Technical Paper

TP09: Evolution of Road Tunnels in Sydney

Advisory Committee on Tunnel Air Quality

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Key Points

The NSW Government has over 25 years of experience in assessing and operating road tunnels, including five tunnels in Sydney that have extensive ventilations systems and stacks.

There have been some important lessons learnt from the assessment, design and operation of these tunnels, including:

- The modelling and assessment processes for stack emissions are well established, robust and conservative.
- Emissions from well designed stacks have little if any impact on surrounding communities and, as such, there is little health benefit in installing filtration and air treatment systems.

There are a number of lessons that can be learnt from the construction and operation of the M5 East, Lane Cove and Cross City tunnels to enable future tunnel projects to have an efficient ventilation system:

- Minimising the gradient of the tunnel
- Locating ventilation stacks close to entry and exit points
- Designing entry and exit points to reduce congestion
- Increasing the clearance height and width of the tunnel.

Continuing research on international best practice has resulted in NSW implementing a nitrogen dioxide (NO_2) policy which requires tunnels to be designed and operated to achieve some of the most stringent in-tunnel air quality requirements in the world.

Contents

1. Introduction

Sydney currently has five long motorway tunnels with substantial ventilation systems incorporating ventilation stacks. They are (and year opened):

- Sydney Harbour Tunnel – 1992
- Eastern Distributor – 1999
- M5 East – 2001
- Cross City Tunnel – 2005
- Lane Cove Tunnel – 2007.

Several new tunnels are currently being considered or are under construction as part of the Sydney road network, including NorthConnex, the M4 East, M4-M5 Link, New M5, Western Harbour Tunnel, Beaches Link and the F6 Extension Stage 1.

Some community groups have expressed concern about major tunnel projects over the years partly due to the potential impacts on air quality. Successive NSW Governments have responded by subjecting these tunnels to detailed environmental assessment prior to approval and extensive monitoring of in-tunnel air quality during operation.

The effectiveness of ventilation stacks in dispersing emissions from the M5 East, Cross City and Lane Cove tunnels have been measured as part of project approval conditions which required extensive ambient air quality monitoring to ensure that residents in surrounding areas experience little, if any, increase in exposure to vehicle emissions.[1, 2, 3]

NSW Government agencies have over 25 years of experience in assessing, designing and operating these tunnels. Lessons have been learnt and applied along the way through both successes and mistakes. Agencies can draw on the experience from these tunnel projects, and similar examples from overseas, in the design and development of new tunnels.

This Paper highlights the key lessons learnt from the assessment, design and operation of ventilation systems to manage air quality in and around tunnels.

1 Holmes Air Sciences (2001). Eastern Distributor Motorway Monitoring Program, Validation of Monitoring Data.
2 Holmes Air Sciences (2008). Air Quality Validation Report, Cross City Motorway.
3 PAE Holmes (2009). Air Quality Validation Report: Lane Cove Tunnel.

2. Lessons Learnt

2.1 Tunnel ventilation system design

It is important that tunnels are designed and operated to deliver a good user experience to ensure community acceptance of road tunnels as an effective transport solution.

It is fair to say that, particularly in the first years after opening, the M5 East did not deliver a good user experience. In light of this, the Lane Cove and Cross City tunnels were designed to ensure that in-tunnel air quality met community expectations. In practice however, the Lane Cove and Cross City tunnel ventilation systems have proved to be over-designed.

The lessons learnt from the M5 East, Lane Cove and Cross City tunnels will enable future tunnel projects to design and operate efficient ventilation system that delivers a better user experience. These lessons are discussed below.

Minimising the gradient of the tunnel

The M5 East has a gradient of eight per cent at the exit of the westbound tunnel. The increase in gradient resulted from a late design change to facilitate the placement of tunnel spoil between Bexley Road and King Georges Road. This was to substantially reduce the number of truck movements on local roads during construction.

The unintended consequence of this change was that vehicles exiting the westbound tunnel are under significant load with multiple consequences for air emissions. Firstly, vehicle emissions per distance travelled significantly increase with increase in grade. This is especially the case for ladened heavy vehicles (e.g. trucks returning from Port Botany). Secondly, the steep grade slows down heavy vehicles which contribute to congestion throughout the westbound tunnel, further adding to vehicle emissions as compared to free flowing traffic. As a consequence of these outcomes, the Cross City and Lane Cove tunnels were designed to minimise gradients.

A key design requirement for all new road tunnel projects is to minimise grades to reduce emissions.

Locate ventilation stacks close to exit points

In order to address strong community concern regarding the location of the proposed three stacks for the M5 East, the ventilation system was redesigned to recirculate the tunnel air to a single stack 900 metres from the tunnel. The resultant design proved to be inefficient, using significantly more energy than equivalent tunnels operating with ventilation stacks located near the portals.

The most energy efficient and cost effective location for stacks is at or near to the tunnel portals. The reasons for this include:

- Fully uses the piston effect of traffic pushing air through the tunnel and avoids the use of additional energy to pull air though a service tunnel to a remote stack location.
- The stack can be built into the cut and cover structure of the portal. As such, an additional building for ventilation is not required (see *Technical Paper No. 4 – International practice for tunnel ventilation design*).

Designing entry and exit points to reduce congestion

Smoothing traffic flows at the entry and exit points avoids congestion, improves user experience by shortening the length of time in the tunnel and reducing vehicle emissions within the tunnel.

The Lane Cove Tunnel was built with two, two-lane entries and two, three-lane exits to facilitate smooth traffic flow within the tunnel.

Increasing the clearance height and width of the tunnel

Sydney's tunnels have traditionally been built with a tight cross-section to minimise construction costs and spoil generation. This has had two unintended consequences. The first is that the small cross section of the tunnel increases the friction for any given volume of air flowing through the tunnel compared with a larger cross section tunnel, limiting the amount of ventilation air generated by the traffic, and resulting in greater energy requirements for ventilation. Secondly, lower clearance height compared to the adjacent network results in a greater frequency of over-height truck incidents, resulting in tunnel closures and network congestion. Increasing the cross-sectional area of the tunnel will increase airflow under free flowing traffic conditions – improving in-tunnel air quality, reduce energy use and will also improve user experience by reducing the sense of confinement.

2.2 Predicting the impact of stacks

The predictive air quality modelling for tunnel stacks is robust and conservative. There is sufficient knowledge through monitoring and experience, demonstrated over 25 years across multiple road and industrial projects to tailor stack dispersion modelling for the specific characteristics of each project (see *Technical Paper No. 5 – Road tunnel stack emissions*).

2.3 Effectiveness of stacks in dispersing emissions

Discharging vehicle emissions via well designed stacks ensures the emissions are dispersed and diluted so that there is little if any on local ambient air quality.[4] Modelling and monitoring studies generally agree that the impacts of emissions from road tunnel stacks on their surrounding communities are mostly indistinguishable from the impacts from all other sources (principally surface traffic emissions, domestic and industrial emissions, and background contributions, including natural sources).[5]

2.4 Filtration and tunnel air treatment

Emissions from well designed road tunnel stacks have little if any impact on surrounding communities and, as such, there is little health benefit in installing tunnel filtration and air treatment systems in tunnels with well designed stacks. Numerous measures have been identified that are both cheaper and more effective at improving air quality than road tunnel filtration.

An 18 month trial of filtration of tunnel air was conducted in the westbound tunnel of the M5 East from March 2010 to September 2011. The filtration plant removed 200 kilograms of PM per year at a cost of $760,000 or $3,800,000 per tonne (operating costs only).[6] Based on the damage cost[7] for Sydney[8], the estimated annual health benefit of removing 200 kilograms of PM is $56,000 at 2011 prices. This comparison suggests that the operating cost of removing PM in the M5 East was around 13 times the health benefits.

4 NZ Transport Agency (2013). NZ Transport Agency – Guide to road tunnels. Retrieved from http://www.nzta.govt.nz/resources/guide-to-road-tunnels/

5 NHMRC (National Health and Medical Research Council) (2008). Air quality in and around traffic tunnels final report.

6 AMOG (2012). M5 East Tunnel Filtration Trial Evaluation Program – Review of Operational Performanc

7 Damage costs are a simple way to value changes in air pollution. They are estimates of the costs to society of the likely impacts of changes in emissions. Damage costs assume an average impact on an average population affected by changes in air quality. Damage costs consider the impacts of exposure to air pollution on health – both chronic mortality effects (which consider the loss of life years due to air pollution) and morbidity effects (which consider changes in the number of hospital admissions for respiratory or cardiovascular illness).

8 PAEHolmes (2013). Methodology for Valuing the Health Impacts of Changes in Particle Emissions. Retrieved from https://www.epa.nsw.gov.au/~/media/EPA/Corporate%20Site/resources/air/HealthPartEmiss.ashx

The then NSW Department of Environment Climate Change and Water (DECCW) engaged external experts to undertake a study to identify and analyse a range of emission abatement initiatives.[9] In the Sydney region, the report identified 12 emission-reduction measures which were over 10 times cheaper than tunnel filtration, with costs ranging from $1,000 per tonne to $274,000 per tonne of PM_{10} removed.

2.5 In-tunnel air quality criteria changes

Since the inception of road tunnel projects in Sydney, ventilation design requirements have been set around specific air quality criteria to protect the safety and health of tunnel users. In the past, the carbon monoxide (CO) criterion has been used to provide protection against all other motor vehicle pollutants, such as NO_2 and visibility.

However, over time, emissions of NO_2 have increased in relative importance when setting in-tunnel air quality criteria due to:

- emission standards for CO from new petrol cars reducing much more than emission standards for NO_x
- the increasing number of diesel cars on the road and emitting significantly more NO_2 and less CO than petrol cars.

Consequently, there is relatively more NO_2 compared with CO in tunnel air than was previously the case.

This change is recognised around the world and has led many bodies to consider or implement in-tunnel NO_2 criteria. The NSW Government has now adopted an In-Tunnel Air Quality (Nitrogen Dioxide) Policy which requires tunnels to be designed and operated to achieve some of the most stringent in-tunnel air quality requirements in the world.

More information is available in *Technical Paper No. 07 – Criteria for in-tunnel and ambient air quality*.

9 Sinclair Knight Merz [SKM] (2010) Cost Abatement Curves for Air Emission Reduction Actions.

3. Current Projects

Several new tunnel projects are being considered, or have recently been approved, as part of the Sydney main road network. Figure 1 is a schematic representation of the location of existing, under-construction and planned tunnels in Sydney.

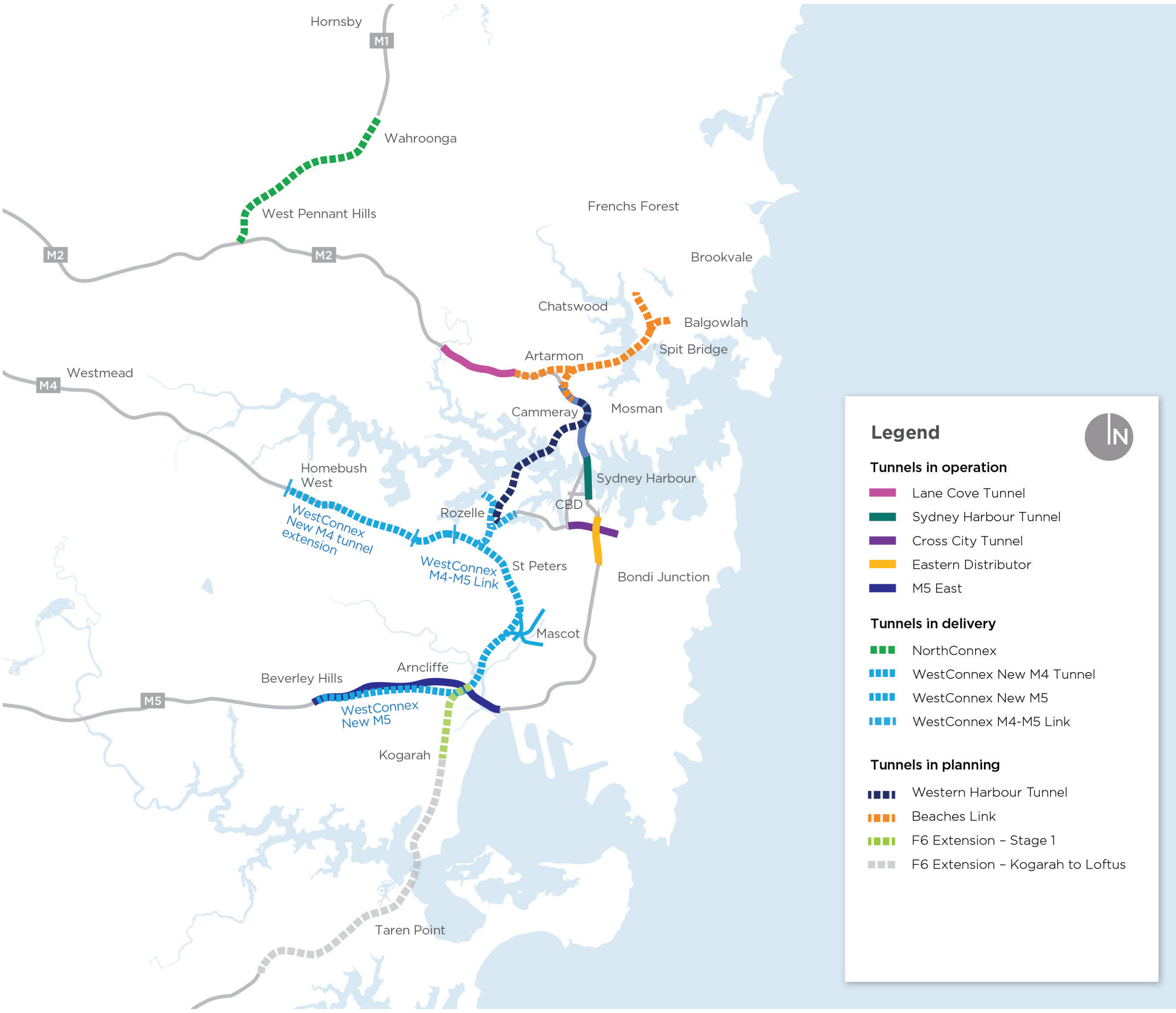

Figure 1: Existing, under-construction and planned tunnels in Sydney

3.1 NorthConnex

NorthConnex is a nine kilometre tunnel that will link the M1 Pacific Motorway at Wahroonga to the Hills M2 Motorway at West Pennant Hills, removing around 5,000 trucks off Pennant Hills Road daily.

The tunnel motorway includes interchanges to the north and south to accommodate connections at either end of the project. When complete in 2019, it will link Sydney's north to the orbital network and enable travel from Newcastle (M1) to Melbourne without a single set of traffic lights. For more information, visit the NorthConnex website http://northconnex.com.au/

NorthConnex will have a ventilation outlet at the Southern and Northern interchanges. The interchanges have been designed to integrate with the existing urban environment.

3.2 WestConnex

WestConnex is part of an integrated transport plan. The M4-M5 Link, M4 East and New M5 are part of the WestConnex project. For more information visit the WestConnex website at https://www.westconnex.com.au/

Figure 2: WestConnex and Sydney Gateway

M4-M5 Link

The project involves tunnels connecting to the M4 East project at Haberfield and the New M5 at St Peters via Rozelle. The M4-M5 Link project includes an interchange at Rozelle with provision for a future connection to the Western Harbour Tunnel and Beaches Link. It also includes an underground tunnel from the Rozelle Interchange to Victoria Road near Iron Cove Bridge, known as the 'Iron Cove Link'.

The interchange at Rozelle will be mostly underground and located at the site of the old Rozelle Rail Yards. By building the interchange mostly underground, the project will deliver new active transport options in Rozelle and up to 10 hectares of new green space. The M4-M5 Link will also provide an additional 2.5 hectares of green space in St Peters. The project was approved in April 2018. Construction is planned to start in 2019.

M4 East

The M4 East project is about 6.5 kilometres long (with 5.5 kilometres of tunnels).The project will connect to the widened M4 Motorway and extend it via twin motorway tunnels from Homebush to Haberfield with three lanes in each direction. The M4 East will alleviate the congestion on Parramatta Road that motorists face daily when they come off the M4 Motorway. The M4 East received planning approval in February 2016 and work started in March 2016.

New M5

The New M5 duplicates the M5 East from King Georges Road Interchange Upgrade at Beverly Hills to a new interchange at St Peters.

The New M5 will provide twin underground motorway tunnels, nine kilometres long, from Kingsgrove to the St Peters Interchange at the site of the old Alexandria landfill facility. It will also include underground connection points for the M4-M5 Link and the proposed F6 extension Stage 1. The New M5 tunnels will be marked for two lanes in each direction, with capacity to add a third.

The St Peters Interchange will provide motorists with connections to Alexandria and Mascot. It will also include a connection to the future Sydney Gateway. The proposed Sydney Gateway will feature a seamless, high capacity road link between the St Peters Interchange, Sydney Airport and towards Port Botany.

Local streets and intersections around the St Peters interchange are also being upgraded to ensure safe and efficient connections for the New M5.

3.3 F6 Extension Stage 1

F6 Extension Stage 1 is a proposed four kilometre continuous twin tunnel connecting with the New M5, 75 metres underground, passing under Rockdale to an interchange at President Avenue, Kogarah. The F6 Extension Stage 1 will be designed with a provision for a future extension south.

3.4 Western Harbour Tunnel

The Western Harbour Tunnel will connect to WestConnex at the Rozelle Interchange, cross under Sydney Harbour between the Birchgrove and Waverton areas and connect with the Warringah Freeway at North Sydney.

As part of the project, the Warringah Freeway Upgrade will make the road safer and more efficient.

3.5 Beaches Link

Beaches Link is a tunnel which will connect to the Warringah Freeway, cross under Middle Harbour connecting with the Burnt Bridge Creek Deviation at Balgowlah and the Wakehurst Parkway. The Wakehurst Parkway will be upgraded to two lanes each way between Seaforth and Frenchs Forest.

The project will also offer new ‘east-west’ connectivity with links to the Lane Cove Tunnel and the M2 Motorway via a Gore Hill Freeway Connection.

4. References

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