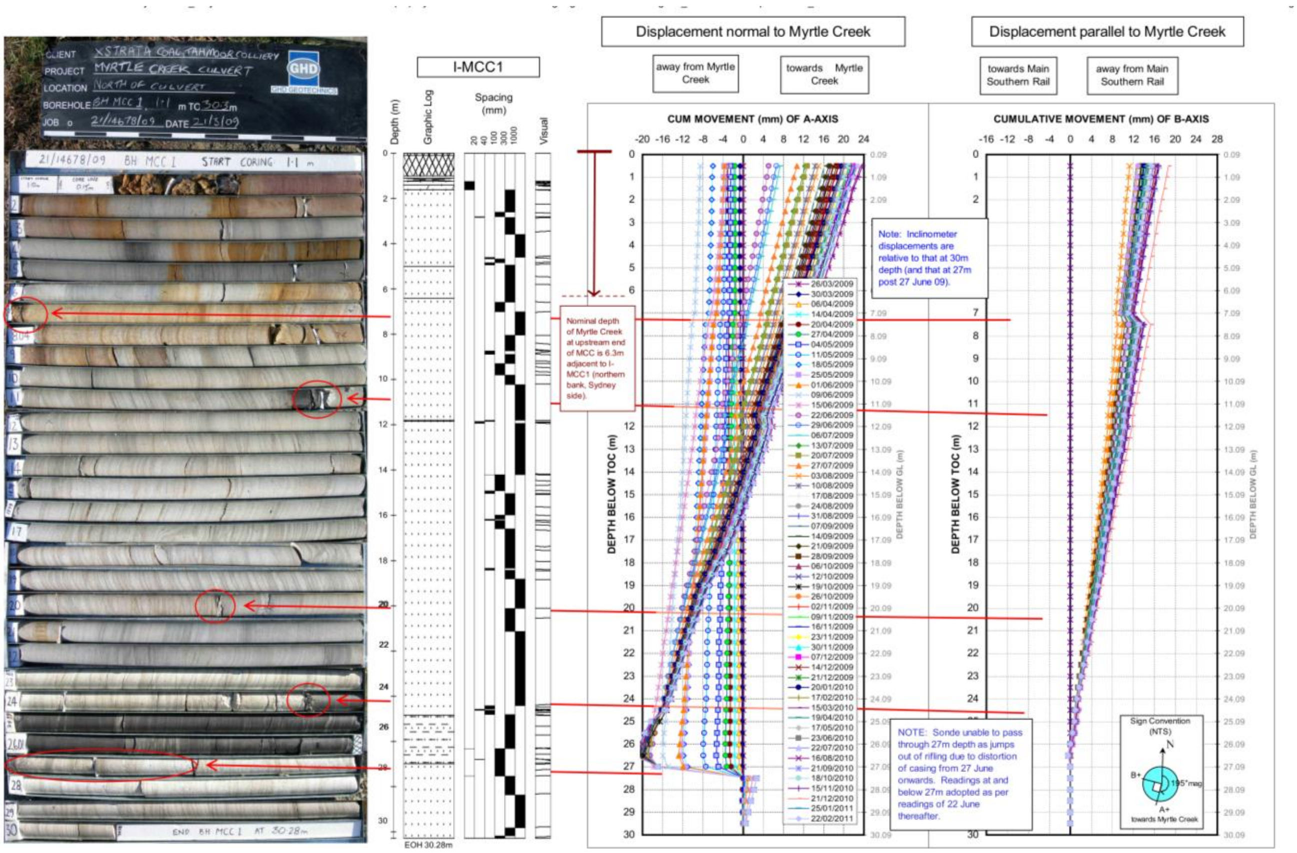


Figure 4: Principal strain changes around MCC due LW26 (17 May to 05 December 2011).



Nominal depth of Myrtle Creek at upstream end of MCC is 6.3m adjacent to I-MCC1 (northern bank, Sydney side).

Note: Inclinometer displacements are relative to that at 30m depth (and that at 27m post 27 June 09).

NOTE: Sonde unable to pass through 27m depth as jumps out of rifling due to distortion of casing from 27 June onwards. Readings at and below 27m adopted as per readings of 22 June thereafter.

Figure 5: Profile of response to retreat of LW25 by inclinometer upstream Sydney-side of MCC.

It is noted from Figure 5 that multi-directional shearing was indeed recorded at no less than 5 horizons throughout the 30m depth of an inclinometer installed adjacent to MCC - this being indicative of relative displacements throughout this depth of the rockmass, with particular shearing at 27m depth (about 19m below the adjacent floor of Myrtle Creek).

While it is possible that the focal point of valley closure has been shifted due to the influence of the stiffened culvert, it is noted that the upstream and downstream monitoring extends beyond where the influence of the rockmass stiffening is likely. Additionally, concentration of valley closure effects to the side of a valley has been observed elsewhere.

It is concluded that the strengthened culvert experienced manageable deformation and stress as a result of the mining of LW 25, and during LW26. In terms of risk management, there is substantial structural capacity remaining in the ribs to withstand additional creek closure movements. In addition, the structural capacity of the ribs can be increased by installing horizontal struts, if required, and, even if the strengthened culvert were to fail, the potential impact on rail operations is mitigated by the structural steel baulk installed above MCC.

4. CONCLUSIONS

This paper presents the recorded response of infrastructure critical to the safe operation of the Main Southern Rail. To the authors' knowledge, LW25 was the first longwall mining to retreat beneath Main Line Rail without restriction upon rail operation or mining activities, and has been accomplished successfully.

Longwall LW26 has subsequently also retreated beneath the Main Southern Railway on the northern side of LW25 with similar success – again through track and infrastructure management and without interruption to rail operations, without impact upon rail safety, and also without restriction upon underground mining activities.

5. RECOGNITION

The authors are pleased to record that the project in its entirety, being the tasks described by Pidgeon et al (2011) and as described herein, is a world-first in terms of subsidence management whilst mining beneath a Main Line. The project has been recognised: (i) by The Institution of Engineers Engineering Excellence Awards for 2010, winning in Newcastle Division and being a finalist in the National Awards; (ii) through winning 2010 Aust Mining Prospect Award for "Coal Mining of the Year"; and (iii) as a finalist for the 2010 Consult Australia Awards.

6. ACKNOWLEDGEMENT

The success of the project to date is the result of the considerable and valuable contributions of many. In addition to the organisations represented through the affiliations of the authors, they wish to acknowledge the support provided by Xstrata Coal, Tahmoor Colliery, and the rail operator, ARTC. The contributions from BMT WBM in installation and monitoring of the EL Beams within MCC and Meadows Consulting for optical surveying within and near MCC, are acknowledged. Further, the acumen of personnel from Xstrata Coal, who appreciated the benefit of continued monitoring to enable an understanding of the response of the culvert to be developed, is particularly recognised.

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