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THE 2001
GOTTHARD ROAD TUNNEL FIRE

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The 2001 Gotthard road tunnel fire

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Abstract: *With its single tube of 17 km in length, roughly 7 million vehicles per year and an average of 4,000 trucks each working day, the Gotthard road tunnel is undoubtedly overstressed. The October 2001 fire caused 11 unnecessary fatalities. Thanks to the readiness of the equipment and the tunnel staff, the fire did not claim more victims. About 500 people who were in the tunnel when the fire started were able to escape. The analysis of the behavior of the ventilation system and how the users reacted to the event has shown where further areas for increasing tunnel safety have to be emphasized. It has become evident that changes must not be limited to upgrading the infrastructure. One area in particular is to focus on better motorist information, consciousness and awareness.*

Introduction

In spite of the tragic fire of October 2001, the Gotthard road tunnel should be praised for an excellent overall record of availability and security. During its 23 years of operation, 123 million vehicles have used it instead of a pass road, which is 25 km longer than the tunnel, 1000 m higher and is closed six months during the winter.

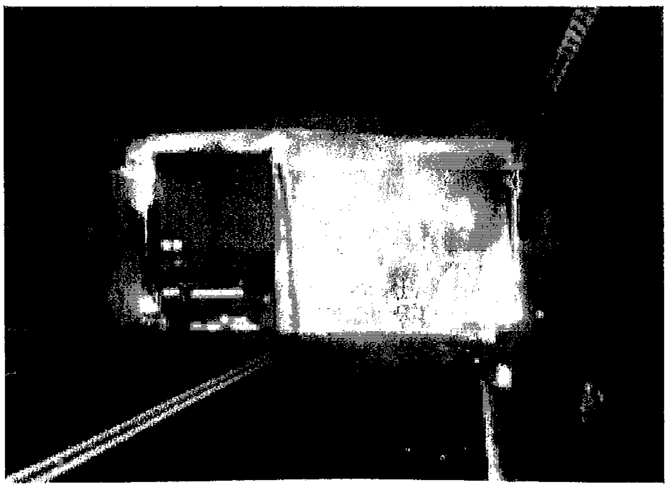
Statistically, the accident rate of the pass road is far higher than that of the tunnel. The latter is even lower than the nationwide average accident rate (defined as the number of events per 100 million vehicles·km).

Nevertheless, public opinion shows special sensitivity to tunnel safety and we are called upon to undertake every reasonable effort to further increase it. This has to be done not only by upgrading technical systems, but also by working on an adequate and responsible behavior of those involved: firstly, the tunnel staff, but mainly the tunnel users. In spite of the tragic and unnecessary 11 fatalities, the October 2001 Gotthard tunnel fire has allowed further lessons to be learned. Looking at the operating data since the fire, it can be seen that there have been positive consequences of the fire.

Foreseeable and new experiences

The origin and the development of the fire have been abundantly reported in press releases, in several technical papers (see references) and in reports of the public prosecutor. In summary, there was a head-on collision of two trucks, the ignition of spilled diesel fuel and the rapid spreading of the fire to a truck loaded with tires and to other vehicles which were blocked at a relatively close distance to the accident (see Figures 1 and 2).

In comparison with experiences during previous truck fires in the Gotthard tunnel, the 2001 fire developed with extreme rapidity. The heat release increased quickly, and in matter of a few minutes probably exceeded 100 MW.



Figures 1-2: Scene of the Gotthard tunnel fire moments after the rescue teams arrived from the south portal.

Nevertheless, nearly all of the tunnel users who were close to the fire zone left the tunnel unharmed – either through the carriageway itself, against the fresh air stream flowing in from the portal, or by going to a shelter and waiting for rescue through the parallel security tunnel. It is not known why one truck driver left the safe shelter again, returned to his truck and was not found, or why the driver of the incident truck, found dead on the road some 300 m north of the accident location, did not reach one of the shelters.

The first reaction of the drivers nearest to the accident was highly appropriate: they lost no time in sounding the alarm and evacuated the zone, warning and urging incoming vehicles to return and go out of the tunnel. This shows the positive effect of informed users who are familiar with the tunnel, especially the considerable number of motorists – mainly truck drivers – who are frequent users of the tunnel.

More important than the heat, from a point of fatalities, was the smoke production. It developed nearly as quickly as the heat. The combustion of the tires was the main source of smoke (see Figure 3). It produced a black, dense and poisonous smoke, which moved to the northern side, respectively, inside the tunnel. Although the ventilation system reacted quickly, worked properly and ensured that no smoke spread to the southern, portal-near side, it was not able to extract all of the exceptionally large amount of smoke moving to the north.

Whereas all users trapped nearest to the fire zone were fully aware of the situation and nearly all of them reached the shelters, some of the users further north, between 300 m and 600 m from the origin of the fire, were surprised and stayed in their cars or could not find/reach a shelter. This behavior is reminiscent of previous fire events, which fortunately were without serious consequences for the users. In these cases rescue personnel had a very difficult time convincing some motorists to leave their cars and enter the shelters. Considerable effort in the past few years has been undertaken by the Federal authorities, tunnel staff, press and by regular radio messages to make known to the public the correct behavior required in the case of incidents or fires in tunnels.

As we know, 23 vehicles were involved and destroyed, 13 of them trucks. The users directly involved were estimated to number 50 people. Some 30-35 of them saved their lives by going to the shelters. Others left the tunnel through the carriageway. The ventilation system of the security gallery and the shelters worked correctly. No smoke or heat penetrated into the shelters and the emergency doors operated normally (see Figure 4).

Behavior of the ventilation system near the fire zone

Analyzing the local and temporary behavior of the air streams close to the fire, one has to take into account that the ventilation system of this 17 km long one-tube tunnel is extremely complex and has to be seen as a whole. It is not only linked with all the necessary equipment for aerodynamical purposes (air control in the traffic space, air temperatures and pressures, working regime of the fans), but also with several other systems which are involved in case of a serious disturbance, like the communication system, the traffic control and others.

The exhaust fans involved were reset from the initial reduced semi-transversal regime (see Figure 5) to full operation between 4 and 6 minutes after the beginning of the fire. Because of the extremely rapid development of the fire, it was unavoidable that the smoke spread towards the north side before the full exhaust rate had become effective. A distance of 500 m north of the fire, where most of the fatalities occurred, the smoke arrived about 4 minutes after ignition, still enough time for some users to turn their vehicle around and leave the tunnel or get to a safe place, but too short for some unaware users who waited and did not realize what was happening further along the tunnel.

Figure 3: Remains of the burnt tires.

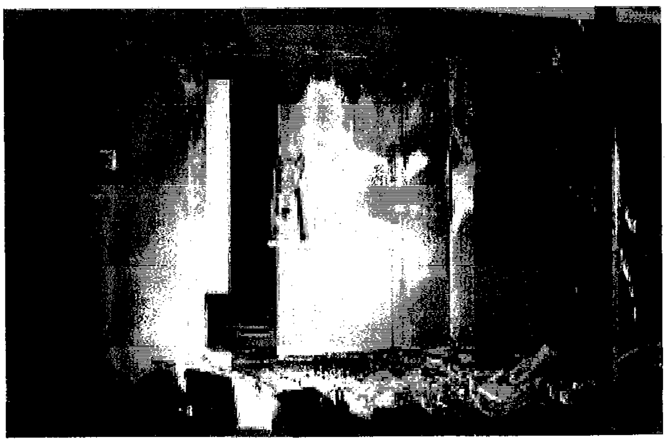


Figure 4: The shelter door no. 69 worked correctly during the fire.

One has to consider that the tunnel air extraction occurred uniformly through regular openings in the ceiling, since the new smoke extraction system operated by motorized dampers was not yet fully installed at that time. Figure 6 shows a plot of the propagation of the smoke as best deduced from the data of the various control equipment. An accurate analysis of the balance of the air flows during the fire showed clearly that the northbound drift was considerably amplified by the predominant piston effect of the traffic, 38% of it heavy vehicles, evacuating the 16 km long northern part of the tunnel.

The affect on the ventilation of the Gotthard tunnel due to the fuzzy piston effect caused by trucks is well known. It is due to the extreme length of the tunnel, the relatively small traffic space (40 m²) and the large number of trucks. This effect, so far, has not caused any major harm during normal operation, but it may be a determining risk factor during the transient regime in an emergency situation. It can now be eliminated with the new extraction system operated by means of dampers.

Heavy damage

Shortly after the fire, following a first inspection by the structural engineer, one could identify a zone of 230 m of length where the intermediate ceiling had collapsed or showed severe damage. This was defined as the 'red zone' where no access was allowed prior to structural support measures. Beyond that zone, structural damage was limited, but the electromechanical equipment was destroyed. This extended zone was 750 m long. A thick black smoke deposit, which covered all surfaces and stranded vehicles, extended over more than one kilometer from the fire.

Typical damage patterns of the intermediate ceiling, over the 230 m, where 7 trucks burned out completely, are showed in Figure 7. In the northern part, the side of the slab towards the exhaust air – over the burning trucks – collapsed, whereas the other side presented surface damage. In the central part measuring 56 m and with no vehicles, the ceiling did not collapse, but exhibited great deformation, cracks and extended concrete spalling. In the southern part, where the fire initiated, both halves of the ceiling collapsed, but on one side it did not fall down onto the road, but was just held up by the lateral secondary prefabricated lining.

In spite of the impressive general destruction, one could observe some parts and equipment, which showed a surprising resistance to the fire.

- The prefabricated lining on both sides, although locally deformed and fissured, offered resistance on the whole length and acted as an excellent protection for the primary concrete lining. The latter resisted with practically no loss of mechanical quality.
- The vertical dividing wall in the crown, and especially the integrated suspension bars, resisted with no remarkable reduction of the mechanical properties. Whereas the ceiling had to be entirely replaced for the whole length of the red zone, the wall has been neatly fitted at the lower end and could stay in place.
- The sidewalks were damaged, mainly by secondary effects caused by melted parts of the vehicles and fallen debris. The ducts under the sidewalks remained undamaged. The electrical cables (high voltage, command cables and glass-fibers) did not lose their function and it wasn't even necessary to replace them.
- The fresh air duct, which worked with a reduced air flow during the whole time of the fire, remained unharmed, as did the electrical equipment which is installed inside. The radio emitting cable above the ceiling worked correctly during the whole fire. This was an essential factor for the entire rescue and extinguishing operations.
- The two emergency cabin doors and the shelter door, which were situated in the red zone, showed some minor deformations and the destruction of the elastic joints, but remained operable during and after the fire.

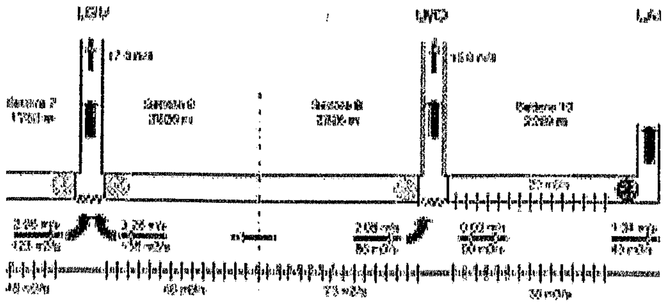


Figure 5: Air flow in the tunnel immediately before the fire (09:41:27).

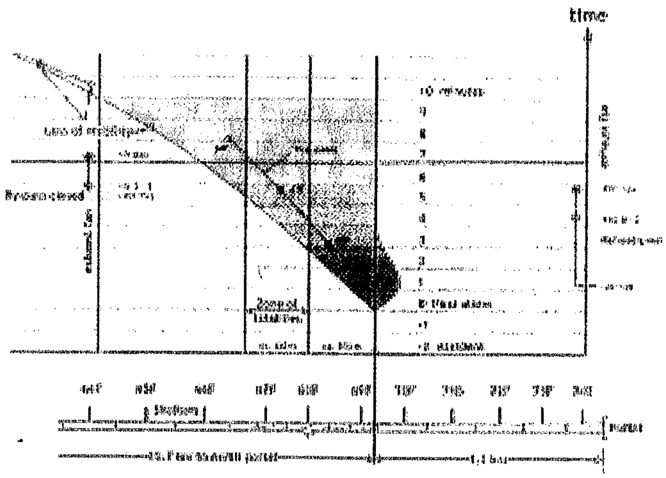


Figure 6: Plot of the propagation of smoke.

Reopening after 2 months

Considering the importance of the tunnel as an artery for national and international transport, the authorities set up three basic conditions for the repair and reopening operations:

- reopening as soon as possible.
- security standard as before the fire.
- risk reduction by means of appropriate new traffic management.

The short time factor, when planning the repair works, was very difficult. One had to face unforeseeable activities and restricted accessibility to the damage zone – blocked by destroyed vehicles and debris from the damaged structures. Furthermore, there were limitations imposed by the forensic police and by specialists in charge of monitoring and evaluating the contamination and pollution prevention (see Figure 8).

Due to an exceptional effort of the maintenance teams and with the help of the excellent and dry late autumn

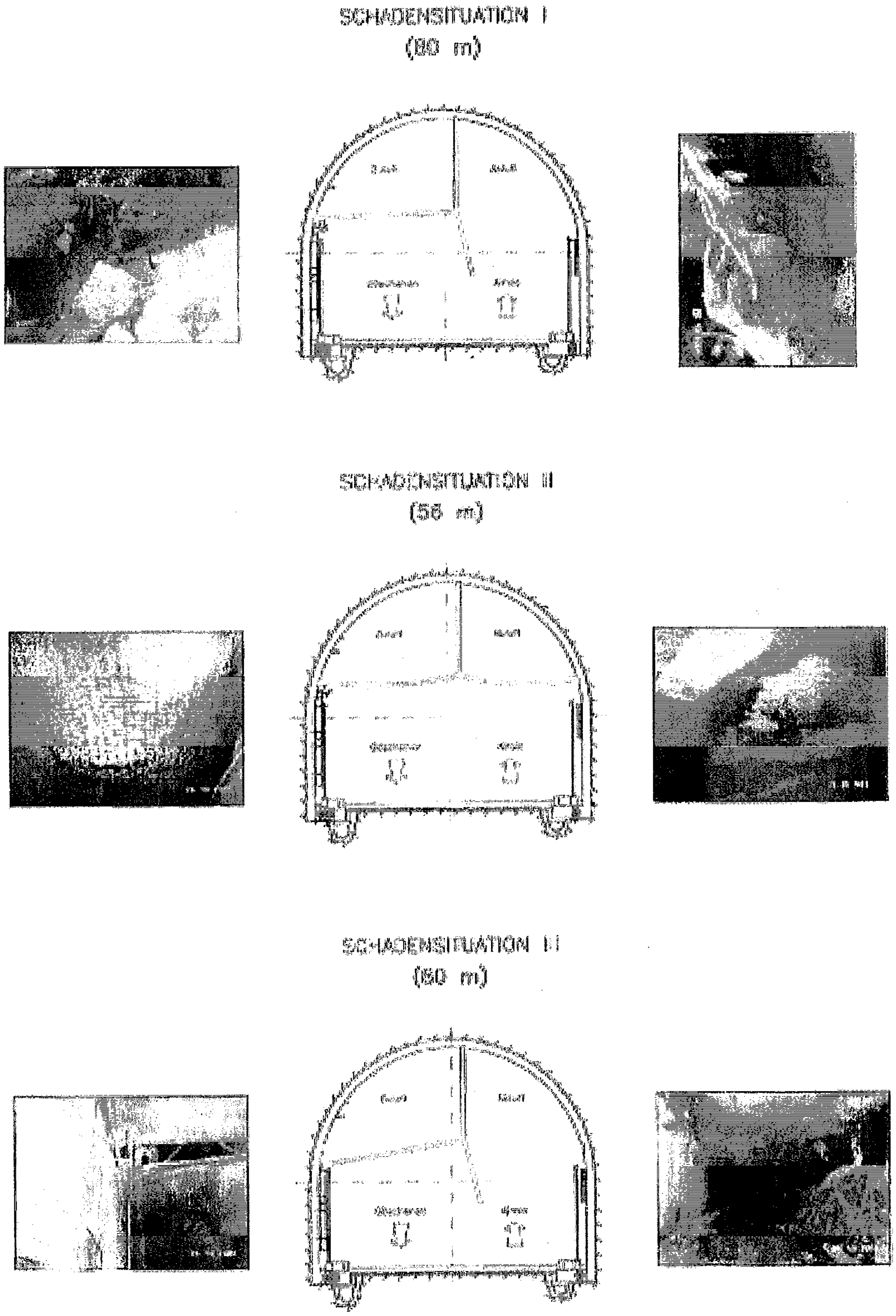


Figure 7: Ceiling damage patterns found in the 'red zone.'

Figure 8: Debris of the destroyed vehicles had to be left untouched in order to allow examination by the forensic police.

weather, it was possible to leave the mountain pass road open during the whole period of the repair works. It was, however, limited to passenger cars and light trucks.

The analysis of the damage situation, the concept and the procedures of the works had to be done in a very short time. This involved a small team and in tight collaboration with the tunnel staff, the contractor and the suppliers of the various special materials. It was an advantage that the tunnel crew had been trained to face similar scenarios, although not to the extent that really occurred. The maintenance set contained adequate auxiliary equipment, like support material, suspension bars, etc., ready to install in a very short time.

The following additional factors allowed a rapid planning and realization of the work:

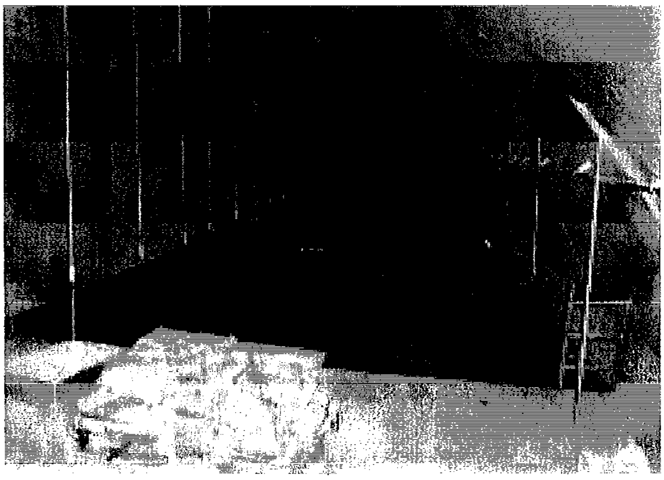
- Efficient use of the time, some three weeks, during which the tunnel was blocked after the fire and not yet opened by the public prosecutor: design, contracts, preparing of the precast elements.
- No temporary solutions, which would have needed subsequent construction under traffic.
- Adequate use of existing logistics, equipment and resources. All members of the operating staff, engineers, supervisors and contractors had previously worked in the tunnel and were entirely familiar and prepared for their task. Thanks to good collaboration with the management of other big tunnels, it was possible to use a whole set of lightning equipment (700 m) originally designated for another tunnel; this eliminated having to wait for the rather long production schedule for new lighting.
- It was evident that the solution should be based on precasting, reducing working time in the tunnel itself (see Figures 9 and 10).
- The enforced closing of the tunnel made it possible to accelerate other upgrading and maintenance projects, in particular the improvement of the ventilation system. The readiness of the latter could therefore be advanced by six months.
- Certain works, which were not relevant for safety, have been executed after reopening – during the night closures, for instance, the lateral secondary lining walls, the substitution of the normal steel hangers with stainless steel hangers.

New traffic management

On December 20, 2001, the St. Gotthard road tunnel reopened – resuming the link between the northern and southern parts of Switzerland. Some traffic limitations were imposed in view of further improvements of the security equipment.

For safety reasons it was decided to reopen the tunnel to heavy traffic in a unidirectional manner – with the alternate transit of trucks on the basis of a precise timetable (about 1 hour transit for 2 to 4 hours of waiting time).

The prescribed distances between the trucks in the tunnel (150 m) were indicated with the introduction of different kinds of horizontal and vertical traffic signs.



Figures 9-10: Works before and during the assembly of precast ceiling elements.

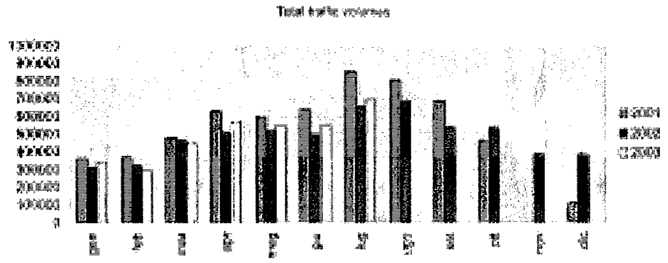


Figure 11: Total traffic volumes.

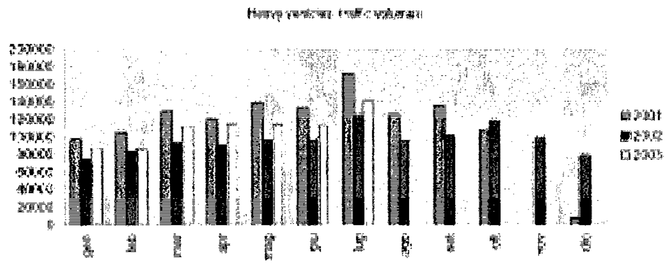


Figure 12: Heavy vehicle traffic volumes.

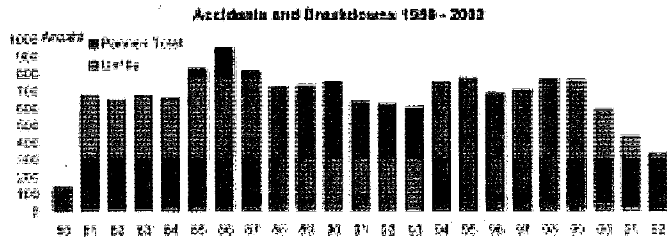


Figure 13: Accidents and breakdowns: 1980-2002.

Their purpose was to inform truck drivers that this distance had to be respected in any situation, even in the case of slowing down or standstill in the tunnel. This kind of truck traffic restriction, which caused considerable problems to the management of the access ramps, was maintained until the end of September 2002.

The daily transit in the two directions at that time was of 2,500 to 3,000 trucks (before the fire about 4,000). After that period, corresponding to the availability of the remotely controlled smoke-extraction dampers, a new management of heavy trucks with bidirectional traffic was adopted (one truck every 20 to 60 seconds) with regulation position situated on the access ramps and near the portals.

This system is still in operation with quite satisfactory results. The average daily transit of trucks amounts to about 3,000 to 3,500 vehicles. No limitation has been imposed on private traffic during the whole time. Its decrease is due to different reasons, but probably includes the psychological effect that the fire incident has provoked on the users (see Figures 11-12).

A significant improvement of the users' behavior has to be mentioned, both for the attention and concentration paid and for the respect of the rules.

To further improve the transit conditions, an increase in the lighting level was decided, as well as the exclusive use of fully transverse ventilation, instead of the semi-transverse ventilation. These two measures allowed for a significant improvement in the visibility conditions inside the tunnel.

The improved users' awareness has resulted in a considerable reduction in the number of accidents and breakdowns in the tunnel (see Figure 13).

Current and new upgrading projects

A confirmed trend focuses on the self-rescue of users, considering that in case of emergency in the decisive phase, i.e., during the first 10 minutes, there will not be any help from the outside.

In this respect, a series of measures has been adopted to inform users about the way to get to a safe place. They are (not in order of importance):

- signs every 50 m inside the tunnel, which indicate the distance and direction of the nearest shelter (already installed).
- highlighting, with white and green color, the shelters' entrances (in progress, see Figure 14).
- information panels inside of the shelters (already installed).
- installation of a reinforced illumination and flashlights at the shelters' entrances (in progress, see Figure 14).
- installation of light spots along the side walks (in progress).
- automation of the radio information in four languages in case of a critical event.
- communication with the shelters by means of loud-

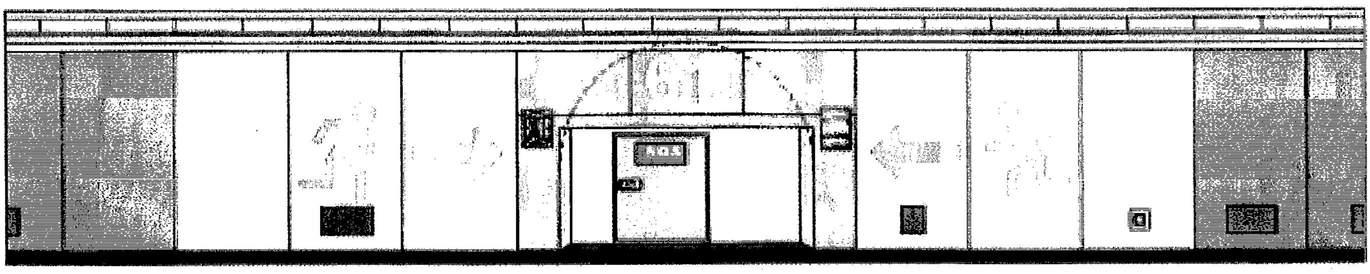


Figure 14: New layout of the shelter entrances.

speakers and pre-packed messages in four languages.
- indication in four languages on the way to behave inside the SOS shelters without exit.
- improvement of the information sheets distributed to users at every possible occasion.

Outlook for tunnel management

Tunnel management tries to find the correct balance between private and heavy commercial traffic, without exceeding the capacity and avoiding traffic congestion inside the tunnel.

As already mentioned, users' attention and awareness have considerably increased, helping the operator's tasks. This trend will increase by the relatively simple new measures giving a maximum of information to users, like:

- highlighting the shelter entrances.
- signals to shelters along the tunnel walls.
- signals for vehicle distances.
- more frequent radio messages.

The operator's aim is a high standard of information and preparation, which implies the availability of the best possible technology and instrumentation for the efficient management of the tunnel.

Conclusions

In comparison to other cases of big tunnel fires, the Gotthard tunnel did not require new or modified upgrading of mechanical equipment. The damper project was already ongoing before the fire, and is today operating.

The increased security record since the fire is due to the better awareness of the users and new traffic management.

The new measures undertaken are focused on practical issues:

- increased readiness of the operators and quicker response of the system (e.g., starting procedure of the exhaust fans).
- better signalization in the carriage way and highlighting the entrances of the safe havens.

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