INTERNATIONAL CONFERENCE
5 – 7 MAY 1999, LYON, FRANCE

TUNNEL FIRES AND ESCAPE FROM TUNNELS

LEARNING FROM REAL EVENTS

Dealing with Truck Fires in
St. Gotthard Road Tunnel

Eng. A. Henke, Lombardi Engineering Ltd., Minusio
Eng. M. Gagliardi, Centro di manutenzione, Airolo

(pages 369 – 378)
LEARNING FROM REAL EVENTS
Dealing with truck fires in the St. Gotthard road tunnel

Ing. A. Henke, Lombardi Engineering Ltd., Via R. Simen 19, CH-6648 Minusio
Ing. M. Gagliardi, Centro di manutenzione, CH-6780 Airolo

ABSTRACT

A large truck fire occurred in the St. Gotthard road tunnel on the morning of October 31, 1997. Rescue, extinguishing, clearing the traffic space from debris and securing the damaged structural parts took only 13 hours before the tunnel could be reopened. This third truck fire in the world’s longest and most heavily trafficked motor tunnel had a similar origin and evolution, and comparable consequences, to those of the two previous events (1991, 1994). The fact that certain similarities appear makes it possible to optimize the means of prevention and emergency intervention and to be better prepared for possible future incidents. For the St. Gotthard tunnel, a stock of specially developed emergency equipment has been provided which allows the reopening of the tunnel after such events in the shortest time possible. The main body consists of prefabricated supports and suspension bars for the intermediate ceiling.

1. REMINDING SOME TUNNEL DATA

The world’s longest and central Europe’s most important Alpine tunnel is probably also the one of which the most has been written. However, after nearly 19 years of operation and some 95 millions of vehicles which have passed through the tunnel, it may be good to recall the main project features (Fig. 1), i.e.:
- situation along the main North-South highway through Switzerland, crossing the Alps,
- altitude between 1080 and 1250 m above sea level. In order to be able to pinpoint this altitude, which is nearly the same as the pre-existing rail tunnel also running from Göschenen to Airolo, one has to take in mind that the St. Gotthard pass road has its culmination at 2100 m, whereas the new Gotthard base rail tunnel, for which works have recently started, runs at a level between 500 and 600 m above sea level.
- length: 17 km
- cross-profile: one running tube with bi-directional traffic. The traffic space is relatively small compared to the newer tunnels: the side walks have limited widths because of the prefabricated walls and the available height under the ceiling includes no reserves.
- In addition, there is a parallel security gallery along the whole length of the main tunnel, with cross-passages every 250 m and an independent fresh air supply.
Figure 1: General layout of St Gotthard road tunnel
The tunnel is equipped with a classical transversal ventilation system, characterized by 10 ventilation sectors, 4 ventilation shafts for a total length of 2200 m and 6 fan stations. The total installed fan capacity is 5000 m³/sec, corresponding to some 23 MW of motor power. During normal operation, the system works in a semi-transversal mode by opening the dampers at the shaft bases, allowing intermittent and naturally drafted outlet of the tunnel air.

2. OPERATING BEHAVIOR

A cursory study of statistical data is not sufficient in order to be able to assess the risk of fires in the St. Gotthard tunnel. Since its opening to traffic in 1980, the tunnel has experienced an impressive increase in traffic flow (Fig. 2). The annual traffic volume, as well as the peak traffic flow, have both become considerably higher than the forecast figures used for the layout of the design. Still, passenger car traffic has virtually stabilized at present, with about 6.3 million vehicles per year, whereas truck traffic is still increasing from year to year. Overall truck traffic is 16% of the total volume. During average workdays, however, the truck percentage varies between 20 and 35% (Fig. 3). It should be kept in mind that during the night (between 10 p.m. and 5 a.m.), and on Sundays, trucks are banned on Swiss highways. Peak traffic is likely to occur on Sundays and during holidays. The maximum over 24 hours was registered on August 1st, 1998, with more than 40'000 vehicles.

The exemplary performance is possible thanks to the experienced management by the tunnel staff, operating alternately in one of the two portal control rooms. In addition, a quite good user discipline is evident. Motorists, in general, drive correctly and maintain a regular traffic flow, which is a dominant factor for the good operation of a long bi-directional tunnel.

The frequency of minor disturbing events is somewhat higher than that of other tunnels: an average of 2 broken down cars or cars out of gas per day, and some false alarms per day. Registered accidents, however, do occur less often than on comparable open motorways (Table 1) and also less than in urban tunnels. A similar trend may be seen with the fires. During the last 7 years of operation, a total of 39 fires have been registered. Four of them, one involving a bus, the others with trucks, were more than a simple passenger car event and required the closing of the tunnel for variable durations between 4 hours and two and a half days. Although the frequency rate is low, there is no logical explanation why the fires seem to have occurred more often in recent times.

<table>
<thead>
<tr>
<th>Event Type</th>
<th>Mean per year</th>
<th>Rate (events/10⁶ driven km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Break downs (incl. out of gaz)</td>
<td>600</td>
<td>5.6</td>
</tr>
<tr>
<td>All accidents</td>
<td>55</td>
<td>0.51</td>
</tr>
<tr>
<td>Vehicles fires (with and without accidents)</td>
<td>4</td>
<td>0.04</td>
</tr>
<tr>
<td>Big fires</td>
<td>0.5</td>
<td>0.005</td>
</tr>
</tbody>
</table>

Table 1: Rate of different events in the St. Gotthard Tunnel
Figure 2: Evolution of traffic volume

Figure 3: High percentage of trucks
3. **FIRE FIGHTING SYSTEM**

As part of its safety concept, the St. Gotthard tunnel is equipped with a classical and complete detection and alarm system, which is made up of the following main elements:
- a fire detection system with detectors every 25 m
- emergency stations (telephones and push buttons) every 125 m
- automatic video monitoring.

The automatic reaction of the ventilation system and the traffic guidance are programmed according to generally established patterns. The fire ventilation mode allows the extraction of smoke through fixed dampers, placed in regular intervals of 16 m in the ceiling. The nominal smoke extraction capacity is 145 m$^3$/sec.km. In reality, the extraction rate may vary from one point to another due to the influence of the turbulency pressures generated in the traffic space by the moving vehicles. This effect is more strongly marked than in other tunnels which are shorter, with greater useful cross-sectional areas and less trucks driving towards one another in the same traffic space.

Besides the technical equipment in the tunnel, there are efficient emergency means and personnel resources ready at both portals, in particular:
- a control room with staff on duty 24 hrs/day
- firemen and rescue team: 4 men on permanent duty at each portal; during normal working hours, the whole crew of the maintenance centers can be mobilized
- 4 fire fighting vehicles
- personal protection equipment

In addition, it is possible to mobilize the fire brigades of several regional towns, as well as the local ambulances.

4. **RUN DOWN OF THE OCTOBER 31, 1997 FIRE**

The fire alarm rang at 7:21 a.m. on October 31, 1997. The vehicle which caught fire was a transporter of 8 brand new passenger cars. The driver, aware of the danger and probably not realizing that he eventually could have reached the portal, which was less than 1 km in front of him, stopped and called the police from the nearest emergency station. When the fire started, 60 vehicles were in the tunnel, including 20 trucks. About half of them were driving towards the fire and had to be stopped.

One minute after the call, all the necessary emergency systems were activated, partly automatically and partly manually. The first team of firemen left the south portal, which was the closer one, 4 minutes after the alarm. The fire brigade of the opposite (farther) portal left 5 minutes later.

One hour after its beginning, the fire was reported under control and half an hour later the fire was extinguished. However, cooling went on for 2 more hours. Some more time was needed to get all the blocked users out of the tunnel and to extract the carcass of the burned-out truck (Figs. 4, 5).

From various collected data and interpreting the reports of the firemen, it was possible to establish a rough estimate of the size of the fire and its thermal development. In fact, according to the quantity of combusted material, the total released energy amounted to about 25 MWh. The developed heat power versus time can be approximated by the scheme on Fig. 6.
Figure 6: October 31st, 1997, Fire size versus time

Figure 7: Evacuation of tunnel users into shelters
Maximum air/smoke temperature reached at least 700° C, since various aluminum parts were completely fused. Maximum temperature in the ceiling structure and its steel reinforcement, however, did not exceed 500° C.

5. **BEHAVIOR AND EVACUATION OF THE USERS**

As in most tunnel fires, the first alarm was given by the involved motorist himself. He stopped the truck and called from the nearest SOS station. The automatic fire alarm followed 1 minute after the first call. Many additional calls, made by other users, came in.

The first patrol was in place 3 minutes after the alert. It immediately took care of the blocked users near the incident. Passenger cars were pulled back, turned and directed out of the tunnel. Trucks were left and their drivers escorted to the shelters. Since it was unavoidable that the smoke plume spread up to some hundred meters away from the fire, several vehicles ended up blocked in the smoke. Thanks to the action taken by the second rescue team which advanced from the northern (farther) portal, it was possible to evacuate the traffic space completely. As in previous experiences, it was not surprising that several users remained in their cars in spite of the rather hostile surrounding of dense smoke. They all were escorted to the nearest shelters (Fig. 7). Along the involved tunnel sector of up to 1000 m, 60 persons went or were led to the shelters. Once again it showed that most motorists are reluctant to leave their cars, even in the face of imminent danger. Only a few of them went to the shelters themselves, as they were expected to do. Fortunately there were no major injuries. Only one person suffered light smoke intoxication; she was dismissed from the hospital after a short check-up.

In fact, there was at no time any imminent danger for people. The development of the fire and the expansion of the smoke were slow enough to permit a safe evacuation. One particular aspect became evident, i.e., the danger for the men fighting the fire under the false ceiling. It was difficult to assess the residual resistance of the heat-damaged structure. The popping of concrete debris constitutes a real hazard, especially when the ceiling cannot be seen behind the dense smoke layer. The final evacuation of the tunnel after the fire had been extinguished, took quite a long time. 30 users had to be brought back into the tunnel to get their cars and several trucks had to be turned.

6. **DAMAGES AT STRUCTURES AND EQUIPMENT, URGENT FIRST INTERVENTION**

From the first inspection, it clearly appeared that the tunnel could not be reopened after the clearing of the traffic space, because the gravity of the damages did not allow sufficient safety. The following urgent interventions were already started while the removing of the burned out carcass was still going on:

- **Electrical equipment:** removing all the damaged elements over a length of about 100 m mounting of emergency lighting
- **Structural parts:** removing loose parts, mounting suspension bars and pulling up the deformed and fissured false ceiling
- **Road pavement:** shifting of the damaged upper strata and erecting provisional ramps.
These urgent works were finished by 8 p.m., when the tunnel was reopened for traffic. The closure took less than 13 hours.

Damage to the electrical equipment was heavy. The following material was completely destroyed:
- 3 video cameras
- radio transmission cable
- traffic lights
- SOS station
- traffic signs
- lighting
- cable trashes
- transit communication cables.

The visible damage of the ceiling consisted mainly of broken-off debris of concrete parts, which made the steel reinforcement visible for 90 - 100 m². Vertical deformation in the largest field reached nearly 10 cm. Obviously the necessary security was not ensured without provisional suspension. This was confirmed by laboratory tests: the reinforcing bars, which were first exposed to high temperature and then to the extinguishing water, showed a residual ultimate traction resistance of 290 - 350 N/mm². This corresponds to about 50% of the nominal value of new bars.
Fine cracks in the concrete could be made out as deep as 5 cm into the interior of the slab. In addition, there were several serious structural cracks.

An important factor for the rapidity of the security intervention was the readiness of the prepared fitting material. In fact, the control centers keep specially precast emergency equipment available, mainly to guarantee provisional support of the ceiling in the shortest time possible (Fig. 8). In addition, the tunnel personnel was familiar with the material, thanks to a detailed set of instructions, drawings and several training sessions in the tunnel. Thus there was no lengthy planning and discussion during the real event: everybody knew what to do. Compared to the previous truck fire, with very similar consequences, time for making the ceiling safe was halved.

7. FINAL REFURBISHMENT

The maintenance and repair concept, which is extremely important for such a long and heavily trafficked single tube road tunnel, includes 2 yearly periods when the tunnel is closed during the night (8 p.m. to 5 a.m.), for a total of 15 - 20 nights per year. During this time, traffic is diverted over the pass road.
The final repair works were planned and organized so that they could be carried out during these periods. Three elements of the ceiling, 120 m² over a length of 24 m, were demolished and replaced by precast elements in reinforced concrete, combined with permanent stainless steel anchor bars, fixed in the tunnel lining. The adjacent 2 elements on each side were jet treated, reinforced by shotcrete and secured by suspension bars. Finally, the lateral precast lining walls were replaced by new ones over a total length of 136 m.
The total cost of the repair works, including the electro-mechanical equipment, amounted to approximately 1,7 million CHF.
8. CONCLUSION

Long traffic tunnels are rather complex systems. With respect to incidents and fires, it becomes evident that every tunnel has its own typical risk scenarios for which the control and rescue teams become more and more familiar. The very awareness of this fact makes the tunnel safer.

The experience with the three truck fires in the St. Gotthard tunnel, which all occurred in a more or less similar way, allows the operating staff to deal better with potential further events. There is less of a surprising effect and the right decisions in a real case are easier to make. In addition, the prepared stock of precast support equipment for the ceiling, as well as the appropriate training of the crew, allow reopening of the tunnel in a very short time. The time factor is important, since the tunnel closure causes general costs for the economy. The public pressure for reopening the tunnel is strong, especially during the winter when the alternative pass road is closed by snow.

Finally, one can point out some further practical experiences which could be of general interest:
- Most fires develop slowly and there is a real possibility that burning trucks can leave the tunnel. The users have sufficient time to get to a safe place (shelters).
- The existence of shelters, with various security equipment, should be made better known to the users (more and bigger escape signs, leaflets, radio communication).
- The behavior of the false ceiling in reinforced concrete over a fire is generally favorable. Even when heavily damaged and deformed, it is unlikely to collapse instantly. On the other hand, the spalling of concrete debris may be a risk for the advancing rescue team.
- In a long tunnel, the problem of caring for blocked users who are far away and not aware of the incident must not be underestimated.