Subsidence Hazards and Mitigation Strategies on Minmi to Buchanan Section of the Hunter Expressway

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Summary

The Hunter Expressway Alliance has been commissioned by the Roads and Traffic Authority to design and construct a new dual carriageway motorway between the F3 at Minmi and Buchanan in the lower Hunter Valley. The route of the proposed motorway passes over an area where coal has been mined for over a century and further mining is proposed in the future. Subsidence movements associated with the sudden collapse of standing pillars and proposed future mining have potential to impact on some of the major bridge structures and sections of pavement. This paper presents an overview of the mining hazards identified and the various mitigation strategies that have been implemented to protect the project against these potential hazards.

1. Introduction

The Hunter Expressway is a new four lane dual carriageway motorway jointly funded by the Australian and New South Wales Governments and aimed to improve the current freight movement in the region and relieve congestion on the New England Highway. Figure 1 shows the route of the Hunter Expressway.

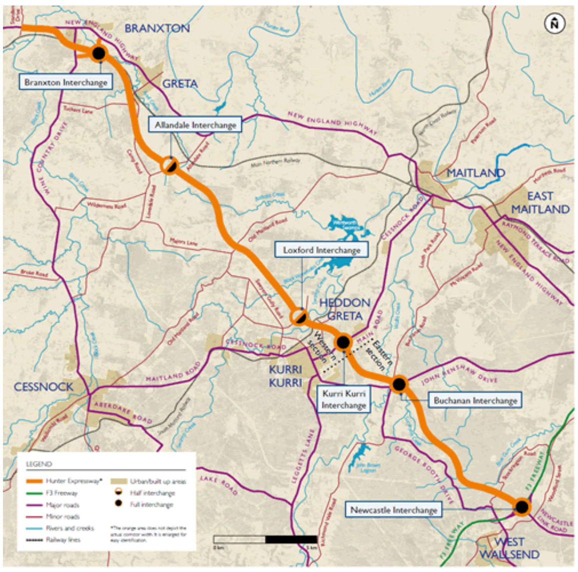

Figure 1: Route of the Hunter Expressway

The Hunter Expressway Alliance (HEA) is a consortium comprising constructors Thiess and designers Parsons Brinckerhoff and Hyder Consulting partnering with the NSW Roads and Traffic Authority (RTA) and is responsible for the delivery of the 13 km expressway section between Seahampton near the F3 Interchange and Kurri Kurri.

The expressway passes over an area where coal has been mined for over a century and further mining is proposed in the future as shown in Figure 2. The Alliance is constructing 28 bridges including 3 twin-bridge viaducts crossing valleys up to 50 m deep and 5 km of road pavement within the mined area.

Subsidence movements associated with the sudden collapse of standing pillars and proposed future mining have potential to impact on some of the major bridge structures and sections of pavement.

The strategies adopted for managing the subsidence risk include both mine fill and bridge design components. Abandoned mine voids, such as those shown in Figure 3,

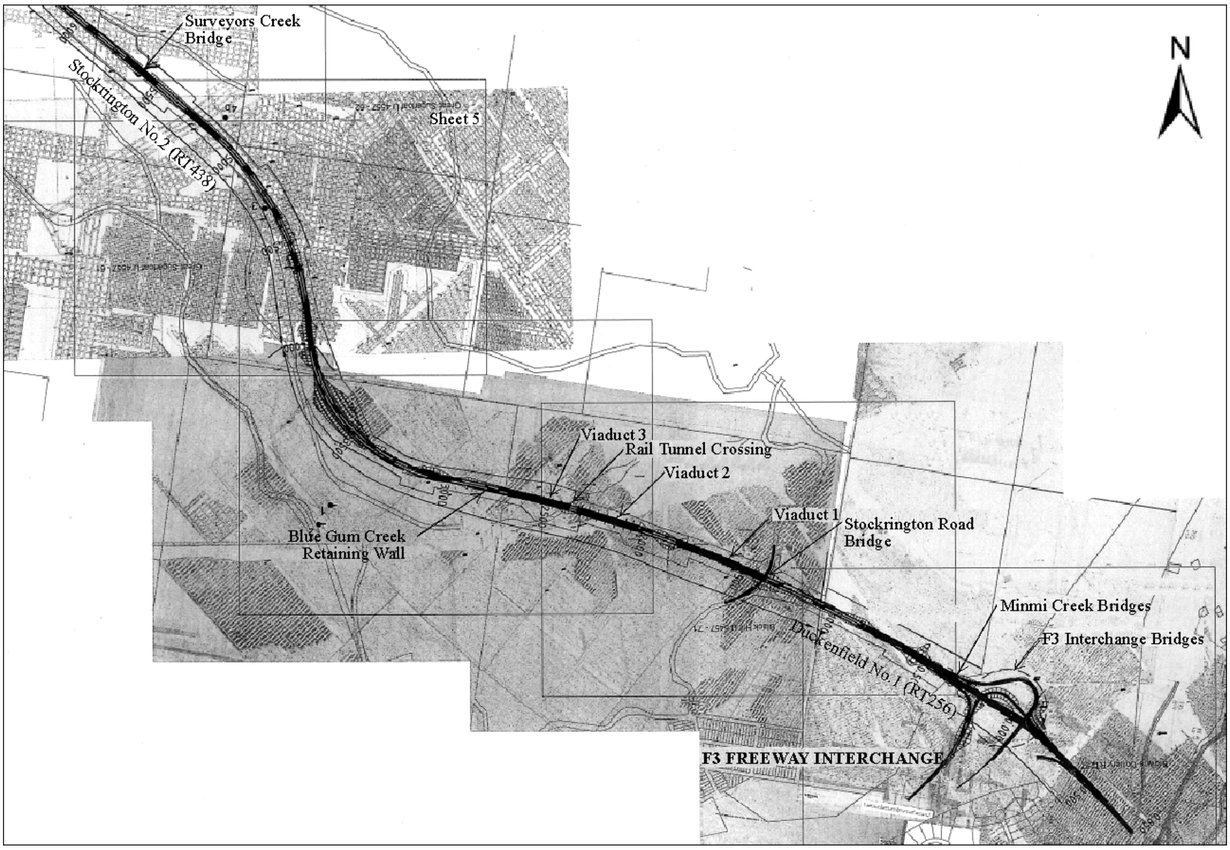

Figure 2: Abandoned coal mine workings below Hunter Expressway between the F3 Interchange and the Buchanan Interchange.

Figure 3: Mine workings in Borehole Seam near Viaduct 3 during filling operations

below the bridge structures are to be filled with cement stabilised fly ash to ensure ongoing pillar stability and limit vertical subsidence to low levels even if adjacent untreated areas of standing pillars become destabilised in the future. The bridge structures are designed to accommodate both the low levels of vertical subsidence that cannot be prevented by filling alone and the potentially much larger horizontal ground movements that are considered possible if adjacent areas of standing pillars were to collapse.

The bridge design strategy involves three levels of design: accommodating normal working loads as per normal bridge design, accommodating the maximum horizontal ground movements that could reasonably be expected to develop from adjacent pillar instability as a one off event using sacrificial elements that can be replaced without undue difficulty, and designing the structures so that larger than expected horizontal ground movements can be accommodated without any potential for catastrophic collapse.

2. Past Mining Activities

The eastern section of the expressway, from F3 interchange at Minmi, through Seahampton to the historical Burrumjim Dam at Blue Gum Creek, is underlain by a number of abandoned coal mine workings in the Young Wallsend Seam at approximately -10 m RL (Australian Height Datum) and the Borehole Seam at approximately -40 m RL. Record tracings indicate that the coal in Borehole Seam was mined by various Collieries in the early 1900s (Duckenfield No 1, Browns, Seaham No 1 and Stockrington No 2 Collieries). Mining in the Borehole Seam has progressed generally westward from the area below the F3 Interchange.

Mining methods for the early Borehole Seam mines were hand mining, generally of Welsh bords and some pillar extraction (Brunskill, 2010). The working heights are approximately 1.3 m in the Duckenfield No 1 Colliery and approximately 1.7 m in the Seaham No 1 Colliery. The Young Wallsend Seam was mined by Wallsend Borehole Colliery with mechanised mining systems (cutter, loader) and continuous miner operations including pillar extraction. Record tracings indicate the mining at the F3 interchange took place between 1984 and 1987 and progressed in the northward direction. The working section in the Young Wallsend Seam at Wallsend Borehole Colliery is nominally 2.4 m.

The section of the expressway between Skyline Ridge to Buchanan, from chainage 4000 to 6000, is located above the abandoned workings of Stockrington No 2 Colliery. This section of workings has been mined by relatively modern mining techniques. The pillars formed on development are typically square pillars at 30 m centres on development and subsequently extracted using continuous miners. The pillars formed on development are considered to be long-term stable with no potential for subsidence.

3. Subsidence Hazard

The subsidence hazard to infrastructure associated with the Hunter Expressway is the sudden collapse of small standing pillars in the workings causing subsidence at the ground surface. The consequences of any sudden collapse are likely to be significant with potential to render bridge structures located over or near any collapse zone unserviceable, possibly requiring their demolition and subsequent reconstruction. Damage to pavement and other roadside structures located over or close to the potential collapse zone is also probable in the event of a pillar collapse event. There might also be potential for loss of life depending on the timing, location, and final design of the pavement and roadside structures and any measures designed to mitigate the impacts.

3.1. Subsidence potential in Borehole Seam

The major subsidence hazard is associated with the standing pillars formed in the Duckenfield No 1 and Seaham No 1 Collieries from F3 Interchange to Blue Gum Creek as indicated on the record tracing. The status of these pillars remains uncertain, but available information indicates that large areas of small pillars are still standing and these pillars are considered to have potential to collapse suddenly in the future releasing their potential energy to cause vertical subsidence at the surface estimated to be in the range 0.5 m to 0.8 m with associated horizontal movements estimated to be up to 0.3 m in areas of steep topography.

In addition, record tracings indicate large areas of the workings in the Borehole Seam that are cross-hatched. This cross-hatching is interpreted as representing areas of pillar extraction. However, exploration drilling carried out to date indicates that some of these pillar areas have not collapsed and potential of future collapse remains. The uncertainty surrounding the status of the pillars as shown on record tracings makes prediction of potential subsidence difficult.

3.2. Subsidence potential in Young Wallsend Seam (YWS)

Record tracings from Wallsend Borehole Colliery indicate that the majority of pillars in the Young Wallsend Seam below the F3 interchange area were mined using a system of mining known as pillar pocketing. It was initially anticipated that the pillar extraction had caused full subsidence as fracturing encountered in the previous site investigation and cracks consistent with overburden fracturing above a goaf are apparent in the rock batters on the F3 immediately north of the interchange with the Newcastle Link Road. However, groundwater observations and camera inspections conducted during exploration drilling below the F3 Interchange indicate that there has not been any significant subsidence in the panel where the pillars have been pocketed. The implication of these observations is that the pillars are still standing despite evident collapse of the roof of individual roadways. This presents a hazard for the bridge structures particularly since additional subsidence in the Young Wallsend Seam can also be triggered by the future pillar collapse in the Borehole Seam below. Subsidence at the ground surface due to collapse in both seams is estimated to be up to 0.8 m.

3.3. Difficulties in estimating potential subsidence

The potential subsidence and subsidence profile is difficult to estimate for a pillar collapse scenario because such events are not normally monitored, so the database of experience of such subsidence is limited. For the Hunter Expressway Alliance, the estimated subsidence at the ground surface is based on the assumption that conventional subsidence parameters in a pillar collapse are similar to the subsidence parameters routinely measured above longwall mining operations with allowance made for the volume of coal that remains in the coal pillars after mining.

The likelihood of a pillar collapse is difficult to assess given the uncertainty surrounding the current status of the pillars, the condition of the adjacent underground roadways, and the potential for external factors to trigger pillar instability. The UNSW pillar design approach indicates that the probability of failure of the pillars in a typical panel is of the order of 1 in 1000, although the characteristic period for this probability is itself uncertain.

The likelihood of pillar collapse becomes further complicated when external subsidence trigger factors such as rising mine water levels, adjacent mining, earthquakes, and mine fires are considered. These factors are recognised as having potential to initiate pillar instability and subsidence. Some of these factors such as rising water levels are considered inevitable within the timeframe of the project.

4. Risk Mitigation Strategy

4.1. Treatment strategy

The mine subsidence treatment strategy was developed as an iterative process that involved consultation with all relevant stakeholders including the wider HEA design team (structures, drainage, geometry, utilities, pavements, environment), the RTA Peer Review team, and the NSW Mine Subsidence Board.

Given the uncertainty surrounding the long-term stability of standing pillars below the alignment, the design strategy adopted involved ensuring that the major structures are protected against any potential for ground movements that can reasonably be anticipated; particularly the major bridge structures including three viaducts that will stand as high as 35 m above the valley floor. This strategy involved mine filling works to reduce the magnitude of potential ground movements to levels that could be accommodated in the bridge designs.

Although the pavement and roadside infrastructure is also located in areas that may be impacted by mining subsidence, these impacts can generally be mitigated by adopting designs that can accommodate the ground movements while accepting some level of remediation after subsidence occurs so that mine filling along the full length of the alignment is not required.

Consequently, the risk mitigation strategy adopted differed depending on the project infrastructure; bridge structures and the mine void treatment were designed to accommodate or satisfy agreed subsidence parameters; whilst other infrastructure was designed to accommodate subsidence without loss of serviceability or be readily repairable without significant impact on the motorway serviceability.

4.2. Section Bridge structures

Australian Standard AS5100.2 – Bridge Design Part 2: Design Loads (Clause 19.2) requires bridge structures to be designed to cater for anticipated mining subsidence effects.

Mine subsidence resulting from the collapse of abandoned underground mine workings is expected to be a one-off effect that may occur over a period of minutes or hours. The effects may consist of vertical displacement, change in the slope of the ground, development of surface strains and horizontal movements.

To reduce the magnitude of the subsidence movements to levels that can be managed by the proposed bridge structures, the mine workings in the area below and immediately surrounding the bridge structures are being filled with a cement stabilised fly-ash grout prior to the commencement of construction.

The grout treatment is designed to fill the mine voids to a distance equal to or greater than 0.5 times overburden depth from each of the bridge piers and each abutment. Some residual subsidence is expected in the event of an adjacent pillar collapse as abutment load causes elastic compression of standing pillars within the treated area. The bridges have been constructed to accommodate a maximum of 25 mm of vertical subsidence at any given pier location.

Filling is not expected to eliminate the potential for horizontal subsidence movements caused as adjacent hillsides above untreated pillars subside. The magnitude of horizontal movement expected from an adjacent pillar collapse is mainly dependent on the surface topography. This magnitude is estimated at each of the various bridge structures based on the adjacent topography in the range of 50 mm to 300 mm.

The bridge structures are designed to accommodate these movements with serviceability and ultimate limit state factors of 1.0 and 1.2 respectively for the design mine subsidence displacements.

An envelope of maximum movements of the substructure relative to the deck at each support was prepared by combining the estimated movement vectors on both sides of the valley. This envelope was used to size pile sleeves, bearing sliding plates and expansion joints.

A key design feature for bridges where horizontal movements are predicted has been the incorporation of double-sleeved piles for footings that intersect the potential plane of horizontal shear movement. This plane is inferred to occur at a level close to the base of valley floor (nominally between 2 m above and 10 m below the base of the valley). The double-sleeving of piles provides an annulus of free space between the outer and inner sleeves to accommodate potential horizontal movements.

In the event that "larger than expected" horizontal movements are experienced, the bridge structures have been designed so that they do not collapse catastrophically even if the bridge is subsequently rendered unserviceable.

At the bridges where horizontal movements are predicted, provision for upsidence has also been made. Generally, the provision of double sleeved piles and pile cap void space, is sufficient to isolate piles from the uplift associated with upsidence.

In summary, the design philosophy for bridges subject to subsidence has been to provide a flexible structure with the foundations isolated from the horizontal ground movements, and with articulation designed to accommodate potential ground movements such that rehabilitation work is minimised.

The major viaduct structures will also incorporate monitoring to detect structural movements caused by any future mine subsidence.

4.3. Pavement

Pavement damage due to mine subsidence is expected to occur as a result of vertical subsidence, tilt, horizontal strains, and ground curvature.

Initially a continuously reinforced concrete pavement (CRCP) was prescribed for all pavement sections within mine subsidence areas. During the preliminary design phase, a desktop study was undertaken on previous mine subsidence cases to assess the responses of both CRCP and flexible pavements.

The salient conclusion from the HEA pavement design workshops was that pavements in areas with potential risk of mine subsidence would perform better if a flexible rather than a rigid pavement design was adopted.

It was also concluded that CRCP would not be able to withstand the compressive strains that are expected to be developed in subsided areas. If overloaded in compression, the CRCP is expected to fail by buckling and possibly stepping with high repair costs, a long repair period, and public safety implications.

Of the flexible pavement options, full-depth asphalt pavement is favoured ahead of deep-lift asphalt over cement stabilized or lean mix concrete sub-base because of the potential for stepping failure associated with cemented pavement layers.

The flexible pavement type has been recommended as the preferred pavement type for mine subsidence areas and the requirement for CRCP in areas where there is potential for mine subsidence has been amended accordingly.

4.4. Other Motorway Infrastructure

The potential for subsidence and potential magnitude of subsidence movements has been widely communicated within the HEA design team and design of all elements has been prepared with the knowledge of potential subsidence impacts. The response to potential subsidence movement has been to design elements that can accommodate subsidence or be readily repairable.

Most retaining structures are associated with bridges, and are substantially protected by the mine void filling in those areas. Those retaining walls not associated with bridges have been designed to be flexible and/or repairable.

Longitudinal and cross drainage systems have been designed to provide for a target minimum fall of 1% and pipelines are of rubber-ring joint construction to facilitate the accommodation of ground movements that may occur during a subsidence event.

5. Treatment Design and Specification

Mine void filling operations are being carried out from drill pads such as the one shown in Figure 4. The number of holes is determined by the layout of the mine voids, the accuracy of the existing mine plans, the success rate of hitting the mine voids, the presence of collapsed areas and the type of grouts used. The intention is to minimise drilling while meeting the requirement of filling the mine void treatment area.

Drilling depth will vary between 65 m and 140 m across the project. Borehole inclinations typically range from vertical up to 15° from vertical. Steeper inclinations can be drilled where required in order to minimise the number of pads and vegetation clearing.

A track mounted Atlas Copco L8 is used where the rock strata is intact and stable enough to allow the borehole to be drilled without the need for temporary steel casing. Air flush drilling with drag bits (without water or foam additives) is being used for overburden and weathered rock. Down-the-hole-hammer (DTHH) is being used when the rock is in good condition and stable holes can be formed. The diameter of the DTHH holes is 140 mm.

A track mounted Huette 205 is being used to drill the holes requiring simultaneous casing. This rig is also being used where improved drilling accuracy is required. The drill string comprises both an inner drill rod fitted with a PCD drag bit and an outer steel casing tube with casing shoe. The drill rods are rotated clockwise and the casing is rotated anticlockwise. Both inner and outer tubes are drilled into the ground simultaneously thus supporting any unstable rock before borehole collapse can occur. This twin wall drill string is relatively stiff and operates with a very small annulus between the string and the borehole wall. These factors combine to reduce borehole deviation. The simultaneous drilling system is used from surface to the base of the borehole. Water combined with compressed air is used as flushing medium during drilling. The borehole diameter is approximately140 mm to allow inclinometer and down-hole video camera to pass. Where casing is used, the internal diameter of the casing is 115 mm.

In order to minimise transfer of gases between the mine void and atmosphere, a short length of PVC pipe is installed at each borehole collar location. A 150 mm diameter PVC anti-static pipe is installed into the borehole and the annulus between the pipe and the ground grouted.

The mine fill scope of works involves supplying, mixing and placing a cement stabilised fly ash material into the mine voids below the Hunter Expressway corridor. The grout is a cementitious mix with the inclusion of appropriate bulking materials as required. The general grout requirements are as follows:

- The grout is to have a minimum compressive strength of 2 MPa for the barrier grout and 1 MPa for the infill grout at 28 days.

Figure 4: Production drilling with Huette 205 rigs at Viaduct 3 West

- The barrier grout mix is to be suitably workable and the infill grout mix shall be suitably flowable.

Each section of the treatment area is being validated using a combination of:

- Total grout take versus calculated grout volume at each location.
- Camera monitoring before and after grouting in relevant boreholes (grouted and adjacent holes).
- Camera monitoring in adjacent boreholes while grouting is carried out to monitor grout flow
- (Cored) boreholes to confirm that relevant areas have been grouted up. Cores are checked for grout take and fractures. The strength of the recovered grout is also confirmed.
- Geophysical and optical logging of the validation holes are also being used to confirm the effectiveness of the filling operations.

The number of validation core holes may be reduced as confidence in the filling process is gained. The location of the validation holes is based on construction records.

6. Treatment Implementation

Drilling started on 9 December 2010 at Viaduct 3 and was followed by first grouting one week later. Drilling commenced at the F3 Interchange in March 2011, with first grouting operations also one week later.

Grout was initially supplied using agitator trucks until the batch plant became operational on 8 February 2011. The batch plant is located between Viaduct 1 and 2. The infill mix is pumped through a fixed pipeline for up to 850 m to each drill pad and into the boreholes. Grout will be supplied to the F3 Interchange filling operation using agitator trucks until the second batch plant at the F3 Interchange is operational.

By early April 2011 more than 200 boreholes had been drilled with up to six drill rigs operating. At the end of the drilling operation it is expected, that some 2000 boreholes will have been drilled.

Approximately 13,000 m^3 of grout had been placed by the first week of April 2011, the majority at Viaduct 3. Grout injection rates have exceeded 500 m^3/ day at peak times.

Each borehole is surveyed and inspected by camera. Based on this monitoring the conditions of the mine voids and possible impacts on grouting operations are assessed and used to design the layout of further drilling and grouting operations. The underground conditions are compared to the available mine record tracings and the surveyed location is used to correct the mine map where necessary. In general the mine voids encountered have been within a few metres of their expected location.

The camera inspections of all the boreholes and during filling operations have been a vital part of the validation process.

7. Acknowledgements

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The views expressed in the paper are those of the authors and do not necessary reflect those of the supporting organisations.

8. References

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