SWOV Fact sheet

The road safety of motorway tunnels

Summary

This fact sheet discusses the safety of motorway tunnels in the Netherlands. Broadly speaking, it is not certain whether crashes in the Netherlands are relatively more frequent in tunnels than on open road stretches. However, there are certain factors that increase the risk in tunnels, such as the proximity of the tunnel wall, limited sight distance, merging or exit lanes in or near the tunnel and great differences in lighting at the entrance and exit.

Road safety in tunnels can be improved by creating emergency lanes which increase the distance to the tunnel wall, by limiting the gradient percentage, thus minimizing speed differences (separate lanes for heavy traffic are an alternative), and creating wide layouts in horizontal bends where these cannot be avoided. In addition, tunnel entrances and exits must be carefully designed: the lighting must be of a high quality, and, if there are no emergency lanes, exit lanes and weaving sections should be avoided in the vicinity of the tunnel as well as inside the tunnel. Furthermore, tunnels should be equipped with high-quality outlet systems for fluids.

Background and content

In the last decade, several disasters in Alpine tunnels and the increased fear of terrorist attacks have increased international interest in the safety of tunnels. Also in the Netherlands, various organizations have therefore been working on increasing the safety of road tunnels. The most important issue is to prevent major disasters and, if a disaster *does* happen, to limit its consequences.

For road design and infrastructure a distinction is made between internal and external safety. Internal safety is the safety of the road users, and external safety is that of those living in the vicinity of road incidents. Because of their enclosed areas, internal safety is the more important factor for tunnels. This fact sheet looks at the road safety of motorway tunnels in the Netherlands. Using national and international studies, it discusses tunnels' specific safety problems and the factors that play a role in road crashes occurring. Finally, some effective measures that can increase tunnel safety are presented.

How large is the problem?

In the Netherlands, there are fourteen motorway tunnels (see the overview at www.autosnelwegen.nl, which does not include the Roertunnel in the A73). In the Netherlands all tunnels are managed by the Directorate-General for Public Works and Water Management and the total length of tunnel tube comprises almost 10 kilometres. In addition to the tube itself, the tunnel also has influence on road safety at some road length in front of and behind the tunnel (the so-called influence area).

During the period 2001-2004, there were 26 serious crashes in motorway tunnels or within 50 metres of a tunnel in the Netherlands; 3 of these crashes were fatal. In the period 2005-2008 the number of serious crashes had decreased to 19, two of which were fatal. This number of serious crashes comprises approximately 1% of all registered crashes with severe injury on motorways managed by the Directorate-General. The abovementioned number of tunnel crashes in the Netherlands has been established by combining the crash data of the Registered Road Crash Database (BRON) with the database of road features of national roads (Weggeg). As was mentioned earlier, all crashes within 50 metres of a tunnel are considered tunnel crashes.

Road crashes and disasters

A tunnel incident is called a disaster when the aid of the fire-brigade is needed in a serious incident. This can be a fire, but can also be hazardous substances escaping or entrapment and/or serious injury of a person (Ministry of Traffic, 2004b). If, for example, there is a fire or leaking vehicle in a tunnel, smoke and toxic gasses spread through the tunnel and cannot immediately disappear in the open air. This is especially dangerous for those inside the tunnel. Air ventilation systems, fire

extinguishers, escape routes, monitoring systems, road safety policy, and disaster plans should reduce these dangers.
The risk of a disaster is small, but it does have much more serious consequences than a road crash. A disaster can sometimes be caused by a road crash, but it can also have another cause, such as technical failure of a vehicle carrying a hazardous substance or failure of mechanical or electrical systems within the tunnel itself. Therefore, prevention of crashes in tunnels reduces the risk of disaster happening, but only to a limited extent. This can also save many expenses.

Tunnels and open road sections
Compared to crashes on open road sections, especially the *consequences* of crashes are worse in a tunnel. However, whether, generally speaking, crashes are relatively *more frequent* in tunnels is unknown. According to Directorate-General studies, the motorway tunnels in the Netherlands have more injury crashes per motor vehicle kilometre than open road sections (Directorate-General for Public Works and Water Management, 2004a). However, international research indicates that tunnels have relatively fewer injury crashes than open road sections (Brilon & Lemke, 2000; Nusbaumer, 2007). Research of the Ministry of Traffic (2008) indicates that on road sections with merging and exit lanes (for example from three to two lanes or the reverse) the number of crashes is nearly always higher than at adjacent road sections. The number of crashes is also higher than average at tunnel entrances and at the deepest point of the tunnel.

Tunnels occupy less than a half percent of the total length of motorways in the Netherlands (more than 2,500 kilometres of separated lanes, excluding connecting roads and entrance and exit lanes, Statistics Netherlands). Therefore, the 1% proportion of serious tunnel crashes is relatively high. This, however, is no basis for hard conclusions as the numbers of crashes are small and subject to annual fluctuations, there has been no correction for differences in traffic volume, and the registration rate of crashes is probably higher for tunnels than for open road sections.

What are the causes of crashes in and near tunnels?
It is not possible to point to direct causes of tunnel crashes in general; too many factors are involved. Below we will discuss specific hazard factors that play a role in crashes occurring in tunnels.

No emergency lanes
Most tunnels in the Netherlands have no emergency lanes. In case of a break-down this can cause serious inconvenience to traffic and, moreover, it is difficult for emergency services to reach the break-down. The lack of emergency lanes also causes different driving behaviour. When entering a tunnel, some drivers change their lateral position on the carriageway to keep further away from the tunnel wall. Some distance into the tunnel they revert to their normal lateral position (Martens & Kaptein, 1998).
If an emergency lane is present, the abovementioned effects on lateral position and speed reduction are limited (Martens & Kaptein, 1998). A German study reckons with 20% fewer crashes per motor vehicle kilometre when an emergency lane is present (Brilon & Lemke, 2000). The 1993 *Guidelines for Designing Motorways* even mentioned a reduction of 20 to 30% (Directorate-General for Public Works and Water Management, 1993).

Closed construction
For a small group of road users, the presence of a tunnel wall and tunnel roof can invoke feelings of anxiety. Especially the tunnel wall at the entrance of a tunnel is perceived to be a hazard. In addition, some drivers reduce their speed and overtake less frequently as soon as they enter a tunnel (Ministry of Transport, 2008). This can reduce the homogeneity of the traffic flow, thus decreasing road safety (Verwey et al. 1996).
Although the number of drivers who feel uncomfortable when entering a tunnel is small (Admundsen, 199), the effect of this group on traffic flow should not be underestimated (Martens & Kaptein, 1997)[1]. Tunnel fear causes discontinuity in the traffic flow, and can lead to crashes because the motorist will have less attention for the driving task.

[1] The research mentioned was done in the early nineties. It is possible that several disasters in tunnels at the end of the late nineties caused an increase in tunnel anxiety among motorists.

Gradient
More crashes occur at the deepest point of a tunnel than at other tunnel locations (Ministry of Transport, 2008); possibly because there the vehicle speed is higher and the braking distance is longer (Ministry of Transport, 2004a). On the rising slopes heavy vehicles sometimes slow down considerably, which results in greater speed differences between the individual vehicles. This is a safety hazard: the more vehicles deviate from the average speed, the greater the probability of a crash (Verweij, 2000). The American design guidelines (AASHTO, 2001) state that the crash rate increases as the lorries going uphill reduce speed. German studies show that the crash rate on motorways increases as the gradient is steeper; in addition, the crash costs also become increasingly higher (Bressler, 2001, 2003). This indicates that the crash severity increases with steeper gradients. This relation exists for both the crash rates and the crash costs on both uphill and downhill slopes. On slopes with a separate lane for slow vehicles, the crash rate does rise when the gradient increases, but the crash costs decline (Bressler, 2001).

Dimensions and alignment
The more complicated the geometry of the tunnel, the more crashes occur (Van Ees et al., 1997). Bends are sometimes difficult to judge and tunnel walls and ceilings reduce the view of the road and possible traffic jams (Van Kleef et al., 2001). Urban motorway tunnels have a higher crash rate than rural ones (PIARC, 1995); this is the case for all crashes as well for as for injury crashes. The narrower design of urban tunnels, due to the limited space, is mentioned as the most important cause.

Lighting conditions
The transition from an open road to a tunnel is also a transition in lighting conditions, especially during daytime. It is important to make the transition in lighting at a tunnel entrance and exit gradual, because the eye needs several seconds to adjust to the altered situation. When the transition in lighting is too sudden, the road user cannot perceive any details for a few moments and can be distracted. Tunnel entrances in the Netherlands have high quality lighting (Schreuder, 1993).

Other hazard factors
Swiss and Austrian research shows that the longer a tunnel, the safer it is (Robatsch & Nussbaumer, 2004). However, other researchers point out that the monotonous visual surroundings in a tunnel can lead to orientation errors and errors due to loss of concentration (Van Kleef et al., 2001; Peterson, 1999). Moreover, the break-down and/or incident rates increase as the tunnel is longer.
The higher the traffic volume, the higher the crash rate (Robatsch & Nussbaumer, 2004). This relation is also valid for motorways in the Netherlands (Commandeur et al., 2002).
Entry and exit manoeuvres in and near tunnels have a negative road safety effect if there is not enough manoeuvring space (Directorate-General, 2004a; 2008).
A single tunnel tube for traffic in two driving directions is less safe than two separate tunnel tubes with one driving direction each (PIARC, 1995; Nussbaumer, 2007). Head-on collisions can occur in tunnels with oncoming traffic, generally with severe consequences. The Netherlands has no tunnels with oncoming traffic, but this situation can occur during road works in a tunnel. After some crashes occurred in such a situation, the Dutch Transport Safety Board recommended an analysis of alternative solutions during road works in tunnels. (RvTV, 2004).

What do Dutch legislation and guidelines say?

Legislation
Legislation which applies to infrastructure in the Netherlands consists, for example, of the Infrastructure Act, the Road Traffic Act and the Town and Country Planning Act. In addition, for tunnels longer than 250 metres, the Additional Safety Act Road Tunnels (Warvw or 'Tunnel Law') applies. Furthermore, tunnels that are part of the trans-European road network (the E-roads) and are longer than 500 metres have to comply to the European Commission's minimum safety requirements (Directive 2004/54/EG). This European guideline is implemented in the tunnel act and the Housing Act (according to the Housing Act, a tunnel is a construction 'not being a building' for which a buildings decree must be issued).

Design guidelines
In principle, the same design guidelines apply to tunnels as to road sections outside tunnels. The Dutch *New Guideline for the Design of Motorways* (NOA; Directorate General for Public Works and Water Management, 2007a) does not contain specific guidelines for tunnels. However, it gives

specifications for other large constructions (river crossings and subways) concerning the maximum gradient. At a designed speed of 100 and 120 km/h a maximum gradient of 5% is acceptable for large constructions, as opposed to 3% for the common vertical stretches. The *Guidelines for the Design of Motorways* (ROA; Directorate General for Public Works and Water Management, 1993) indicate that an emergency lane should only be omitted after careful consideration of serious arguments based on a cost-benefit analysis. Such a situation can occur in a deep tunnel. Generally, emergency lanes are not included in Dutch tunnel design for reasons of cost-effectiveness, unless the expected future traffic flows warrant this (Directorate-General for Public Works and Water Management, 2004b).
The Directorate-General for Public Works and Water Management of the Netherlands has also made recommendations on the minimal distance between a tunnel entrance or exit and a merging or exit lane (Directorate-General for Public Works and Water Management, 2008). The advised distance depends on the set speed limit. The European directive (2004/54/EG) states that the number of lanes should not change within a distance of ten driving seconds in front of the tunnel entrance. The Directorate-General for Public Works and Water Management deviates from this ten-second requirement in that the distance between an exit lane and a tunnel entrance is often shorter than recommended in the EU guideline, whereas the distance between an exit lane and a tunnel exit is often longer (Directorate-General for Public Works and Water Management, 2008). No arguments are presented for the ten-second requirement and what it is based on is not known. It does not distinguish between the type of divergence or convergence points. Despite that, the guideline has now been incorporated in the Dutch Tunnel Law (Warvw).

Quality requirements
The Dutch *Policy Document Tunnel Safety* discusses process and safety requirements for tunnels (Ministries of Transport, Foreign Affairs, and Housing, Spatial Planning and the Environment, 2003; 2005). The Directorate-General's Centre for Tunnel Safety has formulated an integral approach for the safety issue of underground road infrastructure: *Safety Guidelines, parts A-E*. Furthermore, the independent Committee for Tunnel Safety was established in the Netherlands. This committee is formed by independent experts who give advice on tunnel safety in the early stages of a tunnel project.

Recent developments
Commissioned by the Ministry of Infrastructure and the Environment, a new evaluation has been made of the role of the Tunnel Law (Warvw) and the Housing Act in the process of planning, decision-making and realizing safe motorway tunnels (Andersson Elffers Felix & Grontmij, 2011). The minister of Infrastructure and the Environment has incorporated the recommendations in a proposal on a new safety norm for tunnels. The Cabinet has agreed to this proposal for amendment of the Tunnel Law (Ministry of Infrastructure, 2011). The amended law is intended to create clarity on the safety requirements for tunnels and on how to comply with these. In addition to these norms, a regulation will be created which prescribes a standard set of safety measures for every tunnel type (installations and systems). The new law also attempts to prevent any unnecessary delay and therefore fits in with the Commission Elverding's procedure *Faster and Better* (2008). The new Tunnel Law is expected to become operative per July 2012 after consent of the Council of State.
Because of the adjusted method, the Commission for Tunnel Safety will have a less important role; therefore, the minister has advised to abolish the Commission. The knowledge and advisory role of the commission will possibly be transferred to CROW/CURNET in cooperation with the Centre for Building Underground and the Netherlands Institute for Safety.

What safety measures can be taken?
In the Dutch *Safety Guidelines, part C* (Directorate-General for Public Works and Water Management, 2004b) measures are discussed that can secure safety in motorway tunnels. In addition, there now is a guideline for the design of convergence and divergence points in and near tunnels (Directorate-General for Public Works and Water Management, 2008). Effective safety measures for tunnels in the Netherlands are emergency lanes, shallow gradients (or separate lanes for slow traffic), wider bends and using separate tunnel tubes (for separate groups of users as well). In addition, entry and exit lanes and weaving sections in or near the tunnel should be avoided as much as possible. The street lighting at the tunnel entrance and exit should also be of high quality, there should be continuous surveillance of the tunnel, as well as enough ventilation, the tunnel must be provided with emergency exits, et cetera. Furthermore, the tunnel should be provided with a high-quality outlet system for hazardous fluids (consisting of the road surface, the sewage system, water basements and pumping

equipment) in order to prevent large quantities of rain water, fuel or other hazardous liquids from remaining in the tunnel tube.

Despite abovementioned safety guidelines, tunnels are high-risk links in the road network. That is why additional preventive measures are important. For Dutch motorway tunnels these measures are, for example, a lower speed limit, ramp metering, an overtaking prohibition for lorries, a detection system for hazardous materials, and dynamic or graphic route information panels. Furthermore, new developments may contribute to increasing tunnel safety. Vashitz et al. (2008) studied the use of an in-vehicle information system in tunnels and concluded that the information system reduces fear and boredom while driving in tunnels, and can therefore make a contribution to the improvement of tunnel safety. Manser & Hancock (2007) discuss how the speed in tunnels can be influenced by patterns on the tunnel walls.

Which costs and benefits of measures have been considered?

For the emergency lanes in tunnels, the Directorate-General for Public Works and Water Management has, in a number of cases, carried out a cost-benefit analysis with the so-called BOMVIT model (Directorate-General for Public Works and Water Management, 2003a). Among other things, this model looks at improvements in traffic flow and road safety benefits (costs saved in relation with deaths, the injured and material damage). The largest benefit of emergency lanes in tunnels with high traffic volumes turns out to be freer traffic flow: less congestion caused by breakdowns and crashes. When only road safety benefits are considered, emergency lanes in tunnels are not cost-effective. This is the reason that, as we mentioned earlier, tunnels in the Netherlands are not fitted with emergency lanes.

German research also shows that the social benefit of emergency lanes in tunnels increases strongly when the traffic volume increases (Brilon & Lemke, 2000). This is mainly due to a freer traffic flow. The usefulness of an emergency lane also increases with an increase in freight traffic and with a steeper gradient, because in those cases it can be used as a separate lane for heavy traffic or as an overtaking lane.

The Dutch Directorate-General for Public Works and Water Management has carried out a cost-benefit analysis for tunnel gradients using the BOMHIT model which was derived from the BOMVIT model (Directorate-General for Public Works and Water Management, 2003b). This model was used to compare tunnel gradients of 4.5% and 6%. Also in this model, most of the benefit is in the traffic flow. This can mainly be attributed to an increase in capacity due to a less steep gradient. When only the road safety benefits are considered, a shallower gradient is not cost-effective.

In summary, we may conclude that the costs and benefits of emergency lanes and slopes in tunnels can be realistically traded off when including the traffic flow benefits in the calculations.

Conclusion

The number of serious crashes in motorway tunnels in the Netherlands is small, mainly because there are only fourteen of such tunnels. All of these are managed by the Directorate-General for Public Works and Water Management and together they comprise a length of approximately 10 kilometres. A comparison of tunnels with open road stretches shows that the consequences of tunnel crashes are more serious, especially in case of a fire or when toxic fumes are released. No general statement can be made about whether crashes happen more frequently in tunnels. Recent crash data indicates that in the past years the number of crashes in tunnels per road length was higher than that on other parts of the motorway network. Tunnels occupy less than a half percent of the total length of motorways in the Netherlands but 1% of the total amount of serious crashes takes place in tunnels.
A tunnel has many extra risk factors. Since these risk factors usually occur simultaneously, it is often difficult to indicate the main cause of a tunnel crash. The risk factors that distinguish tunnels from the open motorways stretches in the Netherlands are: the closeness of the tunnel wall, gradients and speed differences, and road alignment and (limited) sight distance. Road safety in tunnels can be improved by adding emergency lanes which increase the distance to the tunnel wall, shallower gradients (or separate lanes for heavy traffic) which minimize speed differences, and making unavoidable bends wider. Furthermore, entrances and exits of tunnels should be designed carefully: the lighting should be of a high quality, entry and exit lanes and weaving sections should be avoided, both inside the tunnel and in the vicinity of the tunnel, if there are no emergency lanes. In addition, the tunnel should be provided with a high quality outlet system for fluids.

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