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Influence of Road Enclosure Structures on Ventilation

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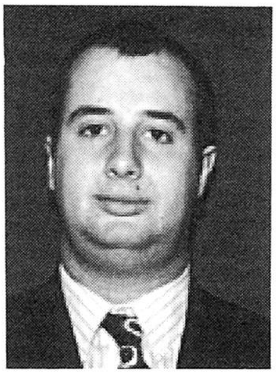

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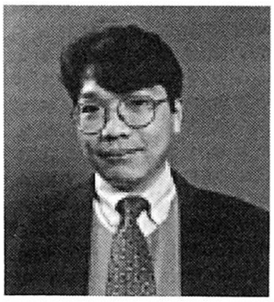

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Summary

It is perceived that road enclosures offer a cheaper alternative to conventional tunnels as a means of environmental impact mitigation. Ventilation is required within road enclosures, for dilution of vehicle emission products and to allow control of smoke in the event of a fire incident. This paper examines the influence of road enclosure structural design on the effectiveness of the ventilation. The implications of using existing tunnel standards are also reviewed.

1. Introduction

There are already a range of measures available for mitigating the environmental impact of road schemes. Examples include the provision of environmental barriers, noise reducing surfacing, landscaping and planting. Whilst these are all effective in their own right, in areas of severe impact they may not be adequate. A road enclosure provides an alternative method of mitigation.

A road enclosure is here defined as an enclosure or covering formed over a road for the purpose of mitigating the environmental impact of the highway. The enclosure is likely to be of a lightweight form of construction, commensurate with its required acoustic performance, although it may incorporate relatively "heavy" main structural members.

A road enclosure has also been called a surface tunnel. However, the use of the word 'tunnel' is not considered appropriate, since the enclosure is likely to incorporate some or all of the following features:

- openings on the roof to allow natural ventilation.
- transparent panels to allow natural light to illuminate the road.
- access to the outside through doors in the walls.

The potential use of road enclosures does not restrict to any one road cross-section. Their application to different width roads from single carriageways to dual 3 or 4 lane motorways has been considered by designers in Europe. Varying road elevations, such as embankment, cutting, at grade, retained cutting or retained embankment, will also need to be considered in their design.

A further variable is the level of the road within the enclosure relative to the ground level outside. Where they are at the same level, the enclosure, apart from its foundations, will be fully above ground, and lightweight forms of construction can be employed. However, as the road level within the enclosure becomes lower than the adjacent ground level, the walls are likely to be of a heavier construction, since they must withstand horizontal earth pressures. Eventually, a point is reached where the walls will be fully buried and its roof will be at or just below ground level. A lightweight roof, perhaps sustaining some planting, can still be provided. This will be taken as the limiting arrangement to be considered, since any further burying of the enclosure will require a solid roof, which in effect creates a tunnel.

2. Road Enclosures in Europe

The main purpose of road enclosures in Europe is to mitigate noise pollution, but in some cases they also mitigate vehicle emissions and visual intrusion.

Road enclosures are becoming widely used in Germany where there is a very stringent daytime noise emission target. This cannot be achieved alongside motorways unless an enclosure is constructed, and as a result several are being planned. The road enclosures that have been built to date are only on more minor roads.

Examples are the Züblin type road enclosure, a partially buried concrete structure with open roof slots in Stuttgart and a proposed at grade structure with a glazed roof in Cologne, Germany. A glass roofed structure in Switzerland with cladding designed to match surrounding buildings is in operation and from France an open sided concrete framed structure has been constructed on the outskirts of Paris.

3. Ventilation

Ventilation is required for two main reasons within road enclosures;

1. dilution of pollution products from the vehicles and;
2. control of smoke in the event of a fire incident.

Enough fresh air must be supplied to the tunnel to reduce toxic exhaust products to below safe exposure limits and maintain visibility at acceptable levels. The important pollutants are CO and nitrogen oxides which are toxic, and particulates from diesel vehicles which reduce the visibility.

In a fire incident the ventilation system must be capable of controlling the smoke to allow safe evacuation of tunnel users. It should also be capable of maintaining a clear area for fire fighting operations to be undertaken.

3.1 Design Considerations

It is current tunnel ventilation practice in the UK that the longest tunnel without mechanical ventilation should be 300m and that there should be line of sight through the tunnel. The length can be extended to 400m where the traffic flow is not frequently congested. It is unclear if this maximum length is related to the requirements for pollution control or for smoke control in the event of a fire.

3.2 Pollution

The major pollutants generated by traffic in tunnels are CO, nitrogen oxides and particulates from diesel vehicles. The UK Department of Transport draft Design Guidelines for Planning, Equipping and Operating Tunnels on Motorways and Other Trunk Roads, states that the major pollutant to consider is CO. Specifically if the level of CO is below the desired limit then the levels of other pollutants will be well within safe margins. However, the visibility in the tunnel should also be considered due to the increase in the numbers of diesel vehicles in recent years.

The UK Health & Safety Executive (HSE) safety exposure limits for CO are 300 ppm for short term exposure and 50 ppm for long term exposure. The Department of Transport draft Design Guidelines for Planning, Equipping and Operating Tunnels on Motorways and Other Trunk Roads suggests that a 250 ppm limit on CO is sufficient in most British tunnels as traffic is in the tunnel for less than 2 minutes and 250 ppm is significantly less than the HSE short term exposure. However, if the traffic is likely to stop in the tunnel, and this includes in the even of an incident which stops the traffic, the limit must be reduced. The PIARC document from 1987 suggests that 100 ppm CO be used as the design limit for tunnels where the traffic may be expected to be stationary.

3.3 Smoke Control

In the event of a fire incident the smoke from the fire should be controlled to allow safety evacuation of tunnel users. In a conventional tunnel, smoke is generally forced in one direction to keep the upwind direction clear for evacuation. Provided a method of maintaining a clear escape route can be found, however, it is not essential to have the smoke forced into one direction. It is possible using fully transverse ventilation to extract the smoke at source. It may also be possible to allow smoke egress with natural ventilation openings close to the fire source utilising the natural buoyancy of the smoke.

3.4 Running and Maintenance Costs

In road enclosures, a design requirement which strongly influences the choice of ventilation system is that the running and maintenance costs of the road enclosure should be kept as low as possible. This leads towards there being no mechanical ventilation in road enclosures and therefore natural ventilation schemes are preferred.

4. Natural Ventilation

Natural ventilation relies upon the movement of air by moving traffic or on the buoyancy of pollutants and combustion products to ventilate the tunnel. To achieve sufficient natural ventilation a number of ventilation arrangements can be proposed. The key advantage of natural ventilation through louvred openings is to obviate the need for mechanical ventilation, so reducing operating and maintenance costs compared with a conventional tunnel. However, a disadvantage of louvred openings is that they allow the escape of some noise and pollution. Also, louvred openings allow the escape of smoke in the event of a fire when compared with a conventional tunnel. However, risk of flammable spills inside the enclosure could lead to explosions and fire.

4.1 Parallel Slots

Construction of slots parallel to the longitudinal axis of the tunnel, illustrated in figure 1, would allow air exchange, between the tunnel air and the open environment, along the length of the tunnel. In the moving traffic case the pressure generated by the flowing traffic would induce air exchange through the slots, thus diluting the pollutants.

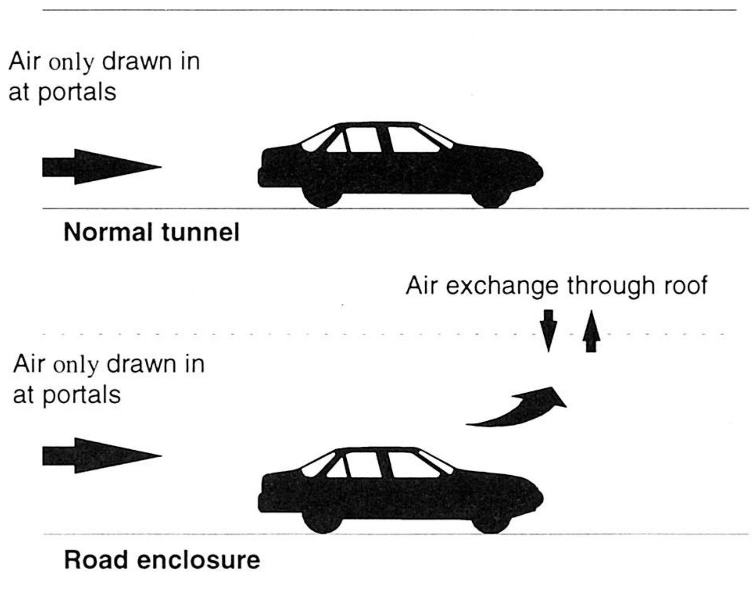

Fig 1 Air exchange through slots parallel to the longitudinal axis of the tunnel

In the event of stationary traffic the buoyancy of the pollutants would drive the pollutants through the slots. A parallel slot system has been employed in Germany. It has been demonstrated from experiments in the German tunnel, which involved stationary traffic and the portals being blocked, that the pollution levels did not become a problem, suggesting that this arrangement works sufficiently well for stationary traffic.

In the event of a fire the system would work in a similar manner as a natural smoke ventilation scheme used in large buildings. Installation of downstands (smoke curtains) in the tunnel roof would contain the smoke above a defined area, reducing the hazard range, and the natural buoyancy of the smoke would keep a clear area below for escape. The smoke would be retained within the reservoir, between the downstands, as a substantial amount would flow through the slots. The slot size should be between 3% and 15% of the roof area as used within large buildings. The slots must also be at the highest point in the surface tunnel to enable the smoke to flow out.

4.2 Perpendicular Openings

Another possible arrangement is to provide openings perpendicular to the longitudinal direction of the tunnel, illustrated in figure 2. By including contractions and expansions at the openings pressure could be induced by moving traffic which would drive flow through the openings.

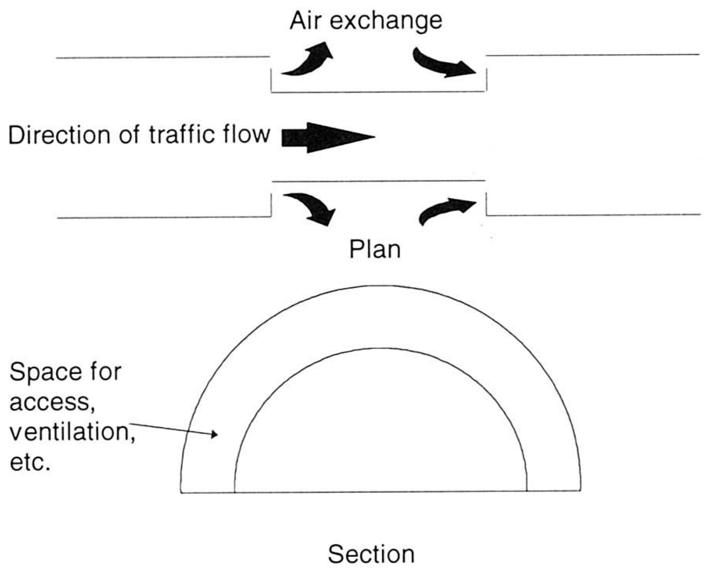

Fig 2 Air exchange through slots perpendicular to the longitudinal axis of the tunnel

In stationary traffic this scheme would not work as well as parallel slots because the openings are not arranged efficiently for the low buoyancy exhaust gases. Also, as the openings are at discrete locations the pollution must travel some distance to them which will allow it to cool and lose buoyancy. Therefore it is likely that this scheme would be suitable for use where stationary traffic would not be frequent except in an incident. Other measures could be used to ensure that in stationary traffic engines were switched off to reduce pollution levels.

In a fire incident the sections between contractions and expansions could be utilised as smoke reservoirs to collect the smoke and allow the smoke to escape through the associated openings.

4.3 Maximum Road Enclosure Length

Using the schemes outlined above it should be possible to extend the length of the road enclosure without forced ventilation from the usually accepted 300m. This extended length has been investigated using simple tunnel ventilation models. However, as the origin of the 300m maximum length is unknown the calculation of the possible extension is difficult.

Pollution levels in tunnels depend upon the traffic flow and the tunnel geometry. Calculations performed for a congested traffic flow situation in a hypothetical motorway tunnel demonstrated that with no ventilation the pollutant levels did not exceed the design criterion of 100 ppm of CO for tunnel lengths up to 900m. By allowing 5% of the roof open, as slots parallel to the longitudinal direction of the tunnel, it seemed possible that the tunnel length could be doubled. However, using the simple modelling techniques available for this study the extension in length is not certain. In particular using this simple model there is an apparent exit portal effect which increases the pollutant concentrations close to the exit portal. Further investigation of the flow regime in the exit portal area would need to be carried out for specific designs.

The finding that the pollutants did not exceed the limit for tunnel lengths up to 900m implies that a conventional tunnel, with a construction the same as that modelled, could be extended to 900m, if pollution is the only consideration. Similarly, by allowing 5% of the roof to be open in the form of a continuous slot, a road enclosure could be built to a length of 1800m, assuming the same arrangement as the hypothetical case.

The results of tunnel extension outlined above only cover the specific example modelled, i.e. a hypothetical motorway tunnel with congested traffic flow. It should be noted that other arrangements not considered may give differing results. It is clear therefore that due to the nature of road enclosure design, each road enclosure should be considered on its own merits.

5. Conclusions

The main findings of the study into the ventilation of proposed road enclosures tunnels are:

- Natural ventilation appears to be a viable option for road enclosures.

- The use of a prescriptive maximum length may not be helpful in the innovative design of the road enclosure solution. Demonstration of the ability of the ventilation system, under expected operating conditions, to maintain pollution levels below acceptable limits and control smoke in the event of a fire may be a better approach to innovative design.

- Consideration should be given to each road enclosure using advanced ventilation modelling techniques which can take account of the complex geometry including slot configuration, such as scaled model experiments or computational fluid dynamics computer modelling, to determine ventilation performance.

- In the event of a fire it is acceptable practice within large buildings to use natural ventilation for smoke control in association with smoke curtains and reservoirs. Due to the nature of road enclosures with stationary traffic it is possible to consider best practice employed in large building design as a guide to the control of smoke in road enclosures.