

LANE COVE TUNNEL

COLLAPSE AND SUBSIDENCE

REPORT - 2 NOVEMBER 2005

Disclaimer

This publication contains information regarding occupational health, safety, injury management or workers compensation. It includes some of your obligations under the various workers compensation and occupational health and safety legislation that WorkCover NSW administers. To ensure you comply with your legal obligations you must refer to the appropriate Acts.

This publication may refer to WorkCover NSW administered legislation that has been amended or repealed. When reading this publication you should always refer to the latest laws. Information on the latest laws can be checked at www.legislation.nsw.gov.au or contact (02) 9238 0950 or 1800 463 955 (NSW country only).

© WorkCover NSW

**REPORT PURSUANT TO SECTION 88 OF
THE *OCCUPATIONAL HEALTH AND
SAFETY ACT 2000***

**LANE COVE TUNNEL COLLAPSE AND
SUBSIDENCE**

2 NOVEMBER 2005

27 March 2006

**WORKCOVER AUTHORITY
OF NEW SOUTH WALES
92 – 100 Donnison Street
Gosford NSW 2250**

The WorkCover Authority of New South Wales (WorkCover NSW) is a statutory corporation constituted pursuant to section 14 of the *Workplace Injury Management and Workers Compensation Act 1998*. WorkCover NSW serves the NSW Government and community in the areas of occupational health and safety, rehabilitation and workers compensation insurance. WorkCover NSW was established on 1 July 1989.

WorkCover NSW exercises various powers and authorities and has duties and functions under the legislative framework for occupational health and safety and workers compensation in NSW.

The functions of WorkCover NSW include

- Ensuring compliance with the workers compensation legislation and the occupational health and safety legislation;
- Responsibility for the day to day operational matters relating to the schemes to which any such legislation relates;
- Investigating workplace incidents; and
- Assisting in the provision of measures to deter and detect fraudulent workers compensation claims.

WorkCover's investigations into work place incidents are conducted under powers conferred by the *Occupational Health and Safety Act 2000*. Pursuant to Section 88 of the *Occupational Health and Safety Act 2000* the Minister may request WorkCover NSW to prepare a special report in relation to a work place incident which resulted in injury or death to persons or constituted a danger to persons.

Information about WorkCover NSW is available on its website, www.workcover.nsw.gov.au or from its offices at:

92 – 100 Donnison Street
Gosford NSW 2250

Locked Bag 2906
Lisarow NSW 2252

Telephone: +61 2 4321 5000

INDEX

	<i>Page</i>
EXECUTIVE SUMMARY	4
The Incident	4
Contributing Factors	4
PART 1 – INTRODUCTION	5
Appointment	5
Conduct of the Investigation	6
Background	6
Relevant Parties	7
Incident	7
Glossary	10
PART 2 – CIRCUMSTANCES OF THE INCIDENT	11
The Occurrence	11
PART 3 – POTENTIAL CAUSES OF THE INCIDENT	15
Geological Conditions	15
Large Span Width of Tunnel Intersection	16
Proximity of Tunnel Excavations to Ground Surface	17
Tunnel Roof Support Installations	18
Possible Exacerbating Factors	20
PART 4 – CONCLUSIONS	22
ATTACHMENTS	
Figure 1 – Composite Site Plan of MC5B/MCAA Intersection	
Figure 2 – Section S1	
Figure 3 – Geological Mapping Data at MC5B/MCAA Intersection	

EXECUTIVE SUMMARY

The incident

In the early hours of 2 November 2005 the roof area of a ventilation tunnel, being excavated as part of the construction of the Lane Cove Tunnel, collapsed. The four workers carrying out the excavation works within the tunnel evacuated without physical injury. The roof collapse caused the road above the area to subside and damage a three storey building in close proximity to the area of the subsidence.

Contributing Factors

Based on information reviewed to date, there appear to be at least (4) factors that are considered to have combined to cause the incident of 2 November 2005. These are:

- i) The geological conditions at the site
Relevant geological features include:
 - The presence of low strength shale in the crown of the tunnel at the incident location;
 - The presence of an igneous (doleritic) dyke intersecting the rock mass at the incident location; and
 - Significant fragmentation of the rock mass at the incident location.
- ii) The large span width of the tunnel intersection.
- iii) The proximity of the tunnel excavations to the ground surface.
- iv) The inadequacy of the tunnel roof support installations.

Factors i), ii) and iv) interacted to cause the collapse of the roof of the tunnel intersection excavation. Once active, the roof instability mechanism was able to propagate upwards and impact the overlying apartment block and road retaining wall, due to factor iii).

These contributing factors may have been exacerbated by changes in tunnel design, inappropriate construction sequencing and problems encountered in the installation of roof support elements.

The WorkCover NSW investigation is ongoing, therefore the findings within this special report are provisional.

PART 1 – INTRODUCTION

APPOINTMENT

- 1.1 This report is submitted at the direction of the Minister for Commerce.
- 1.2 On 2 November 2005 the Minister directed WorkCover NSW to provide a special report in relation to the Lane Cove Tunnel collapse and subsidence that occurred on 2 November 2005.
- 1.3 The Minister's direction is pursuant to section 88 of the *Occupational Health and Safety Act 2000* which provides:

88 Minister may require and publish special reports into incidents

(1) The Minister may direct WorkCover, or any department of the Government responsible to the Minister, to prepare a special report for the Minister with respect to:

(a) any incident that occurred at a place of work and that caused the death of or bodily injury to any person, or

(b) any incident at a place of work that constituted a danger to any person.

(2) The Minister may, if the Minister thinks fit, cause such a report or any part of such a report to be made public, whether by causing the report or part of the report to be published or otherwise. The Minister may table a copy of the report in Parliament.

(3) No liability is incurred by the State and no personal liability is incurred by, or by any person acting at the direction of, the Minister, WorkCover or a department of the Government in respect of anything done in good faith in connection with the preparation or making public of a report under this section.

(4) No liability is incurred by a person for publishing in good faith:

(a) a report made public under this section, or

(b) a fair report or summary of such a report.

(5) This section applies to a mine.

(6) In this section: "liability" includes liability in defamation. "the State" includes the Crown in right of the State and the Government of the State.

- 1.4 This report is provided pursuant to section 88(1)(b). It is a special report in relation to an incident at a place of work that constituted a danger to persons. At the time of the collapse there were four workers carrying out excavation works within the part of the tunnel where the collapse occurred. The collapse also caused instability to a nearby occupied apartment building. Whilst no persons suffered physical injury as a result of the collapse and subsidence, the collapse and subsidence constituted a danger to the persons working within the tunnel and to persons in the vicinity of the area.

CONDUCT OF THE INVESTIGATION

- 1.5 This section 88 report is based on the observations of WorkCover NSW inspectors who visited the site on the day of the incident and subsequently in the ensuing days and interviews conducted with relevant personnel from the tunnel constructors, designers, geotechnical and engineering specialists. The inspectors have also reviewed a large number of documents produced by the tunnel constructors that detail the progress of the construction. WorkCover NSW has also retained an external geotechnical engineering consultant, who has provided technical input and generally assisted in the preparation of this report.
- 1.6 It should be noted the investigation is still continuing to determine whether there have been any breaches of the Occupational Health and Safety Act 2000 and associated legislation. The investigating inspectors continue to interview relevant parties and have indicated they will need to reinterview certain witnesses in an effort to clarify some discrepancies identified. Given the investigation into the incident is ongoing, the views expressed within this report must be provisional.

BACKGROUND

- 1.7 The Roads and Traffic Authority engaged the Lane Cove Tunnel Company to design, construct, maintain and operate the Lane Cove Tunnel (LCT). The LCT and associated works are being constructed to link the M2 Motorway with the Gore Hill Freeway.
- 1.8 The Lane Cove Tunnel Company contracted Thiess John Holland Joint Venture to design and construct the tunnel and associated works. The construction of the LCT commenced in 2004 and is anticipated to be completed in 2007.
- 1.9 The main features of the project are:
- Twin 3.6 km tunnels linking the two arterial roads

- Widening the Lane Cove River Bridge
- A new interchange on the Pacific Highway at Artarmon
- Widening the Gore Hill Freeway
- Three new traffic ramps at Falcon Street, Neutral Bay
- A 7km continuous shared cycleway and pedestrian path between Naremburn and North Ryde
- Improvements to Epping Road, Lane Cove

RELEVANT PARTIES

1.10 The parties who are relevant in the terms of this report are:

- Thiess John Holland Joint Venture (**TJH**) who were the successful tenderers to design and construct the project.
- Parsons Brinckerhoff Australia Pty Ltd (**PB**) who were engaged by TJH to design the project.
- Pells Sullivan Meynink Pty Ltd (**PSM**) who provided geologists and geotechnical staff to assist both PB in the design stage and TJH in the construction phase. Staff was seconded to these two organisations at different stages of the project.
- Coffey Geosciences Pty Ltd (**CG**) also supplied geotechnical advice during the design stage.
- URS Australia Pty Ltd (**URS**), the Independent Verifier for the project.

INCIDENT

1.11 On Wednesday, 2 November 2005 TJH employees were carrying out excavation works at the junction of two tunnels, the Marden Street ventilation tunnel and the Pacific Highway exit ramp. At approximately 1:40 am a large section of the tunnel roof collapsed in the area underneath the Longueville Road off-ramp to the Pacific Highway at Lane Cove. The employees working within the tunnel evacuated the tunnel without suffering physical injury.

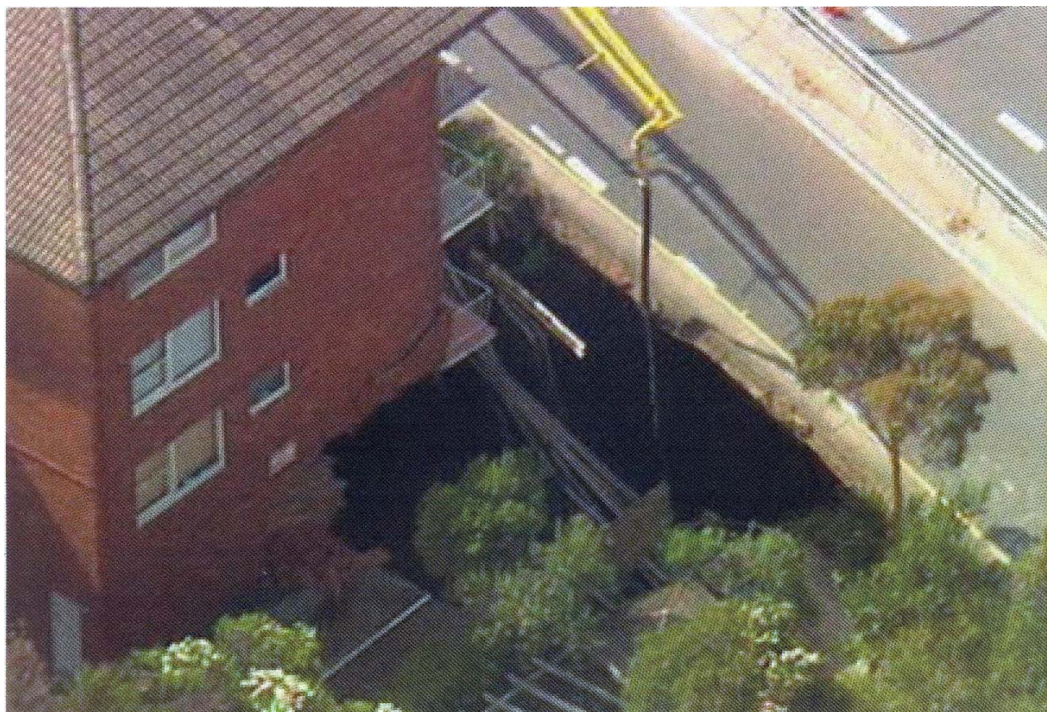
1.12 The collapse led to a significant ground subsidence that affected the stability of a block of home units situated at 11-13 Longueville Road, Lane Cove.¹ There were also concerns relating to a retaining wall that

¹ See Plates 1 and 2

supported the Pacific Highway off-ramp. The incident caused the off-ramp and Longueville Road to be closed and residents of the home units to be evacuated.



Damage to the unit block at 11-13 Longueville Road, Lane Cove **Plate 1**



Looking down on the south western corner of Kerslake Apartments, 11-13 Longueville Road, 2 November 2005 **Plate 2**

GLOSSARY OF TERMS

1.13 The following table explains some of the terms used in this report:

Acronym	Term	Description
	Bedding plane parting	A generally horizontal to subhorizontal fracture in a sedimentary rock sequence
CG	Coffey Geosciences Pty Ltd	Supplied geotechnical advice during the design stage
Ch or ch	Chainage	Location in metres of tunnel excavation from a set point
CS	Construction Sequence	Refers to minimum and maximum cycles of excavation and ground support to be installed as excavation advances
	CT Bolt or Rock Bolt	Support mechanism that is inserted and grouted in place to secure rock strata
	Dolerite	A medium grained basic igneous (volcanic) rock
	Dolerite Dyke	An igneous dyke comprised of dolerite
	Drive	Excavation
	Dyke	Igneous rock intrusion
	Engineering Geologist	Considers rock structure for the purpose of engineering projects.
	Geological Mapping	Recording of rock mass characteristics on a geological mapping sheet to assess adequacy of ground support types.
	Ground Classification	Refers to nature of geology in a location. Eg LCTG7 or G8 (Shale of low to very low strength).
SD	Ground Support Determination	A determination of tunnel support mechanisms based on the ground classification and

		geological mapping.
	Joint plane fractures	Inclined to steeply dipping or subvertical fractures in a rock mass (note: where two or more sets/families of joint plane fractures occur and they intersect orthogonally they can divide the rock mass into a series of columns, blocks or wedges).
LCT or LCTP	Lane Cove Tunnel (Project)	
MCAA		Pacific Highway Exit Ramp excavation. Location of incident.
MC5B		Marden Street ventilation tunnel.
PB	Parsons Brinckerhoff Australia Pty Ltd	Designers of the LCT project.
PSM	Pells Sullivan Meynink Pty Ltd	Provided Geologists to PB and TJH.
	Supported Ground	Area of tunnel excavation where support has been installed
	Road Header	Tunnel excavating plant comprising cutting heads & conveyor to clear cut rock away from face
	Shotcrete	Aerated, lightweight concrete that is sprayed on to wall and roof of tunnel
TJH	Thiess John Holland Joint Venture	Designers and constructors of LCTP
	Transition zone	The length of tunnel MC5B from chainage 185 to chainage 188.5

PART 2 – CIRCUMSTANCES OF THE INCIDENT

THE OCCURRENCE

- 2.1 The incident occurred at the junction of two tunnels: the Marden Street ventilation tunnel (referred to as MC5B) and the Pacific Highway exit ramp excavation (referred to as MCAA). Over the previous weeks, MC5B had been advancing towards the line of MCAA and reached the intersection point with MCAA around 17 October 2005. Once this point was reached, MCAA was excavated first to the east (referred to as the “up” or “upper drive”), and then to the west (referred to as the “back” or “down” drive). Work was continuing on this western excavation at the time of the collapse.²
- 2.2 On the evening prior to the incident, 1 November 2005, the tunnelling crew (crew B) commenced their shift at 1900 hours. The crew was comprised of four workers: the leading hand, the road header operator, the loader operator and the driver of the dump truck.
- 2.3 The crew on the preceding shift had made one cut (an advance of the tunnel face of 1.5 metres), shotcreted and had positioned the bolting machine for use once the shotcrete had cured. Crew B installed five four metre rock bolts and grouted them. They then washed down the grouting machine, moved the bolting machine into tunnel 5B out of the way, and repositioned the road header for another cut on the left hand side of MCAA down drive. The crew cut approximately one metre into the left side of MCAA down drive and had commenced loading out and “mucking out” spillage from the front of the road header when, at about 1:40am, the rock collapse commenced. The leading hand describes what happened:

I was standing on top of the road header next to the operators cab talking to the operator... We were just doing a bit of mucking out waiting for the shotcreters, ...and I noticed the whole roof, from the centre to right side of MCAA coming down as a whole mass and back towards us, and we were out of there. I can't remember from that point, when we turned around there was stuff falling on our lid and from that point I have a gap in my memory until I reached the truck. One comment from the truck driver was he heard a banging and crashing and got out of his cab, and saw the road header cab was almost completely covered.³

² See Figure 1

³ Statement, 17 January 2006

- 2.4 It appears that, once the fall commenced, it increased rapidly when it reached an area where a dolerite dyke was situated.⁴ The crew, under instructions from the leading hand, retreated from the area, back to the entrance of MC5B, which was then secured (taped off).
- 2.5 The shift boss, who was operating with another crew in tunnel MC1A East, was then notified of the incident and travelled to the scene of the collapse with the leading hand of crew B. After observing that the area was still unstable, the evacuation alarm was activated and all tunnels in the Marden Street area were evacuated.
- 2.6 At approximately 2:00am, a hole was observed off the exit ramp in front of the “Kerslake” apartment block (11-13 Longueville Road).⁵ It also appeared that the subsidence had fractured a water pipe, causing a substantial inrush of water into the collapse.
- 2.7 Once the tunnels were evacuated and all workers accounted for, management representatives, geologists and engineers were progressively contacted and requested to attend the site. Subsequently, inspections were carried out both underground at the scene of the collapse and on the surface. At approximately 2.30am the hole was observed to be about 4 or 5m diameter on the surface and had undermined approximately 1-2m under the road.
- 2.8 Staff considered that the collapsed debris required strengthening before any surface activity could occur.⁶ It was proposed to place large diameter hammered rock to form a bridging layer to lessen any pressure on the pile of collapsed debris. However, the need to remove an electrical sub-station and a dust scrubber from the area before the rock could be placed up against the debris pile delayed this action. This strategy was discarded as observation of the hole at appropriately 5:30am revealed the hole had expanded in size. At about 6:00am loud noises were heard to be coming from the hole and it was observed that a substantial secondary collapse had occurred under the existing Longueville Rd exit ramp and a number of piles with the collapsed area of the tunnel were observed to have been undermined by the collapse. The hole at that stage was observed to be around 8-9m diameter.

⁴ See Figure 1

⁵ See Figure 2

⁶ See Plate 3



Collapse debris in MC5B ventilation Tunnel, 3rd November 2005 **Plate 3**

- 2.9 It was at this stage that the decision was made by TJH to commence filling the hole with concrete to mitigate any further collapse. Concrete pumping commenced with one pump at approximately 8am. Two further concrete pumps arrived shortly after and also commenced pouring, the initial pour ceasing at around 3:00pm, having reached a height of 2 metres above the top of the pile. This amount of concrete had been determined as the maximum that could be placed initially without putting pressure on the exit ramp retaining wall. Longueville Road had been closed to traffic at approximately 6:45 am.
- 2.10 After waiting for the first lot of concrete to cure a second pour was commenced at approximately 9:30pm on 2 November 2005 and completed at around 12:30am the following morning. The third and final concrete pour, which was to reach the level of the top of the retaining wall, was commenced at 6:30am on 3 November 2005 and completed mid-morning.⁷ Over the next couple of days, grout was pumped into identified void areas around the collapse to complete the stabilisation works. In total, approximately 2750 cubic metres of concrete and grout was pumped into the collapsed area.

⁷ See Plate 3



Pacific Highway Off-Ramp and south western corner of Kerslake Apartments. Void backfilling with concrete 3rd November 2005 **Plate 4**

PART 3 – POTENTIAL CAUSES OF THE INCIDENT

3.1 Based on current investigations there are at least four (4) factors that are considered to have combined to cause the incident of 2 November 2005. These are:

- i) The geological conditions at the site
- ii) The large span width of the tunnel intersection
- iii) The proximity of the tunnel excavations to the ground surface
- iv) The inadequacy of the tunnel roof support installations.

Factors i), ii) and iv) interacted to cause the collapse of the roof of the tunnel intersection excavation. Once active, the roof instability mechanism was able to propagate upwards and impact the overlying apartment block and road retaining wall, due to factor iii).

The salient features of these causative factors are described below.

GEOLOGICAL CONDITIONS

a) Low Strength Shale

3.2 The bedrock at the site consists of Ashfield Shale. In the area of the MC5B/MCAA intersection, the bedrock in the crown of the tunnel has been documented by the Project Geologist as Ground Class LCTG7 and LCTG8, that is, shale of low to very low strength. Previous investigations and assessments in the area had also indicated that the strength of the shale further decreased closer to the ground surface, in turn passing up to residual soil and/or some overlying fill. This material thus comprised a low strength sequence, from the crown of the tunnel up to the surface infrastructure.

b) The Presence of the Dyke

3.3 The MC5B/MCAA intersection is transected in a southeast to northwest direction by an igneous (doleritic) dyke. The dyke comprises a subvertical, through-going intrusion, generally ranging in true thickness from between 600 and 700 mm. Dyke intersections had been encountered previously in MC5B as well as in the main line tunnels and the occurrence of the dyke in or near the MC5B/MCAA intersection was anticipated by site personnel.

3.4 In previous encounters the dyke was predominantly orange in colour, highly to extremely weathered and of low to very low strength. These conditions are understood to have prevailed through the MC5B/MCAA intersection. The dyke comprises a persistent low strength feature, both laterally and vertically, and its side boundaries constitute low strength defect planes.

c) Rock Mass Joints and Faults

3.5 Mapping documentation completed by the Project Geologist has confirmed that the rock mass into which the MC5B/MCAA intersection has been excavated is relatively highly fractured. The shale in this area is characterised by structures comprising bedding plane partings, joint plane defects and localised faults.

3.6 Bedding plane partings are subhorizontal to locally dipping defects of variable vertical spacing. They are intersected by inclined to subvertical joint plane fractures. Mapping has confirmed the presence of three (3) intersecting joint plane sets, one of which is parallel to the dyke, whilst the other two are both normal and more acutely angled to it. These subvertical fracture sets are locally continuous upwards and spaced as closely as 200 mm apart. They effectively divide the rock mass into a series of vertical columns, which can in turn be subdivided into blocks by intersecting with sub horizontal bedding planes.

3.7 The rock mass in the MC5B/MCAA intersection is further fractured by localised inclined fault structures that were mapped by the Project Geologist. In combination with the bedding plane partings and joint plane fractures described above, the localised faults have further fragmented the rock mass into variously shaped and sized blocks and wedges.⁸

LARGE SPAN WIDTH OF TUNNEL INTERSECTION

3.8 Both the ventilation tunnel (MC5B) and the Pacific Highway Exit Ramp (MCAA) are “Two Lane” tunnels within the Lane Cove Tunnel Project, with spans or widths of approximately 9 metres. At the intersection of the two tunnels however, the width of the underground opening is locally greater. The diagonal width of the MC5B/MCAA intersection is up to 22 m. This is a relatively large effective span width to support, particularly when the roof strata are comprised of low strength and fractured shale. Furthermore, the above described weathered and low strength dyke passes through the intersection as a zone of weakness, aligned closely with the line of maximum span.

⁸ See Figure 3

PROXIMITY OF TUNNEL EXCAVATIONS TO GROUND SURFACE

- 3.9 Having risen in a northerly direction so as to intersect the inclined Pacific Highway Exit Ramp, the crown of the ventilation tunnel at the MC5B/MCAA intersection is at RL 78.8 m, which is 13.3 m below the level of Longueville Road (RL 92.1 m) and in the order of 17 m below the existing Pacific Highway off-ramp and ground level at the western end of the Kerlake Apartments (\approx RL 95.8 m). The depth of cover between the surface and the crown of the intersection is less than the span of the intersection itself. As mentioned above in Section 3.2, the limited cover comprises low strength and fractured shale.
- 3.10 The MC5B/MCAA intersection is also overlain on its southern side by the Longueville Road retaining wall, which incorporates 750 mm diameter concrete piles with deep tie-back anchors. Available records indicate that the concrete piles at this location range in length from 6.4 m to 7.8 m and they extend to depths ranging from RL 88.5 to 88.0 m that is, 9.2 m to 9.7 m above the crown of the MC5B/MCAA intersection. The tie-back anchors however, were up to 18 m long and angled down at 50° below horizontal. These anchors extended to depths in the order of 2 m above the crown of the MC5B/MCAA intersection. Each anchor had been installed into a 125 mm diameter hole that had been over-drilled by 0.5 m, continuously flushed during drilling, reflushed and water tested, before being grouted. Some twenty eight (28) anchors are believed to have been installed into the low strength shale rock mass above the MC5B/MCAA intersection.
- 3.11 It is considered likely that the anchor drilling and installation processes would have locally disturbed and weakened the already low strength and fractured shale strata on the northern side of the retaining wall. The MC5B/MCAA intersection was subsequently excavated immediately beneath the wall anchors.

TUNNEL ROOF SUPPORT INSTALLATIONS

- 3.12 The roof support adopted at any tunnel location on the project is dependant on the assessed "Ground Classification", which in turn relates to a "Ground Support Determination". As mentioned above the assessed ground classes in the area of the MC5B/MCAA intersection were LCTG7, LCTG7/G8 and LCTG8. Early project documents relate a ground class of LCTG7 (for a 2 lane / 9 m tunnel width) to a support system comprising an array of 3 m long rock bolts on a 1250 mm spacing both ways, with an initial 50 mm lining of shotcrete and a second/final 75 mm lining of shotcrete. Ground class LCTG8 required Steel Sets or Lattice Girders, with an initial 75 mm lining of shotcrete and a final 200 mm lining.

- 3.13 The amount of rock bolts to be installed and the thickness of the shotcrete varies depending on the ground support determination (GSD) (based on the ground classification determined by the geologist) in the design documents. If the “as found” conditions vary significantly from what was expected, a “Request Further Information” form was referred back to the tunnel designers who would consider the new information and, if required, issue a revised set of drawings. Any design revisions would be submitted to the independent verifier for approval.
- 3.14 As the project advanced and poor ground conditions associated with low strength fractured shale and dyke intersections were encountered, the LCTG7 ground support system was upgraded to 4 m long rock bolts on 1000 mm x 1250 mm spacings with two (2) cyclic 100 mm applications of shotcrete (Mar VII Support Type). The original LCTG8 requirement for Steel Sets or Lattice Girders in poorer ground conditions however, was also modified, to a less conservative rock bolt and shotcrete application.
- 3.15 When the doleritic dyke was encountered in the MC5B drive in September 2005, geological predictions were that it would be encountered again in the vicinity of the intersection of MC5B and MCAA and a revised drawing for the intersection was issued. It is not clear, however, whether this new design was verified by URS prior to it being adopted for construction.
- 3.16 In the area of the MC5B/MCAA intersection, a modified Mar VII 4 m rock bolt and shotcrete support type was employed, with a supplementary 5 m long rock bolt pattern in the centre of the intersection including the southern and eastern transitions. Shotcrete was to be applied in two layers of 100mm. One layer prior to bolting and the second layer to be sprayed after the bolts had been installed. The shotcrete was to form a complete arch from floor to floor.
- 3.17 These were the roof support installations that subsequently failed during the incident of 2 November 2005. They comprised a staged support approach in what is understood to have been the following sequence:
- an initial application of 100 mm – 125 mm of shotcrete after face advance
 - the installation of 4 m long rock bolts on a 1m x 1m grid pattern
 - excavate remaining bench or benches as necessary
 - the installation of 5 m long rock bolts on a 1.5 m x 1.5 m grid pattern

- a final application of shotcrete to achieve a minimum total shotcrete thickness of 200 mm.
- 3.18 Beyond the transition zones, the modified Mar VII support type only was installed, that is, without the supplementary 5 m rock bolts. It is understood that the MCAA up drive had been installed with 4 m long rock bolts on a 1 m x 1 m grid pattern, with two shotcrete applications comprising a 125 mm thickness. It is understood that the MCAA down drive had been partially installed (on the northern side) with 4 m long rock bolts on a 1 m x 1 m grid pattern, with an initial application of shotcrete of unknown thickness.
- 3.19 Instructions and information about the method of excavation work to be carried out on the LCT project were provided to the crew by induction into Job Safety and Environment Analyses (JSEA). These JSEA included procedures for road header excavation, loader operation, dump truck operation, rock bolting, ventilation and the use of compressed air equipment. Directions on the sequence of construction in particular areas were issued in the form of site instructions that were communicated to the crews by the shift boss and/or leading hand. The site instructions were then usually affixed in the cabin of the road header.
- 3.20 The site instruction issued for the construction sequence in the intersection of MC5B and MCAA required the crew to cut a prescribed minimum distance (about 1-1.5 metres) and stop. The road header would then be pulled back and the newly excavated area shotcreted. The crew would then leave the shotcrete for approximately an hour for it to cure, and then install an amount of rock bolts as determined by the design documents. This process involves drilling a hole, inserting and tensioning the bolts and finally pumping in grout to complete the installation.
- 3.21 Although this support regime was generally considered to be robust by the design team, it was considered necessary to draw the constructor's attention to the need to have a geotechnical engineer monitor the "as found" ground conditions as construction progressed as the design may need to be reviewed or adapted. The geotechnical engineer and/or the geologist was also to direct the installation of spot bolts in the tunnel walls should that be considered necessary.
- 3.22 As mentioned above, instructions to the tunnelling crew were for a small cut of 1 - 1.5 metres and then completion of the full support regime before the next cut. Importantly, the support was to be installed to the full face of the advancing tunnel. Full implementation of the design was considered essential for it to be effective. The shotcrete role is significantly greater given the poor geological conditions as under those conditions the shotcrete can be expected to be directly loaded by the shale and is required to perform as a structural shell.

The sequence of application of the shotcrete and the completion of shotcrete in accordance with the design becomes of more significance than in more favourable ground conditions.

- 3.23 The above described support installations that had been implemented in the MC5B/MCAA intersection, failed during the incident of 2 November 2005. They were not capable of supporting the conditions encountered in and above the roof of the intersection, over the excavated span, as described above.

POSSIBLE EXACERBATING FACTORS

- 3.24 It appears in the hours leading up to the collapse the right hand side of MCAA down drive was excavated in advance of the left hand side. The distance of the advance varies according to witnesses, but it is agreed that this action precluded the installation of full face support of the tunnel as required by the design and would reduce the load capacity of the shotcrete already installed. The consequence of the incomplete ring of shotcrete on the left side would be to significantly reduce the load capacity of the shotcrete that had been installed. The other consequence of the non-square face advance would be to increase the span of the opening and this would inadvertently move the design beyond the anticipated geometry.
- 3.25 Some witnesses expressed concern that the existing shotcrete lining was “undercut”. This means that the excavation went through the shotcrete, removing its contact with the floor. The effect of this would reduce the load capacity of the shotcrete.
- 3.26 There has also been mention of the thickness of the shotcrete applied in the area in days preceding the collapse. One of the tunnel engineers states that he observed what appeared to be a thinner lining on the left hand side of MCAA less than 24 hours before the collapse.
- 3.27 An issue also arises in relation to the random nature of rock bolt testing in tunnels excavated in Ashfield shale. Rock bolt testing crews were required to test 10% of any new type of bolt and 5% of all production bolts in the tunnel system. However, there was nothing in the specification that prescribed the locations where the rock bolts were to be tested. The significance of this is that rock bolts were not tested in MC5B as ground conditions deteriorated.
- 3.28 There is also evidence of a higher incidence of rock bolt failure as ground conditions deteriorated. Drill bit diameters do not appear to have been in accordance with design specifications. The possible consequence of this was insufficient grout take and, linked with the random nature of rock bolt testing mentioned in 3.27, this may have exacerbated the risk of collapse.

PART 4 – CONCLUSIONS

- 4.1 The conditions that prevailed in the area of the MC5B/MCAA intersection, as described in Sections 3.1 to 3.11 above, singularly presented design challenges for the roof support of the intersection. In combination, the low strength shale, the presence of the dyke, the jointing and faulting in the rock mass, the large intersection span, and the relatively shallow depth of cover to surface structures, produced a complex and difficult environment in which to achieve suitably stable tunnel roof conditions.
- 4.2 An initial project design allowance had been made for the installation of steel sets or lattice girders to provide roof support in tunnel excavations characterised by poor shale ground conditions (Ground Class LCTG8). It is noted that the design documentation provided to Workcover NSW does not address support recommendations for the larger span intersections in tunnels where steel sets or girders could have been implemented. However, the ground support option of steel sets or girders for poor (LCTG8) ground conditions in shale, was superseded in tunnel MC5B and in the MC5B/MCAA intersection area, and replaced with a less conservative rock bolt and shotcrete support option. It is understood that an alternative rock bolt and shotcrete support system was provided by the project designers, in response to a request from TJH for a possible alternative to steel sets. The amended support system is described in Section 3.17 above.
- 4.3 The amended ground support system, as installed in the MC5B/MCAA intersection, failed on 2 November 2005, which resulted in the collapse of the roof of the excavation. It is understood from site personnel that the failure commenced near the northwestern corner of the intersection, with small blocks of shale and sheets of shotcrete falling progressively from the shoulder, crown and roof of the excavation. The “unravelling” of the fractured shale extended across to the dyke, which then collapsed in larger blocks. The failure intensified and extended rapidly across the intersection. The failure also propagated upwards and within minutes had manifested at the ground surface as a large hole in the Pacific Highway off-ramp, having undermined the Longueville Road retaining wall and the southwestern corner of the Kerslake Apartments at 11-13 Longueville Road.
- 4.4 The failure of the ground support system has two possible explanations, being:
- i) the design of the support system was inadequate and not capable of supporting the conditions that prevail in and above the crown of the MC5B/MCAA intersection,

or,

- ii) the support system was not installed in full accordance with the design requirements and associated technical specifications.

4.5 To be effective, the adopted roof support system needed to rely on the thorough installation, end-anchorage and full grout encapsulation of the rock bolts installed into shale. Reliance also needed to be placed on the application and curing of a full thickness of shotcrete over the crown and the walls of the excavation.

4.6 WorkCover NSW investigations to date have indicated that:

- The suitability of the geological conditions in and above the crown of the MC5B/MCAA intersection, to be stabilised by the adopted rock bolting strategy, was marginal.
- The rock bolts installed in the MC5B/MCAA intersection appear not to have all been installed to specification. Specifically, adequate drill hole diameter, bolt end-anchorage, and full grout encapsulation of rock bolt installations, was not universally achieved. The effectiveness of the adopted rock bolting strategy and hence the stability of the rock bolted roof, would therefore have been compromised.
- Specified face excavation advancement and the timely establishment of a suitably thick and cured shotcrete lining to the crown and walls of the excavation, were integral to the stabilisation of the MC5B/MCAA intersection. The details of these aspects leading up to the incident require to be further delineated and reviewed.

4.7 The above aspects of tunnel excavation and stabilisation at the incident site, are currently subject to further investigation through data review and personnel interview processes.



WorkCover NSW 92-100 Donnison Street Gosford NSW 2250
Locked Bag 2906 Lisarow NSW 2252 WorkCover Assistance Service **13 10 50**
Website www.workcover.nsw.gov.au

©Copyright WorkCover NSW 0406