Highwall stability implications from longwall mining at Broadmeadow mine

Dan Payne  
*BHP Coal*

Matt Martin

Bob Coutts

Dan Lynch

Publication Details

HIGHWALL STABILITY IMPLICATIONS FROM LONGWALL MINING AT BROADMEADOW MINE

Dan Payne¹, Matt Martin, Bob Coutts, Dan Lynch

ABSTRACT: The Broadmeadow punch longwall coal mine in Central Queensland Australia has experienced significant highwall movement associated with the effect of longwall subsidence when the longwalls approach their final position close to the open cut highwall. In response to this movement Broadmeadow employed two types of broadscale highwall monitoring (radar and laser scanners) to provide full coverage measurement throughout three consecutive longwalls approaching the highwall. This was to attain a better understanding of the mechanism causing the movement and potentially enable prediction of instability. Results from the monitoring found the highwall is displaced to magnitudes unlike those typically measured in open-cut mining, and in direct contrast to typical longwall subsidence behaviour. This paper discusses the ground movements measured, monitoring methods used, safety measures established as well as theorising the failure mechanism. Recommendations are made for mine and pit designs for future punch longwall layouts. The paper shows how the movements measured are more aligned to some measurements made during stream valley closure studies previously presented at the International Conference on Ground Control in Mining (ICGCM) and challenges the mechanisms suggested by previous literature.

BACKGROUND

The mining of longwalls under or adjacent to large voids (eg stream valleys, escarpments or cliffs) is commonly associated with heavily vegetated or steep surface areas. In areas of extreme topographic variance, access for and/or to traditional survey pegs and stations or even new radar or laser technologies is limited. In addition, seldom have the longwall layouts aligned themselves parallel or perpendicular to the surface feature, making interpretation of any available surface movement data more complicated.

The punch longwall layout (Figure 1) is also quite uncommon (only undertaken at a small number of longwall mines in Australia) but creates the perfect configuration to enable a somewhat controlled study of the effect of longwall subsidence on a steeply dipping surface feature (an un-vegetated, evenly excavated open cut highwall). The relatively recently developed radar and laser scanning technology has also enabled near continuous, real time, sub millimetre monitoring of a full 500m wide x 100m high highwall and because punch longwall enables access and clear view the technology could be easily deployed as compared to the highly vegetated and variable topography of stream valleys.

Broadmeadow mine prepares the highwall for long term stability after open cast mining is completed. Slope and batter angles, bench configuration and pre-spilt blasts for the final strip are all designed with the punch longwall end use in mind. The bottom section of the highwall is the scaled to clean the highwall of any loose material. Highwall above the portal access pads is rock bolted as required before steel mesh sheets are draped over the highwall to cover all access pads. Drainage is prepared to direct water away from portal areas and prevent ponding.

The punch longwall layout makes use of abandoned open cut mine strips and drives gateroads directly into the seam at the base of the highwall with no requirement for main entries. The longwall is then retreated back towards the open cut and recovered just short of the highwall.

¹ BHP Coal, Broadmeadow Mine, Moranbah, Queensland, Australia Email: Dan.Payne@bhpbilliton.com

University of Wollongong, February 2019
leaving a safe barrier pillar. Broadmeadow coal mine has mined 11 longwall panels via this method, from two adjacent open cut strips.

![Figure 1: Punch Longwall Layout showing highwall and low wall and gateroad access at the base of the highwall (note the open cut has usually abandoned the pit by the time longwall mining occurs)](image)

The factor of safety of barrier pillars was always >4 using ALTS and therefore were designed for longterm stability, given the shallow overburden depth (90 m). Furthermore, longwall gateroad equipment limited the distance between the longwall and highwall. Highwall stability was also not expected to be an issue due to the high factor of safety and the fact that the seam dips inbye and the highwall is battered back to 65 degrees with two catch benches, so any subsidence was expected to pull the highwall toward the goaf not impacting the stability of the batter slope.

The general configuration of the highwall is approximately 95 m high from the floor of the coal to the natural surface, with wall angles of 65 degrees for the initial 50 m of highwall to the second bench and an angle of 38 degrees from the lower to upper bench. The overall slope angle from toe to crest is 34 degrees. This results in a horizontal distance of 140 m from crest to toe and that the longwall stopline is typically very close to directly under the crest at the natural surface. Figure 2 shows a photo of the gateroad accesses at the pit floor, the sumps between gateroads and the highwall bench slope configuration.

During normal longwall mining, the strata ahead of a longwall face strains towards the longwall goaf (Figure 3a and 3b). Inclinometer monitoring conducted adjacent to the Broadmeadow Mine longwall 11 panel during the start of the block confirmed that the direction of shear movement is in fact toward the centre of the void created by the longwall panel (Figure 4). This movement is caused by the tension generated when the overburden collapses into the goaf. The limit of ground movement on the surface ahead of the longwall face (to the sides and behind the goaf) is used to define the angle of draw. At Broadmeadow an angle of 19-26 degrees has been determined from LiDar (Airborne Lasar Scanning) monitoring and traditional peg surveys of subsidence on the surface. LiDar Typical subsidence ground profiles as shown in Figure 3a have been experienced at Broadmeadow.
Figure 2 – Image of second Broadmeadow Pit (Radar monitoring units positioned on the low wall slope on the left hand side of the photo)

Figure 3a and 3b: Subsidence profile in section from Introduction to Longwall Mining and Subsidence (2007) and Systematic horizontal movements observed in flat terrain found in Mills (2001)

Figure 4: LW11 Inclinometer results showing displacement of shear towards the longwall goaf adjacent to the start of LW11 in confined ground (no adjacent voids) Mills (2016)
In addition, survey peg data has indicated that horizontal movement of points on the survey follow the traditional movement shown in Figure 3b; that being the case they are drawn toward the goaf as the longwall approaches and then move back in the opposite direction (the direction of retreat) as the longwall passes underneath and the surface settles back forward (lays down). It was this traditional understanding that led barrier pillar designers to believe the longwall subsidence would pull the highwall (which would be ahead of the final longwall position) toward the goaf and into an even more stable position.

However, the highwall movement and associated ground deformation observed at Broadmeadow as the longwall approached final position and was recovered, did not conform to either typical longwall subsidence profiles, or typical highwall movement, with values far exceeding any stability limits used in adjacent open cut mines (indicating the onset of failure). This outward movement, while not affecting the global stability of the highwall, destabilised local areas of the highwall around pre-existing defects/geological structure. A significant local wedge failure adjacent to the MG11 portal occurred during the LW11 recovery. This indicates that although the barrier pillar was overdesigned for vertical load, it may have been under designed for the horizontal push of the subsiding ground (overcoming the shear resistance along the bedding planes).

INITIAL OBSERVATIONS

Punch longwall mining at Broadmeadow mine commenced in 2005 from Ramp 4 of the Goonyella Riverside Coal Mine, mining longwall blocks from east to west toward the highwall and sequencing them north to south (Figure 5). Longwall blocks 1-5 were recovered from this first pit. The distances that the stoplines were designed from the highwall (barrier pillar width) varied with blocks 1-3 between 97m and 125m (shortest distance). While blocks 4 and 5 were 161m and 144m respectively. Blocks 6 and 7 were located between the two open cut pits and required conventional mains headings for access, with longwall 8 located at northern end of the second pit.

Concerns over geological structure at the northern end of the first pit meant that a buttress of blasted material was left in front of Longwall 1. After this panel’s extraction, numerous falls above the TG1 and MG1 pads were reported ripping the highwall mesh and a large section of sandstone failed into a sump below the highwall. It is now thought that these incidents may have been caused at least in part by longwall subsidence ground movements. Due to poor access little inspection of the benches was carried out and the highwall stability issues were not connected to longwall subsidence. As no monitoring was in place limited observations were made for the first few longwalls and the barrier pillars grew to 161m (measured shortest distance). However when LW8 was recovered, deformation of the highwall including lipping (horizontal shear and displacement resulting in over hang) of bedding surfaces, floor heaving at the base of the wall and cracking on the upper benches was observed. This visually indicated outward movement of the highwall. Longwalls 8-11 had a distance to the highwall toe of ~100m shortest distance and it was decided to take advantage of highwall monitoring techniques used in the adjacent open cut mines.
Figure 5: Broadmeadow Mine Layout showing underground workings and access from the first open pit for longwalls 1-5 and from the second pit for longwalls 8-11

MONITORING

As well as visual inspections and a few pipe extensometers across cracks on the surface, Groundprobe SSR-XT radar was used for monitoring as the longwall neared the final stages of retreat for LW9 and LW10. This instrument has the capability to scan a distance of 30 m to 3500 m away from the radar setup, identifying failures to a resolution of 0.3 m x 0.3 m and 30.5 m x 30.5 m, respectively. At the reporting distance of 215 m for LW9, the integrated visual imaging system that resolves a 2 m x 2 m pixel was used. The accuracy of the measurement is sub 1mm and scans the entire area in about 13 min.

The Maptek lite Sentry laser scanner was trialled alongside the GroundProbe radar on LW10 and used exclusively for LW11. Like the SSR-XT radar it has a sub millimetre accuracy and is capable of scanning the entire wall. However it can complete the scan in 6 min depending on the block size needing to be monitored. Another advantage of the laser technology is that it is spatially referenced allowing itinerant monitoring. This means the scanner can be shifted to a new location and maintain a correlation in the data before and after moving. Sentry can resume from any surveyed pillar and continue a complete database, while the Radar uses a stable reference point to determine the actual movement between the radar and the monitored surface. When the radar monitoring commenced on LW9, finding a stable reference point was difficult at first due to the global movement of the highwall. Both units are shown in Figure 6.

Figure 6: Ground Probe Slope Stability Radar and the Maptek Sentry Laser Scanning System
Both of these techniques enabled real time graphical display of total displacement and rate of wall movement in the direction of the radar unit (which was positioned perpendicular across from the highwall on the low wall of the open cut strip). The supporting software also allowed real time triggers or warnings of increasing rate of movement and videos of displacement over time were able to be created. Results shown in this paper were only from the ISite Sentry used on LW11. Both monitoring units and techniques worked very well and determined that large scale highwall displacement of up to 1000 mm towards the open cut were occurring on a very similar scale and pattern on all 3 longwalls.

HIGHWALL MOVEMENT RESULTS

As mentioned, the configuration of punch longwall, (mining back to an established open cut highwall) provided the perfect opportunity to monitor ground movement as the entire highwall for 3 consecutive longwalls is visible and relatively unvegetated. Monitoring of the highwall during the recoveries of Longwall 9, 10 and 11 using both the Groundprobe slope stability radar and/or Maptek I-site Laser Scanner has provided high quality and accurate (sub 1mm) information over the entire area to perfectly describe the highwall movement in real time. Scanning from an upper horizon on the low wall (directly opposite and across the pit void from the moving highwall) and using a stable reference point, laser and radar technology easily achieve .4-.6 mm accuracy from that distance (~300 m) which has been confirmed in open cut for several years.

It was found that the first sign of highwall movement away from the longwall and towards the open pit was experienced when the longwall face was 300 m from the highwall toe. Outward movement of the highwall increased as the face retreated closer to the highwall. An early study of longwall 9 only (L. Clarkson, 2016) showed that the rate of highwall movement was directly correlated with the rate of longwall retreat. For all three longwalls, movement would continue over the entire highwall adjacent to the stopline until the longwall reached final position, and then show movement progressively from Tailgate to Maingate as the shields were recovered in sequence. At this stage the highwall movement virtually came to a stop in all three cases.

Variation in the magnitude of movement increased with distance up the stratigraphic section from the seam to surface and was divided into bands of movement by coal seams or other sedimentary layers such as the P-tuff claystone. These provided low friction interfaces for shear movement. The horizons where shear movement was observed with the inclinometer at the start of longwall 11 (although much lower magnitude and in the opposite direction) correlated exactly with the horizons of movement observed along the highwall. However, unlike ground behaviour at the start of the longwall panel, the entire highwall mobilised in the opposite direction (away from the longwall goaf).

Figure 7: LW11 Highwall total movement 19th of Jan to 30th March 2017 as a composite of scans every 13 minutes between those dates
There were three distinct zones of movement up the highwall (Figure 7).

- Directly above the coal seam being mined and below the P-Tuff layer, this section of highwall consisted of sandstone channel deposits and moved <100mm.
- Above the P-Tuff but below the GP5 coal seam, total movement of <300 mm was recorded. The GP5 was located just above the first bench which allowed observation of the lipping surface which formed along this interface (Figure 8).
- Above the GP5 coal seam to the upper bench, total movement of up to 1000 mm was recorded.
- Levee bank behind highwall moved towards the goaf as per the regular subsidence trough behaviour (including the slight difference in longwall take off position alignment with the highwall, ie. closer at the tailgate as shown in Figure 9).

![Figure 8: LW11 Highwall total movement and photo of lipping surface along the GP5](image)

In Figure 7, green areas display where the highwall has moved over 1000 mm towards the monitoring station (pit). As per the legend, blue areas indicate movement away from the scanner (toward the longwall goaf). The 2 blue patches on the lower face itself in Figure 7, are areas where material dropped off the wall leaving cavities behind. The upper dark blue wedge however shows true ground movement away from the scanner. The shape and location of the dark blue wedge clearly represents that the longwall is on a slight angle to the highwall (50 m closer at the tailgate) and undermines the very upper part of the slope at the tailgate end of the wall which is confirmed in a plan view in Figure 9.

The extents of the movement across the highwall quickly dissipated either side of the longwall gateroad entries. Total movement increased towards the centre of the longwall block (consistent with the rounded shape of subsidence contours and protection provided by pillars). Jointing appeared to provide a lateral boundary to movement as demonstrated by the vertical colour changes in Figure 10. These differential movement boundaries were observed in the highwall above the pillar between the belt and travel road portals. This is thought to have contributed to increased highwall instability which observed during the longwall recoveries. It is also interesting to note that instabilities occurred in the lower wall where the movement was the least, whereas the upper wall experienced much more movement. This is because the upper walls are comprised of weathered tertiary material (very soft) and didn’t have pronounced structure.
While it is assumed some deformation had occurred during longwall recoveries in the initial open pit (longwalls 1-7), no visual deformation was observed, and as such no monitoring program was undertaken. There are a number of differences between the first and second open cut pit.

- The initial three panels had a block width of 200 m, before Longwall width was extended to 320 m from LW4.
- Distance from the highwall for the initial open cut pit was greater for the full width panels than for the second.
- Top Coal caving was introduced on Longwall 8 which increased extraction height from 4 m to ~6 m. (although caving is not carried out for the last 450 m of the longwall to prepare for recovery)
Predicting Highwall Instability

Open cut coal mines have standard triggers for assessing highwall instability based on rates of movement. However, the magnitudes of movement generated by the longwall affect (1000mm total and rates up to 1.5mm/hr over +6 weeks) were unprecedented and the rate was controlled by longwall retreat rather than ground failure. Open cut coal highwall instability triggers are in the order of 5mm/hr and are the result of rock failing usually along a structure and show an increasing rate that can progress over as little as 40 minutes (local experience) to failure to as long as many weeks (and longer in open pit hard rock). Therefore although the data could potentially be reviewed every 13 min, interpretation required the geotechnical engineer to use judgment and temper increased rate of movement with increased rate of longwall retreat. Only increasing rates of movement during non-production time or extreme and accelerating rates of movement during steady production could be used as indicators. However, the ability to monitor the entire 500m wide and 100 m high highwall exposure and colour contour it, allowed identification of anomalous localised areas of movement and the triggering of additional protection measures against these.

Effect of Rockfall Mesh above the Portals

Punch longwall mining (accessing gateroads from the base of an open pit) increases the risk of mine inundation due to the low elevation and large catchment area. Therefore large levees are constructed around the open pit on the surface to protect from flooding from adjacent rivers and large sumps are constructed against the highwall between the headgate and tailgate portals to control rainfall in the local catchment of the pit. These sumps conveniently prevent exposure to the working area from rockfall hazards between headgate and tailgate however the portal areas remain exposed.

Due to the frequent access of men and materials through the portal entries under the 50m high highwall to the first catch bench, this portion of the wall is prepared with more stabilisation. The local highwall had been rehabilitated with rockbolts and then had rockfall mesh draped over it, to contain any local loose rocks from falling in the work area. In addition, substantial reinforced concrete portals are installed out to a distance of 15m from the highwall to allow covered access for men and materials and a 10 m exclusion is enforced adjacent to the portals themselves complete with a 2 m high rock bund to create a catch drain for any local rockfalls. This is standard for all punch longwall portal accesses and is independent of the results of this study.

Unfortunately due to the inability for the scanning to see through the draped mesh and the expansion and contraction of the wire mesh during day/night temperature changes, it made interpretation of wall movement in those local areas difficult to impossible (Figure 11) This was the case for both the GroundProbe SSR and the Maptek Sentry.

Figure 11: Effect of mesh draped over portals on radar and laser scanning monitoring
MECHANISM

In theorising the mechanism a review of typical longwall subsidence horizontal ground movement behaviour was undertaken, along with stream valley closure literature. When comparing this information with the full face movement results from the scanning, and looking at the behaviour in section. It was theorised that the forward movement of the highwall is primarily caused by the subsiding ground. It is proposed that as the strata lays down behind the longwall, a massive forward push of the ground occurs which is normally confined by hundreds of meters of solid ground, but in the case of being adjacent to an open cut void (or stream valley) shoves the bedded ground forward like a stacked deck of cards. With the maximum movement near the surface and decreasing downward due to leverage and frictional resistance from the weight of overburden and its proximity to the subsidence trough (Figure 12).

Figure 12: Geological section above the LW11 stopline relative to the highwall showing relative surface ground movement directions

Previous studies have been complicated by the difficulty in getting measurements and making observations, as well as the complex orientation of stream valleys to longwall layouts and mining direction. Figure 13, is taken from Hebblewhite (2001) which showed measurements of the same behaviour (away from the goaf) along the side of longwall panel subsidence and theorised the mechanism to potentially be horizontal stress, strong sandstones, gorge effect, vertical faults, or horizontal structure reactivation.

Figure 13: Measurement of horizontal ground movement away from the longwall goaf and toward the stream valley (Hebblewhite 2001)
There is evidence of another case study in Queensland where multiple pillars failed in a highwall mining scenario and rather than the highwall being pulled into the collapse, it was shoved out into the open cut with the same mechanism as proposed at Broadmeadow.

After properly measuring the magnitude of movement from longwall 9 a RocScience Phase 2 numerical model was built in an early study Clarkson (2016) to simulate the effect of longwall caving with the free face of the open cut excavation. Figure 13 shows the vectors of ground movement generated by the model which shows highwall movement away from the longwall. Although the model had difficulty simulating the effect of the push of the subsiding ground it did show movement of the ground away from the longwall and towards the highwall, albeit greater at the toe than the crest.

![Figure 14: Phase 2 numerical model attempting to simulate ground movement away from the longwall (Clarkson 2016)](image)

**DESIGN CONSIDERATIONS**

From an economic standpoint an underground planning engineer would seek to place the take-off position of the longwall as close to the highwall as possible. In the shallow depth of cover including a sloped bench scenario of punch longwall mining the width of the barrier pillar will never be limited by pillar stability. Design methods such as applying angle of draw from the crest of the highwall may be not be sufficient to account for highwall stability. While the global stability of the highwall was maintained at Broadmeadow, localised failures remobilising along joints or faults can be triggered. These may occur around pre-existing geological structures, cling-ons (material stuck on the wall over blastholes) or blast cracking. For LW11 movement was first observed with the longwall 300 m from the highwall toe, therefore if the longwall is to mine within 300 m of an open pit a number of controls should be considered:

- Feasibility studies should take advantage of technology to scan and map highwalls prior to planning portal locations and longwall stop positions to identify all potential structures that could be affected and specific controls put in place for those (or avoided).
- Catch benches and portal pads have space for adequate bunding against the slope toes to manage pit slope failures.
- Infrastructure placement on the highwall benches and pads allows for potential ground movement, where concrete portal entries are set further off the highwall.
- Cater for access and restricted access to catch benches.
- Ensure catch drains are accessible and regularly cleared to maintain capacity.

**CONCLUSIONS**
The punch longwall layout and the open cut slope stability monitoring technology provide a near perfect scenario for monitoring the effect of highwall movement due to an approaching longwall. The results in this paper add to the body of data that shows that longwall subsidence will push ground forward when adjacent to a void. Additional controls are required and can be very effective for working in close proximity to a highwall or void. Barrier pillar sizes in punch longwalls can be minimised with an understanding of the mechanism, appropriate design and controls.

ACKNOWLEDGEMENTS

The Authors would like to acknowledge BHP for allowing the publication of this paper. The views expressed in this paper are those of the authors and do not necessarily reflect those of the organisation. The assistance of Ross Branch and Andrew Johnstone from the BHP Geotechnical Group Who provided technical expertise with the Radar and Laser scanners and interpretation of the results. Also Jordan Herman from Maptek provided guidance with the laser scanner system and software as well as prepared figures and videos for this paper.

REFERENCES

Introduction to Longwall Mining and Subsidence, Mine Subsidence Engineering Consultants, August 2007