Electrostatic precipitators and ventilation in road tunnels in Japan

Report of a visit by a delegation from the NSW Roads and Traffic Authority to Japan from 30 September – 10 October 2003

February 2004

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Introduction

This report summarises the observations and conclusions of a delegation comprising members of the Roads and Traffic Authority of NSW (RTA) and Baulderstone Hornibrook Pty Ltd that visited Japan from 30 September to 10 October 2003 to investigate current and emerging technology and practices relating to ventilation of road tunnels.

The visit was ordered by the NSW Minister for Roads and formed part of the RTA's ongoing efforts to stay abreast of international developments in road tunnel ventilation. This work coincides with the most intense period of road tunnel development in Sydney's history. After the opening of the Sydney Harbour Tunnel in August 1992, four tunnels have opened since 1999 or are under construction and two more tunnels are currently being considered. Sydney's major completed and planned road tunnels are:

- The Sydney Harbour Tunnel: 2.3km. Opened August 1992.
- The Eastern Distributor: 1.7 km. Opened December 1999.
- The M5 East: long tunnel – 4 km, short tunnel – 900 metres. Opened December 2001.
- The Cross City Tunnel: 2.1km. Construction commenced 2003, due to open 2005.
- Lane Cove Tunnel: 3.6 km. Preliminary work commenced January 2004, due to open 2007.
- Sydney Orbital to F3 link: Tunnel options are being considered as part of a Federal Government study into a possible road link between the M2 and F3 motorways.
- M4 East: Overview report with two tunnel options (3.6km and 6.6 km) released December 2003.

Air quality planning approval conditions for the construction of road tunnels in Sydney continue to be among the most stringent in the world and Sydney's road tunnels continue to meet these environmental standards. However, the RTA has an ongoing program to monitor and investigate developments in tunnel ventilation, including development of electrostatic precipitators (ESPs), technology that uses electrically charged 'plates' to filter particles in road tunnels. Road tunnels in Australia, including major metropolitan tunnels in Sydney, Melbourne and Perth, have all been built without ESPs.

Norway and Japan are the acknowledged world leaders in the construction and operation of road tunnels. Both countries are also involved in the development of ESPs. The RTA visited Norway to investigate road tunnel ventilation in September 2001. The visit concluded that the development of ESPs was a complex area that was the subject of ongoing research and investigation, and that the status of the work did not warrant the installation of ESPs in Sydney road tunnels. A copy of a document arising from the visit, jointly signed by representatives of the RTA and the Norwegian Public Roads Administration, is at Attachment A.

Overview of Japan visit

The 2003 delegation to Japan comprised three members of the RTA and two representatives of Baulderstone Hornibrook, the constructor and operator of the M5 East tunnel and part of the consortium building and to operate the Cross City Tunnel. The delegation:

- Met senior representatives of key Japanese road authorities and research bodies.
- Held discussions with manufacturers of ESPs and other ventilation equipment, and visited their premises.
- Visited six major road tunnels.
- Inspected a trial of experimental equipment aimed at reducing nitrogen dioxide (NO_2) in road tunnels.

The delegation held discussions with representatives of:

- The Japan Highway Public Corporation (JH)
- The Metropolitan Expressway Public Corporation (MEX)
- The Public Works Research Institute
- The Advanced Construction Technology Centre (ACTEC)
- The Ministry of Land, Infrastructure and Transport (MLIT)
- Matsushita Electric Co Ltd
- Mitsubishi Heavy Industries
- Kawasaki Heavy Industries

The delegation visited the following tunnels:

- Kan'etsu Tunnel
- Tokyo Bay Aqua Line Tunnel
- Nishi-Shinjuku Line of the Central Circular Route
- Asukayama Tunnel
- Tennozan Tunnel
- Kanmon Tunnel

Publications on tunnels visited by the delegation are at Attachment B.

The delegation also visited the Keihinjima Ventilation Station, an experimental plant trialling equipment to reduce NO_2 in road tunnels.

Overview of roads and road tunnels in Japan

Japan has more than 1 million kilometres of road. This includes almost 7000 kilometres of national expressways and almost 54,000 kilometres of national highways. The mountainous geography of Japan means tunnels play a major role in providing road links between communities. Japanese road authorities report there are 8000 road tunnels in Japan, with a total length of about 2500 kilometres.

Japanese road tunnels range from very short tunnels requiring no mechanical ventilation to the 11-kilometre Kan'etsu tunnel, which connects Tokyo with Nigata to the north west. Most Japanese road tunnels are in rural areas.

No single agency oversees the construction and operation of road tunnels in Japan. The two biggest organisations with a role in this work are the Japan Highway Public Corporation (JH) and the Metropolitan Expressway Public Corporation (MEX). JH has been operating national expressways and toll roads on behalf of the Japanese Government since 1956. MEX is responsible for major highways in Tokyo and has operated since 1959. Overview documents on JH and MEX are at Attachment C.

Diesel-powered heavy vehicles comprise a higher percentage of vehicles using road tunnels in Japan than in Australia. This can be as high as 30 per cent of vehicles in Tokyo and 50 per cent of vehicles in rural areas.

Regulatory/approval process for motorways in Japan

Plans for Japanese motorways, including tunnels, are developed to coordinate with the improvement plans of local government. The views of local residents are considered before the local government makes planning decisions.

Environmental assessment of tunnels is conducted in accordance with the Environmental Impact Assessment Law and the regulations of local government. Approval for construction is provided by the Minister of Land, Infrastructure and Transport. The Minister is required to confer with the Minister of Finance and relevant local road authorities, and obtain the approval from the local assembly, before giving approval to a project.

No specific environmental standards are set for motorways or road tunnels in Japan. Rather, they are required to meet general environmental standards set by the Japanese Government. The delegation was advised that in 1999 only 20 per cent of motorways met environmental standards.

The development and approval processes for motorways in Japan are shown in the JH and MEX documents at Attachment C.

Air quality in Japan

Ambient air

Japan is a densely populated, heavily industrialised country with poorer air quality than Australia. Extensive areas of the major cities are covered by thick photochemical smog and, in some areas, brown haze, primarily from motor vehicles and industry.

Measures by the Japanese Government to address ambient air quality include tough new laws requiring a reduction in particulate matter and NO_2 emissions from vehicles. Under the new laws, vehicles that do not comply with the standards will need to be replaced or be fitted with particle filters. It is estimated that about 2.2 million trucks, 300,000 buses and 1 million diesel powered cars will need to be replaced over several years.

While introduction of the laws nationally has been postponed by up to two and a half years, the Tokyo Metropolitan Government and three adjoining prefectures applied the new standards on 1 October 2003.

Despite these tougher vehicle standards than those that apply in Australia, monitoring of air quality around road tunnels in Japan is much less stringent. Tunnel operators are not required to monitor air quality or report breaches of air quality standards. Measuring ambient air quality remains the role of local municipal authorities. Japanese road authorities and ESP manufacturers could not provide the delegation any results from monitoring of air quality around tunnels.

In-tunnel air

Carbon monoxide (CO) and visibility levels inside road tunnels are generally monitored by tunnel operators.

The specified limit for CO in Japan is 100 parts per million (ppm). This compares with the stricter 87ppm averaged over a 15-minute exposure in the M5 East and an even tougher limit, 50ppm averaged over a 30-minute exposure, for the Cross City Tunnel.

The specified visibility limits for road tunnels in Japan are comparable to design standards for tunnels in Sydney. The delegation was advised that many tunnels in Japan operate at or near visibility limits, whereas Australian tunnels generally operate well within visibility limits.

History of ventilation of Japanese road tunnels

Mechanical ventilation of road tunnels was first used in Japan in 1958 in the Kanmon Tunnel (3.4km). Initially, tunnels had transverse ventilation. In an effort to reduce costs, Japanese tunnel designers adopted a semi-transverse ventilation system for the Tennozan Tunnel (1.4km) in 1963 and subsequently moved to longitudinal ventilation using jet fans. However, in longer tunnels air speed initially prevented the use of longitudinal ventilation, with the first tube of the Enasan Tunnel (8.4km, 1975) and the Sasago Tunnel (4.4km, 1963) both using transverse ventilation.

Work to develop ESPs to remove particles from tunnel air began in Japan to address poor visibility in tunnels. ESPs were installed for the first time anywhere in the world in the Tsuruga Tunnel (2.1km) in 1979.

The development of ESPs extended the range of longitudinal ventilation. The first long tunnel combining longitudinal ventilation and ESPs was the Kan'etsu Tunnel (11km) in 1985. The Kan'etsu Tunnel, still the longest road tunnel in Japan, combines longitudinal ventilation using intake and exhaust shafts and ESPs in bypass passages. (The Kan'etsu Tunnel was originally a single tunnel with two-way traffic. A second tube was opened in 1991, providing two one-way tunnels with two lanes each.)

A paper describing the development of ventilation of road tunnels in Japan, provided by the JH, is at Attachment D.

ESPs in road tunnels in Japan

More ESPs have been installed in road tunnels in Japan than in any other country. At the time of the RTA delegation visit to Norway, ESPs had been installed in seven of about 930 Norwegian tunnels. In comparison, ESPs have now been installed in about 40 of the 8000 road tunnels in Japan. Most Japanese road tunnels with ESPs are in rural areas.

It has long been difficult to compile a definitive list of Japanese road tunnels with ESPs, partly because no single agency monitors tunnel operation and partly because of confusion caused by variations in names. However, at the request of the delegation, a table was compiled by ACTEC and was revised in conjunction with other Japanese authorities. The table, compiled after the delegation visit and forwarded on 19 December 2003, is at Attachment E.

Road authorities in Japan advised that there is no fixed policy on the installation and use of ESPs, but that tunnels are considered on a case by case basis.

The authorities all indicated that ESPs are generally installed to address in-tunnel visibility, without consideration of air quality outside the tunnel. Inside long rural tunnels, visibility limits are approached well before pollutant gas limits. The authorities reported that installation of ESPs at intermediate points was more economical than ventilation shafts through mountains over the tunnels.

JH rejected claims in Australia that Japanese policy dictates that ESPs are installed in all tunnels over two kilometres long. Confusion appears to have arisen over a JH policy that installation of ESPs is only considered for tunnels over this length.

For most Japanese road tunnels with ESPs, the ESPs are located in bypass passages. This involves part of the air in the tunnel being diverted into the bypass passages to be treated by ESPs. A generic layout of this form of ESP installation can be seen on page 27 of the JH document at Attachment D; the layout for the Kan'etsu Tunnel can be seen in the document on the tunnel at Attachment B.

Despite the primary use of ESPs for visibility reasons in Japanese road tunnels, there are seven tunnels where ESPs are used to reduce particulate emissions into the external environment.

The technology was used in this way for the first time for the Karasuyama Expressway, a covered viaduct, where ESPs were installed in the exhaust ports of the expressway. ESPs also have been installed in the base of ventilation stacks in six tunnels: Tennozan (2km), Kanmon (3.5km), Asukayama (0.6km), Midoribashi (3.4km), Hanazonobashi and Hasumiya.

In each case where ESPs have been installed in ventilation stacks, the reason given was that they were installed to limit particulate emissions in response to community concerns, but without support by technical assessment, dispersion modelling or any air quality monitoring at nearby receptors. MEX advised the delegation that the decision to install ESPs in the comparatively short Asukayama tunnel was 'an experiment'.

ESPs do not automatically operate 24 hours a day in Japanese road tunnels. For example:

- In the Kan’etsu Tunnel, ESPs operate on average 143 hours a month (about 20 per cent of total hours) in the northbound tunnel and 40 hours a month (about 3 per cent of total hours) in the southbound tunnel.
- In the Tokyo Bay Aqua Line Tunnel, the ESPs operate only 12-13 hours a year (about 0.15 per cent of total hours).

No Japanese road authority gave health concerns as a reason for installation of ESPs. Reinforcing the focus on ESPs being used for visibility purposes, the JH document on ventilation in tunnels refers to CO (which is not treated by ESPs) as being harmful to human health but says ‘soot’ (which is treated by ESPs) is ‘detrimental to the visual environment.’

Fabric (‘bag’) filters are in use in 14 tunnels, including installation as recently as the Tokyo Bay Aqua Line Tunnel, opened in 1997. However, as this equipment has been found to only filter about 20 per cent of total particulates, it is understood that its use is being discontinued.

ESP manufacturers

The two major manufacturers of ESPs in Japan are Matsushita Electric Co Ltd and Mitsubishi Heavy Industries. Both are very major corporations: Matsushita is the owner of the Panasonic brand of electrical equipment and Mitsubishi is a corporate giant involved in the manufacture of motor vehicles and heavy equipment.

The delegation visited and held talks with key executive and technical representatives of both Matsushita and Mitsubishi. This included a visit to the Matsushita head office and factory in Nagoya and visits to the Mitsubishi headquarters in Tokyo and the company's massive Takasago Research and Development Centre in Kobe. At each company, the delegation inspected manufacture and testing of the latest generation of ESPs. Representatives of Matsushita also visited Sydney in December 2003, including holding discussions with the RTA.

Matsushita traditionally has been the leader in the manufacture and installation of ESPs in Japan. It has been involved in the activity for 25 years and has installed ESPs in more than 20 tunnels. Mitsubishi has been active in the area over the past five years and has installed ESPs in three tunnels. Mitsubishi has pioneered development of ESPs using spiked plate ionisers and claims that this provides better performance and easier maintenance than traditional ESP ionisers.

Both Matsushita and Mitsubishi claim efficiency of at least 80 per cent removal of particles for their ESPs. While this is guaranteed by the companies, it is based on laboratory data and the performance has not been measured in an operating tunnel.

Research by both companies has targeted improvement of particle collection efficiency and an increase in air speed through the ESPs. The companies report that testing has shown that for air speeds of up to 9 metres/sec an efficiency of 90 per cent can be achieved. ESPs have been developed and installed (Asukayama Tunnel) that can operate at speeds of up to 13 metres/sec. At this speed, however, the efficiency drops back to just over 80 per cent.

Documents providing information about the road tunnel activities of Matsushita and Mitsubishi are at Attachment F.

Nitrogen dioxide experiment

Oxides of nitrogen are gases containing nitrogen and oxygen. They occur naturally in the environment and are also produced by high temperature combustion of fuel in vehicle engines and power plants. Nitrogen dioxide (NO_2) is considered to be the only oxide of nitrogen associated with health concerns.

A report by NSW Health in July 2003 noted that there are no appropriate guidelines for exposure to NO_2 in road tunnels. The report recommended that NSW government agencies with a role in the management of road tunnels investigate international advances in this area.

The delegation visited an experiment that has been underway in Japan under the auspices of MLIT since April 2002 to trial removal of NO_2 from motorway tunnels. The experiment, which is being conducted at the Keihinjima Ventilation Station in Tokyo, involves parallel tests with air first passing through an ESP and then denitrification equipment.

One test involves removing NO_2 by absorption using Matsushita equipment. The NO_2 is absorbed into an alkaline material. The other, using equipment manufactured by Kawasaki Heavy Industries, involves attracting NO_2 to the surface of a metal oxide adsorbent.

The delegation was advised the experiment was producing promising results. It was indicated that the Nishi-Shinjuku Line of the Central Circular Route had been tentatively identified for installation of the NO_2 equipment, but that no final decision had been taken and funding had not yet been provided.

Publications on the NO_2 experiment are at Attachment G.

Findings

- Japan is a world leader in road tunnel construction and operation, with 8000 tunnels totalling more than 2500 kilometres in length.
- Most Japanese road tunnels are in rural areas. They generally have lower traffic volumes than tunnels in Sydney, but have higher percentages of heavy vehicles.
- The relatively high level of diesel heavy vehicles provides visibility problems worse than in Sydney.
- No specific environmental standards are set for Japanese road tunnels. Tunnels are required to meet general standards set by the Japanese Government.
- No monitoring of air quality around road tunnels in Japan is conducted by tunnel operators and no external reporting of the environmental performance of tunnels is required.
- Electrostatic precipitators (ESPs) have been used in Japanese road tunnels since 1979 and now operate in about 40 tunnels.
- There is no fixed policy on installation of ESPs, but tunnels are considered on a case by case basis.
- While there is no policy mandating ESPs in tunnels over 2 kilometres long, ESPs are generally only considered for tunnels over 2 kilometres long.
- Most ESPs are in rural tunnels; few are in urban tunnels.
- Most ESPs have been installed to improve in-tunnel visibility in long tunnels, where visibility limits are reached well before carbon monoxide limits. It has been found to be more economical to treat air with ESPs at intermediate points to improve visibility rather than build additional deep ventilation shafts through mountains above the tunnels.
- Seven tunnels include ESPs aimed at improving external air quality. These ESPs have been installed to address community concerns, without support by technical assessment or air quality measurements. No monitoring data is available to indicate the impact of the ESPs on external air quality.
- Ventilation stacks continue to be used in conjunction with urban road tunnels in Japan.
- The quality of ESPs being manufactured in Japan appears to be more technologically advanced than those previously inspected by the RTA in Norway.
- An experiment aimed at removing nitrogen dioxide (NO_2) from road tunnels has operated since April 2002 and is producing promising results.

Discussion

Road tunnels in Australia continue to operate in line with environmental standards and planning approval conditions without installation of ESPs.

In Sydney, the Sydney Harbour Tunnel and Eastern Distributor tunnel operate without public debate or calls for modifications. Despite controversy over the operation of the main M5 East tunnel, independent reports by NSW Health confirm air quality in the tunnel is within World Health Organisation guidelines and that air external quality has not deteriorated since the tunnel opened.

The decision by the RTA not to install ESPs in Sydney road tunnels is in line with practice in Western Australia and Victoria, the decision in the latter following an independent enquiry by now Federal Court Judge Bernard Bongiorno.

Existing tunnels meet air quality planning approval conditions without ESPs. Planned tunnels appear likely to do the same. However, the RTA continues to seek improvements in tunnel performance and has repeatedly expressed a preparedness to consider installing ESPs if and when the technology develops sufficiently to indicate tangible, cost-effective benefits are likely.

ESP technology appears to be more advanced in Japan than in Norway. The two companies currently principally involved in development of ESPs in Japan – Matsushita Electric Co Ltd and Mitsubishi Heavy Industries – are both sophisticated major corporations. Both are investing significant resources in the development of ESP technology.

In addition, the NO_2 trial being conducted in Japan by the Ministry of Land, Infrastructure and Transport provides a significant technological step forward in an area already identified in Sydney for further study.

The delegation believes it is open to the RTA to conclude that air-cleaning technology associated with ESPs and NO_2 removal has advanced sufficiently to warrant consideration of a pilot of the technology in conjunction with an existing or new road tunnel in Sydney.

Both Norwegian and Japanese road authorities plan and install ESPs on a case-by-case basis. This is considered the appropriate approach to adopt in Sydney.

Existing tunnels present challenges for a pilot of ESPs. While provision already has been made for retrofitting ESPs into the ventilation stacks of the M5 East tunnel, the Cross City Tunnel and the Lane Cove Tunnel, Japanese practice indicates a clear preference for ESPs in bypass passages to improve in-tunnel visibility rather than in stacks.

In relation to the M5 East, construction of bypass passages for ESPs in a tunnel already completed and carrying a high number of vehicles would be complex. While the Cross City Tunnel and Lane Cove Tunnel have not yet been completed, the approved design and private sector financing arrangements do not currently accommodate construction changes such as bypass passages to house ESPs or NO_2 removal technology. It is also the case that the inclusion of separate ventilation tunnels in the Cross City Tunnel and Lane Cove Tunnel, and the predicted lower levels of heavy vehicles for these tunnels, might not rank them as priority tunnels for an ESP pilot.

There would be some logistical advantages in considering incorporating ESPs and NO_2 removal technology for a pilot in a new tunnel, where bypass passages and ESPs could be included in the design submitted for planning approval. However, it is uncertain when a pilot of this nature could occur because the timeframes are still unclear for construction of an M4 East tunnel or a tunnel to link the M2 with the F3.

Given the complex nature of the issues involved, further work is required to determine the best way of undertaking a trial of ESPs in Sydney. This would involve further interaction with manufacturers of ESPs, including possibly an international expression of interest process.

Recommendations

The delegation recommends that:

1. The RTA considers a pilot in a Sydney road tunnel of the latest generation of electrostatic precipitators (ESPs).

2. The RTA further investigates the emerging technology in Japan to remove nitrogen dioxide (NO_2) from road tunnels and considers incorporating the technology in any pilot of ESPs in Sydney.

3. If recommendations 1 and 2 are accepted, a process be established to reach a considered decision on the best way to pilot ESPs in Sydney.

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Index to Attachments

A Road Tunnel Ventilation in Norway

B Publications on tunnels visited by the delegation to Japan

C Japan Highway Public Corporation – General Information 2002
Metropolitan Expressway Public Corporation 2003

D Ventilation in Japanese road tunnels (Japan Highway Public Corporation)

E Road Tunnels with Dust Collectors in Japan

F Panasonic – Road Tunnel System
Panasonic – Tunnel/Road Environment Control System
Mitsubishi – Environmental Pollution Control System

G Experimental Plant for NO_2 Denitrification by Chemical Absorption Process – Matsushita Electric Industrial Co Ltd
Removal System by Adsorption Process from Road Tunnel Ventilation Air – Kawasaki Heavy Industries Ltd