The Tugun Bypass viewed from the northern interchange at Currumbin, QLD

Fire & Life Safety Design Considerations for the Tugun Bypass Tunnel

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The design fire size for a road tunnel has far-reaching implications on the design and costs associated with the tunnel structure and the fire and life safety systems. This article highlights the process of determining the design fire size for road tunnel projects, what the approach was previously, and how a risk review process, as used on the Tugun Bypass project, has significant benefits in obtaining a lower cost, tailored, fire and life safety solution which meets the broad requirements of the project stakeholders.

The design fire size for a tunnel has direct influence on the fire engineering analysis, the tunnel structural design (or its resistance to failure due to fire) and the design of the fire and life safety systems such as the tunnel ventilation, fire detection and fire protections systems.

Until recently, the maximum tunnel design fire size had traditionally been quantified in the design criteria of client briefs for road tunnel projects and was typically rated at 50MW. This was based on the fact that most tunnels within Australia were located in urban areas, the speed limit was generally limited to 80km/hr, and no dangerous goods were permitted to travel through. With the introduction of tunnel projects such as the Tugun Bypass project having parameters outside these usual norms, the standardisation of design criteria was no longer a valid option. An alternative approach was necessary which took into consideration the unique risks associated with each project.

Prior to the design of the Sydney Harbour tunnel in 1992, little consideration was given to fire and life safety design in Australian road tunnels. The design of the Sydney Harbour tunnel fire and life safety systems was based on limited US and PIARC data available at the time. In 2001, the Australasian Fire Authorities Council produced the *"Fire Safety Guidelines for Road Tunnels"* [1]. This document included relevant fire safety issues designed to provide information and guidelines to those Fire Brigades who may be involved in providing comment or requirements to road tunnel developers.

Tunnels up to 2006 were 'fire engineered' mainly for smoke management and egress provisions in line with the *designated* maximum design fire size. Since 2006, the risk review process has enhanced the fire engineering process and considers the maximum credible fire scenarios unique to the project location and operating parameters.

In May this year I attended the *Tunnel Fire Safety & Ventilation Conference* in Graz, Austria, and following the conference was a guest at the PIARC Ventilation Working Group Meetings held at the Graz University of Technology. It was interesting to observe that of the 20 or more countries represented in the PIARC Ventilation Working Group, each had various local Authority requirements to follow either a performance based or prescriptive based approach to fire engineering. This group is currently working on a technical report titled, *"Design Fire Characteristics for Road Tunnels"*, in relation to determining the design fire size for road tunnel projects.

The aim of the report is to provide information and case studies to enable decision-making around the available options rather than advocating a performance based approach over a prescriptive based approach. There was a strong emphasis by the group on the importance of basing the report on solid research and the results from recently executed tunnel fire tests.

Fire testing of the smoke control system in the 2.4km long Kirchdorf S35 Tunnel (20km north of Graz, Austria), May 2010, just prior to opening.

To touch on the outcomes and conclusions from a number of full scale tunnel fire tests, we were able to see from the Runehamar [2], Memorial [3] and Reppafjord Tunnel fire tests [4] that *uncontrolled tunnel fires* (or those where no fire suppression is applied) result in poor visibility, very high temperatures and heat release rates, and significant impact on the integrity of the tunnel structure. These tests also showed that heat release rates in excess of 200MW could be generated from a fully developed non-dangerous goods fire.

By comparison, the results of the Benelux [5] and Piota Negra Tunnel fire tests [6] showed us that *controlled tunnel fires* — or fires where fire suppression is activated — result in cooler tunnel temperatures, limited visibility, lower heat release rates, and generally tenable conditions with the exception of visibility. The outcomes of the fire events in both the Sydney Harbour Tunnel and Melbourne City Link Tunnel reinforce these conclusions.

The Tugun Bypass project involved the design and construction of 7km of new motorway between Tweed Heads NSW and Currumbin QLD, including a 340m long tunnel. The objective of the project was to improve interstate travel through the Gold Coast and relieve the impact of traffic congestion on the local roads at Tugun. The project was designed and constructed under the PacificLink Alliance between Queensland Main Roads, SMEC and Abigroup. 'Best for project' thinking was encouraged by the Alliance at every level and across all aspects of the project. As a sub-consultant to SMEC, Norman Disney & Young was engaged for the design of the tunnel and motorway services. The project was very successful in opening to the public six months ahead of the contract schedule, whilst maintaining total costs below the original project budget.

The project was unique in that:

- the route was located across the NSW/QLD border, thereby doubling the number of stakeholder and interest groups involved
- part of it was constructed below the extension of the main runway of the Gold Coast Airport
- the posted speed limit was 100km/h, higher than most in the country, and
- most classes of dangerous goods (except explosives and flammable gases) were permitted to travel through.

The original project brief issued at the time of tender prescribed that the tunnel and services were to be designed to accommodate the effects of a maximum 100MW design fire. However, given the unique parameters of the project, the Scope of Works and Technical Criteria [7] issued at the time of contract award was amended to shift the responsibility for determination of the design fire size to the Alliance team.

The contract stated that, *"The mechanical ventilation and smoke control systems must be capable of fully functional continuous operation for the range of fire events up to and including a 50MW design fire as a minimum. The design fire must meet this minimum requirement and must address the requirements necessary for the nature of goods that will be permitted in the tunnel."*

The design team needed to be able to identify the full range of possible fire risks and threats, right from the minute to the unmanageable, and review their corresponding consequences in some sort of orderly fashion. A process was needed that clearly demonstrated the project team had exercised its duty of care to all stakeholders, and ultimately, to the public.

Given the large number of stakeholders involved, a Risk Review Workshop Process was decided upon as the vehicle to achieve this, and we acknowledge the good

The Tugun Bypass Tunnel constructed under the extension of the main runway of the Gold Coast Airport.

work done by Risk Consultant, Risk & Reliability Consultants (or R2A) in assisting in the facilitation of these workshops. With over 20 stakeholder groups involved from both sides of the state border, separate briefing sessions were held with each of the individual stakeholder groups, including:

- Design and construction team members
- Local Councils
- Road Authorities
- Airport Authorities
- Fire Brigades, including local commands
- Environmental departments, and
- Dangerous goods departments.

These briefings enabled each group to be given a plain english explanation of the project and its requirements, and sought specific feedback on the potential risks and fire and life safety issues important to that group. It also provided an opportunity for each group to raise issues of concern or opportunity outside of fire and life safety. Minutes were kept for each meeting and all issues raised were fed into a central risk register, and non-fire and life safety issues — such as environmental, safety and operational issues — were passed on to the relevant design group for consideration and inclusion in the design process.

A preliminary fire scenario and impact review matrix (or vulnerability matrix) was prepared for discussion with the stakeholders which listed out all of the foreseeable fire threats down one side, and the various entities which could be impacted by those threats across the top. A preliminary assessment was undertaken of the extent of consequences for each fire scenario, graded from no impact up to multiple fatalities [refer Table 1]. Of significant concern was the impact and magnitude of potential dangerous goods fires, and the effect of operating the deluge system on some types of dangerous goods which reacted with water.

The probability of each fire scenario was assessed, (whether "credible" or not), and whether systems or procedures could be put in place to mitigate the risks. For example, it was agreed that design to accommodate an aircraft misjudging the runway, colliding with the tunnel and bursting into flames was unwarranted, as the likelihood of such was extremely low.

Following the stakeholder briefing sessions, a workshop was held with all external stakeholders to test the credible fire scenarios identified and the proposed precautions. The sessions were also used to canvass the wider stakeholder group on whether there were any other credible fire scenarios needed to be considered by the design and construction team. Each of the fire scenarios identified were systematically reviewed in detail by the stakeholders, and profiling sheets were prepared which recorded the group's comments on the severity of each threat, along with the expected precautions or controls.

The outcomes from the stakeholder workshop were also used as input into the *Incident Management Plans* and to the *Safety Integrity Levels* (SIL) determination exercise for the Information, Communication & Technology Systems. Separate SIL Level workshops were conducted and attended by the design team, the technology providers, the proponent and the end users (operators) which looked at:

- the probability of occurrence of the scenario
- in situ control barriers to identify or avert a major tunnel fire event before it happens (such as normal traffic management, CCTV coverage or contact from the public at the early stage of a hazard), and
- the potential sequence of events in terms of decision making, response, and fire or control system activation times.

Table 1 — Sample Fire Scenario/Impact Review Matrix

	Public	Incident Response	Local Residents	Environment	Infrastructure
Motorcycle	X	X	–	–	–
Vehicle Fire	XX	XX	–	X	X
Bus Fire	XXX	XXX	–	X	XX
Non-Dangerous Goods Heavy Goods Vehicle Fire	XXX	XXX	–	XX	XX
Dangerous Goods — Flammable Gas Heavy Goods Vehicle Fire	XXX	XXX	XX	XX	XXX
Dangerous Goods — Toxic Gas Heavy Goods Vehicle Fire	XXX	XXX	X	X	–

XXX Potential extreme consequence event
XX Potential major consequence event
X Potential moderate consequence event
– No vulnerability detected

By looking at the combined effect of these items, the project team was able to logically establish that, to achieve the required levels of system reliability stated in the project brief, it was only the tunnel control and monitoring system which was required to be formally SIL rated, not the entire traffic management system or the fire protection system, which saved significant costs to the project.

The preliminary risk evaluation process initially established 35 tunnel fire threat scenarios. Following the individual stakeholder briefings and the fire issues risk workshop involving all stakeholders, 13 credible fire scenarios were determined. Similarities within these thirteen credible fire scenarios permitted detailed fire engineering analysis of seven credible fire scenarios.

Four controlled tunnel fire scenarios were analysed — with the deluge system activated — and yielded predicted fire heat release rates in the order of 7MW. Three (3) maximum test cases analysed the effect of a heavy goods vehicle entering the tunnel with a fully developed non-dangerous goods fire on board. These test cases yielded the maximum predicted fire size of 100MW.

Other outcomes of the risk review process identified:

- it is best to activate the deluge system on the fire early (even if the vehicle contains dangerous goods) to minimise the likelihood of the fire penetrating the packaging and exposing the dangerous goods load
- historically, the majority of fires have been limited to single vehicles, and were the result of a vehicle impact
- flammable liquid fuel fires are limited by the pool size which is dependent on the amount of fuel, the slope of the road and the capacity of the drainage system, and
- a high quality traffic management system and well thought out Incident Management Plans are vital to the prevention, detection and management of fire incident scenarios, and minimisation of their consequences.

In summary, the greatest fire and life safety risks associated with large infrastructure projects have low probability but extreme consequences if they occur. By undertaking a risk review process, all of the project stakeholders are brought together at the initial stages to quantify and categorise the risks. By harnessing the experience of the design and construction team and all of the relevant government, emergency services, environmental and specialist risk departments, it positions the expertise for dealing with these risks at the forefront.

The individual stakeholder briefings enable each group to understand the fire safety issues that may affect them, and enables their concerns to be put on the table and addressed early in the process. It is also a way of taking on board wider project issues, ideas, and suggestions which would not necessarily be captured in a wider forum because of time limitations.

The combined stakeholder workshops provide a vehicle for due diligence as each group comes to the workshop informed, and familiar with the objectives of the risk assessment process. All the necessary expertise is in the room to discuss the issues and address the concerns of others with factual responses. Ultimately, the risk review workshops are a vehicle for joint acceptance of the range of fire risk events, and to confirm the appropriateness of the precautions proposed to be put in place to mitigate those risks.

Smoke testing in the Tugun Bypass Tunnel, March 2008.

With agreement on credible tunnel fire scenarios, the fire engineering analysis and design of the tunnel fire and life safety and control systems can be tailored to the unique circumstances of a project. The result is cost-effective solutions at the desired level of safety and reliability acceptable to all stakeholders.

References:

[1] Australasian Fire Authorities Council, 'Fire Safety Guidelines for Road Tunnels', Issue 1, 10 September 2001.

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[3] Massachussetts Highway Department and Federal Highway Administrations, 'Memorial Tunnel Fire Ventilation Test Program; Test Report', United States of America, November 1995.

[4] Eureka Project EU 499 Firetun, Verlang und Vertriebsgescllschaft, 'Fires in Transport Tunnels; Report on Full Scale Tests,' Dusseldorf, November 1995.

[5] Ir. J.W Huijben — Bouwdienst Rijkswaterstaat Centre for Tunnel Safety, 'Tests on Fire Detection Systems and Sprinkler in a Tunnel,' presented at the International Tunnel Conference (ITC), 2-4 December, 2002, in Basel.

[6] Emilio Cafaro, leader of GRF-DENER-C, Energy Department, and Politecnico di Torino and Mario Masiero for Silvani, 'Testing Tunnel Fire Mitigation Systems', Tunnels & Tunnelling International, June 2004.

[7] Roads and Traffic Authority, 'Pacific Highway Tugun Bypass, Exhibit A, Final Scope of Works and Technical Criteria — Appendix 48', 9 February 2006.