HOW SAFE CAN A TUNNEL BE – HOW SAFE WILL IT BE?
DESIGNERS’ PERSPECTIVE

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ABSTRACT
Tunnel system designers have to work with the locally-approved design approaches be it using the local design guidelines or using a risk or performance based approach. Some of the issues raised by the two approaches are discussed and a number of other issues faced by designers are identified.

Keywords: tunnel, design, guidelines, risk, performance, incident ventilation

1. INTRODUCTION
The options available to the designer with respect to the choice of safety-related equipment and systems depend on the country in which the tunnel is located and the relevant legislation that is applicable there. In a number of countries there are no real options as the local regulations define what is required for a particular length and type of tunnel. All the designer has to do is apply them; it’s just a case of “sizing” to suit the particular conditions. In other countries – where a risk or performance based design approach is acceptable – the designer can, in theory, “choose” the most appropriate systems to achieve an acceptable level of safety. The approaches available to designers are discussed and some of the problems they face are identified.

2. DESIGN GUIDELINES
Since the Mont Blanc, Gotthard and Tauern incidents the EU has introduced the Directive on minimum safety requirements for road tunnels on the TERN¹ and this multi-national legislation is, in many countries, now being used for all tunnels. A number of countries have also revised and strengthened their design guidelines as a result of these and other incidents. One would have hoped that after all the experience accumulated throughout the world over the last 50+ years there would be some amount of similarity between the guidelines in different countries. In some things there are but in others there are not.

One of the classic differences concerns short tunnels or, when does a “long bridge” become a tunnel? The “definition” of a short tunnel and the safety measures required varies from country to country as illustrated in Figure 1.

The EU and half the countries shown have a set tunnel length beyond which all the safety measures for a tunnel in that country are required; less than that no particular measures are required. The length that this transition occurs varies from a maximum of 500 m down to just 150 m in the UK. The other countries listed define that some safety measures are necessary in tunnels which are shorter than “real tunnels”.

Passive safety measures such as emergency exits are effective in short tunnels as are some active systems such as emergency lighting but several countries also require that a mechanical ventilation system be provided for an emergency. The practical difficulties of providing such systems in short tunnels have been identified especially when there is a longitudinal gradient and a large design fire. A classic issue occurs when the length of a tunnel is close to the transition between requiring and not requiring a ventilation system, usually a longitudinal system with jet fans. In one tunnel known to the author the original design was with just natural ventilation but this was rejected by one of the project’s stakeholders because “it needs some jet fans to blow the smoke out of the tunnel”. A second design with a longitudinal system was also challenged because “there are too many jet fans in the tunnel, we don’t need that many”. The second design was accepted, albeit reluctantly, once it was explained that you either had an emergency ventilation system or you did not, you could not have half a system, and that the system required that many fans.

One of the “problems” with design guidelines is that they change periodically, often within the relatively long time-span of a tunnel project. In many disciplines the relevant versions of the design guidelines are set at the start of the project and are not changed even if the guidelines themselves change during the course of the project. However this approach is not acceptable for safety-related issues and designers have to adapt their design to satisfy the new requirements. Sometimes those changes are minor and can easily be incorporated into design irrespective of the stage of the project. However some changes can and have had major impacts on projects, especially when they occur once the construction of the tunnel has started. One such example is changing the required ventilation system from a simple longitudinal one with jet fans to one requiring localised smoke extraction. The space available within the tunnel cross section is usually too small to allow a reasonably sized exhaust duct to be incorporated which results in high under-pressures in the exhaust duct, large leakages from the traffic space and high powered motors for the exhaust fans. Often, because of planning and/or environmental impact restrictions, there is also very limited space available for ventilation stations which further increases the pressure losses and, as a result, the motor power required for the ventilation system.

Guidelines usually also mean that the designer has little or no opportunity to optimise a design by improving one safety measure while reducing or replacing another even if the end result improves the safety for tunnel users. A simple example of this would be decreasing the spacing between emergency exits and installing a longitudinal ventilation system instead of one with localised smoke extraction. This approach is intended to be the realm of the risk or performance based design – but is that really the case?

**Figure 1:** Tunnel safety requirements vs tunnel length in various countries
3. RISK OR PERFORMANCE BASED DESIGN

The aforementioned EU Directive requires that a minimum level of safety measures be incorporated in tunnels. However the Directive has also introduced a requirement for risk analyses to be carried out to determine if more or enhanced safety measures are required in a number of specific instances including when the tunnel’s longitudinal gradient is greater than 3%. Many of the countries directly affected by the Directive already require their tunnel design guidelines to be used to determine the necessary safety measures etc but most of the countries have no experience of using a risk-based design approach for road transport infrastructure.

In order for the risk based design approach to work, all of the interested stakeholders need to be involved in the design process so that they can “sign up” to the approach, the assessment of the risks and, as a result, the final design. But does this type of design process really work like that? Irrespective of whether a probabilistic or a deterministic approach is being used the design process should really start with the expected hazards due to the traffic, etc and an empty tunnel; the only safety measures that should be “added” are those necessary to achieve a required level of safety. In practice the starting point is usually not an empty tunnel but one with all the “normal” safety measures – emergency exits, lighting, radio, CCTV, drainage, fire hydrant system, SOS niches, etc as defined in many design guidelines – and the risk analysis process is carried out to demonstrate that these measures achieve the required level of safety. This is certainly the situation with respect to the EU Directive – certain safety measures must be incorporated which might have to be enhanced and/or augmented in certain circumstances depending on the results of the risk analyses. The thought of removing one of the “normal” measures – say the fire hydrant system – or of replacing one measure by improving another would almost certainly never be considered even if the result was that the required level of safety was still achieved.

But what is an “acceptable level of safety”? This is the aspect where the designers using a country’s design guidelines have an easy task – if their design satisfies the guidelines then, by definition, the tunnel is safe enough. But how safe is that? Is it that the number of fatalities per year per kilometre in the tunnel should be no more than that on the open road on either side of the tunnel? Or is it that the tunnel is made to be as “safe as reasonably practicable” whatever that means. Although a number of suggestions have been put forward there appear to be no generally acceptable values for either societal or individual risk with respect to road tunnels; each project using this approach has to go through a process of determining values that the project’s stakeholders believe would be acceptable. The EU Directive suggested that there would be a common risk analysis approach with, presumably, recommended levels of safety but, to date, nothing has been forthcoming.

4. OTHER ISSUES FACED BY DESIGNERS

The different design approaches required when using either design guidelines or the risk/performance based design are not the only issues that designers have to live and deal with. There are also groups, some from within the design community itself, that introduce further problems into the design process. For simplicity these have been identified as the “Bureaucrats”, the “Modernisers”, the “Accumulators”, the “Universalists” and the “Automatons”.

The “Bureaucrats”

A number of countries have introduced changes to their safety guidelines and/or the required safety measures without, it appears, a thorough understanding of the implications. It is only when the designers have to use them for a real tunnel that the implications of those changes become apparent. Even relatively simple changes such as the level of redundancy required
for, say, the smoke exhaust fans have a significant impact on the layout, size and costs of ventilation stations. Furthermore the resulting design of the station is often far from optimal because of space restraints.

Additional safety-related equipment may be a new requirement but then, during the design of a real tunnel, questions arise about how this new equipment can be effectively and reliably integrated with all the other systems that are also required. A good example of this is smoke detectors. It is well known that the principal “problem” with fire detection systems is adjusting their sensitivity to minimise false alarms while giving a reasonable detection time. As a result there is an inevitable delay between the start of the fire and it being detected by such systems but, once detected, the location of the fire can usually be identified. Smoke detectors may detect quickly but the source of the smoke is unknown; is it stationary or is it still moving? Yes, smoke detectors can be a good early warning system but that is all they are. It is then almost impossible to do anything automatically with that information with respect to initiating and/or controlling the emergency ventilation system such as deciding reliably which smoke exhaust dampers to open.

The “Modernisers”

There are a number of instances where systems and approaches that have been shown to work well for many years are now being questioned simply because they are “old”. The message that the “Modernisers” are giving is that this particular approach is old fashioned therefore it is no good today and there must be a better way.

There is a well known proverb which should be heeded by all – If it works don’t fix it. Inventing “new” approaches or systems to “replace” older proven ones is not the way to make tunnels safer. Somebody might believe the message and actually install one of the new “wonder systems” and it might make the “Moderniser” quite wealthy. However, in the event of an incident, it is certain that the courts will determine if the “wonder system” really is an improvement over the old tried and tested one.

The “Accumulators”

This group want to equip tunnels with each and every conceivable piece of safety-related equipment that they can. Is this really done in the belief that it will make the tunnel safer or is it so that nobody can accuse them of not trying to make the tunnel as safe as possible? Do the “Accumulators” also insist that only those who have been suitably “trained” can use their tunnel?

There are two “sub-species”, one usually owns or is responsible for one or more tunnels; the other is often a designer who also believes that the higher the costs of systems etc, they specify, the higher can be their honoraria,

The “Universalists”

These believe that, no matter where in the world a tunnel is located, it should be designed and equipped in the same way – which is usually in the same way it would be in their home country. They take no account of the local situation, resources and conditions. How can the design and facilities provided for an urban tunnel in Europe possibly be suitable for a tunnel 2’000 m up in the mountains of a 3rd world country? Who is going to service and maintain it? What about one organisation that provided a tunnel with systems that nobody in the particular country was capable of maintaining or servicing, it could only be done by bringing people and equipment from other countries. Or another where a sophisticated ventilation system was installed that needed significantly more power than was available at the tunnel’s location?
The “Automatons”

This group believe that everything can be achieved by suitably programming the appropriate systems and that no account has to be taken of the idiosyncrasies of people, particularly when those people happen to be the drivers of the vehicles using their tunnel. There are numerous records of drivers taking what most would believe to be totally unreasonable actions, none of which could possibly have been taken into account in the system programming.

The safety provisions have to take account of the different behaviours of people, especially in a stressful situation. Some countries such as Switzerland, have successfully “trained” their tunnel users how to respond in a tunnel emergency. When are other countries going to follow suit and do the same? Yes, it costs money and time but it is valid for all the tunnels; it doesn’t have to be done for each individual tunnel as is the case for most safety measures.

5. DISCUSSION

Society seems to accept that road accidents occur and some of them result in fatalities whereas they do not appear to accept any fatalities occurring in an incident involving a fire in a tunnel. Bearing in mind that less than 150 people have ever been killed anywhere in the world in road tunnel incidents involving a fire – and that includes those killed by any preceding accident – this means that the fire safety aspects of road tunnel design must be reasonable.

The current trend for trying to improve tunnel safety is towards providing ever more active safety systems almost all of which are directly concerned with reducing the consequences of a fire – as are many of the existing safety measures. The question has to be why are we not improving the passive safety measures which will always function and also have low maintenance costs? Is it because their capital costs can be high or is it because there is no “glamour” in these solutions; no fancy electronics and computers and, as a result, they cannot be “any good”? Although active safety systems may have a lower capital cost many of them have large whole life costs due to the testing, maintenance and replacement that is required and, after all that, they still may not function correctly on the rare occasions they are required. On the other hand they can always be blamed when they don’t work correctly when required! Maybe that is the real reason why so many systems are now being installed – hoping that each will act as a back up for the other when one doesn’t work!

This raises the question of how reliable are each of the systems and is there any confidence that each (or any) of them will work correctly when they are required? If there is not a reasonable level of confidence that they will function correctly when required then why are they being installed? Similarly, but more importantly, what should be done if one of the safety systems is out of commission. The design process – be it based on design guidelines or performance – has determined that each system needs to be installed to achieve the required level of safety in the tunnel so, when that system is not available, should the tunnel then be closed? Or does it depend on how long the particular system is not working? Who takes the decision that the tunnel is not “safe enough” so has to be closed – the operator, the owner, the designer? Has anybody even thought about what systems must be available in order to safely operate the tunnel?

Although no fatalities are acceptable it has to be accepted that in the real world some are inevitable. Resources should be used to achieve the maximum benefit (i.e. in this context, to save the maximum number of lives) and maybe the large sums of money being spent to “improve the safety” of road tunnels (particularly fire safety) could be better spent on other parts of the road network where the cost per life saved is much lower. The cost-effectiveness of different safety measures in road tunnels in the Netherlands – a country where the principles of risk-based design are generally accepted – have been assessed by Arends3,4 and this approach could usefully be adopted in other countries, particularly those with large numbers of tunnels, to optimise their expenditure on tunnel safety measures.
6. CONCLUSIONS

Designers that are required to use guidelines to determine the safety measures needed in road tunnels do not know the level of safety that is actually achieved.

Risk/performance based design is hampered by the lack of generally agreed a) risk analysis process for road tunnels and b) values for acceptable societal and individual risk levels for road tunnels.

The responsible authorities should fully understand the implications of any new requirements before introducing them.

Safety measures that have been proven to be effective should not be challenged.

Equipping a tunnel with each and every safety measure does not mean that the tunnel is safe.

There is no universal design for road tunnels; it must depend on local conditions and resources.

The behaviour of tunnel users cannot be assumed; they have to be “trained”.

The minimum acceptable level of operating safety measures should be determined for each tunnel and a tunnel should be closed when that level is not achieved.

Increased emphasis should be placed on improving passive safety measures rather than introducing more and more active systems.

The cost effectiveness of safety measures should be taken into account when equipping road tunnels.

7. DISCLAIMER

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8. REFERENCES


