AFTES
Post-graduate specialised Master's degree
Tunnels and underground structures from design
to operation; Module 5: Equipments and safety during operation
18. January 2012, Lyon (F)

Aspects of fire safety in road and railway tunnels

Alfred Haack
STUVA, Cologne, Germany
ITA, Lausanne, Switzerland

Starting situation
Fire accidents
Design fire curves
Time temperature curves
Emergency scenarios for metros
Safety measures in road tunnels
Closing

General starting situation:
Busy traffic tunnels with passenger and goods transport

Tunnelling in Germany 2010 [km]

<table>
<thead>
<tr>
<th>type of tunnel</th>
<th>in operation</th>
<th>under construction</th>
<th>planned</th>
<th>oldest tunnel</th>
</tr>
</thead>
<tbody>
<tr>
<td>metro</td>
<td>660</td>
<td>27</td>
<td>46</td>
<td>1902 Berlin</td>
</tr>
<tr>
<td>railway</td>
<td>490</td>
<td>91</td>
<td>181</td>
<td>1843 Köln-Aachen</td>
</tr>
<tr>
<td>road</td>
<td>250</td>
<td>41</td>
<td>154</td>
<td>1834 Altenahr</td>
</tr>
<tr>
<td>total</td>
<td>1,400</td>
<td>159</td>
<td>381</td>
<td>——</td>
</tr>
</tbody>
</table>

Worldwide tunnelling

Europe ~ 2,500 km
(A) ~ 260 km (F) ~ 150 km
(D) ~ 400 km (I) ~ 200 km
(E, P) ~ 500 km (N, S, SF) ~ 500 km

Asia ~ 2,500 km
South America ~ 650 km
North America > 650 km
**Worldwide tunnelling**

**Medium term perspective**

- **North America**: > 650 km
- **South America**: ~ 650 km
- **Africa**: ~ 100 km
- **Europe**: ~ 2,500 km
- **Asia**: (mainly China, Japan, Korea)
- **Australia**: ~ 100 km
- **Australia**: ~ 100 km

**Mega tunnels planned**

<table>
<thead>
<tr>
<th>Tunnel</th>
<th>Country</th>
<th>Length (km)</th>
<th>Completion Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gotthard base tunnel</td>
<td>CH</td>
<td>57</td>
<td>2017</td>
</tr>
<tr>
<td>Lötschberg base tunnel</td>
<td>CH</td>
<td>37</td>
<td>2007</td>
</tr>
<tr>
<td>Ceneri base tunnel</td>
<td>CH</td>
<td>15</td>
<td>2017</td>
</tr>
<tr>
<td>Brenner base tunnel</td>
<td>A / I</td>
<td>55</td>
<td>2018</td>
</tr>
<tr>
<td>Mont d’Albin</td>
<td>F / I</td>
<td>53</td>
<td>2020</td>
</tr>
<tr>
<td>Strait of Tatars</td>
<td>RUS</td>
<td>12</td>
<td>?</td>
</tr>
<tr>
<td>Bering Strait</td>
<td>RUS / USA</td>
<td>97</td>
<td>?</td>
</tr>
<tr>
<td>Strait of Gibraltar</td>
<td>E / MA</td>
<td>35</td>
<td>2025</td>
</tr>
<tr>
<td>Koralin</td>
<td>A</td>
<td>33</td>
<td>2013</td>
</tr>
</tbody>
</table>

**Fire catastrophes - road**

- **Mt. Blanc Tunnel (F/I)**: 24.03.1999, 39 Fatalities
- **Tauerntunnel (A)**: 28.05.1999, 12 Fatalities
- **Gotthardtunnel (CH)**: 24.10.2001, 11 Fatalities

**Fire catastrophes - rail**

- **Station Koblenz (D)**: 07.11.1983, No injured
- **Eurotunnel (F / GB)**: 18.11.1996, 31 injured
- **Station Offenbach (D)**: 23.11.2001, No injured

**Fire catastrophes - metro**

- **Hamburg S-Bahn (D)**: 08.04.1980, 3 injured
- **London Metro (GB)**: 18.11.1987, 31 fatalities
- **Daegu Metro (South Korea)**: 18.02.2003, 196 fatalities

**Starting situation**

- **Fire accidents**
- Design fire curves
- Time temperature curves
- Emergency scenarios for metros
- Safety measures in road tunnels

**Closing**
Effects on users

Endangering of tunnel users

- fire
- smoke
- temperature
- toxic substances (CO, HCN etc.)
- disorientation because of low visibility
- shock and panic
- suffocation due to reduced O2 content
- injuries by falling debris
Effects on fire brigades

Endangering of firemen
- fire
- extremely dense smoke
- very high temperature and heat radiation
- difficult orientation due to low visibility
- injuries by falling debris and spalling concrete
Effects on the tunnel construction

Endangering of tunnel construction
- direct impact by fire
- extreme temperature gradient
- local bursting and spalling of concrete
- local compulsive strains and strengths
- critical deformations of concrete and steel
- disintegration
- collapse of components
Starting situation

Fire accidents

→ Design fire curves

Time temperature curves

Emergency scenarios for metros

Safety measures in road tunnels

Closing

Design fire curves

(heat and smoke release) form the basis for calculating escape and rescue processes

Design fire curve ET 423 of DB

![Design fire curve ET 423 of DB](image)
Smoke release curve ET 423 of DB

Energy release curves for metro

Starting situation
Fire accidents
Design fire curves
→ **Time temperature curves**
Emergency scenarios for metros
Safety measures in road tunnels
Closing

**Time temperature curves**
form the basis for the structural design (statics of the concrete elements, mechanical equipment of a tunnel)
Starting situation
Fire accidents
Design fire curves
Time temperature curves
\textbf{Emergency scenarios for metros}
Safety measures in tunnels
Closing

\textbf{Metro fires caused by arson}

\begin{tabular}{|c|c|c|c|}
\hline
Year & City & Damage & Persons & Vehicles \\
\hline
1984 & Hamburg & 1 injured & 3 & \\
1985 & New York & 15 injured & 16 & \\
1987 & London & 31 fat. / 100 inj. & ? & \\
2003 & Daegu & 196 fat. / 147 inj. & ? & \\
\hline
\end{tabular}

\textbf{Metro fires caused by technical defects}

\begin{tabular}{|c|c|c|c|}
\hline
Year & City & Damage & Persons & Vehicles \\
\hline
1982 & New York & 86 inj. & 1 & \\
1982 & London & 15 inj. & Ca. 3 & \\
1983 & Munich & 7 inj. & 2 & \\
1985 & Mexico City & 21 inj. & ? & \\
2007 & Paris & 35 inj. & ? & \\
\hline
\end{tabular}

\textbf{Problems in case of fire}

- fire load
- flash over after 15 to 25 minutes
- masses of smoke
- very soon loss of visibility
- communication
- constriction
- extinguishing water
Fire load in metro cars
50 to 80 kg/m² (equivalent to wood)

For comparison:
- housing: 30 to 80 kg/m²
- department warehouse: 100 kg/m²

Selected standard emergency scenario

train is burning, but still arrives the next station

Self rescue phase
duration until 15th minute after ignition
requirements:
(1) sufficient visibility: ≥ 10 m
(2) height of mostly smokefree layer above platform level: ≥ 2.5 m

Aided rescue phase
duration from 15th to 30th minute after ignition
requirements:
(1) sufficient visibility: ≥ 10 m
(2) height of mostly smokefree layer above platform level: ≥ 1.5 m

smoke protection measures
(1) larger storing capacity in case of higher ceiling
(2) fixed or mobile smoke curtains to limit smoke dispersion
(3) shafts to extract smoke to surface
(4) calculation of smoke dispersion using zone- or field-models (CFD)
Limitation of smoke dispersion

Requirements for nearly smokefree layer

1. sufficient height
2. temperature \( \leq 50 \, ^\circ \text{C} \)
3. content of oxygen \( \geq 14 \, \text{Vol.\%} \)
4. concentration of toxics small, e.g. CO \( \leq 500 \, \text{ppm} \)
5. sufficient visibility \( \geq 10 \, \text{m} \)

Calculation of evacuation

1. dimensions of station
2. number of persons
3. escape route, capacity of stairways

Simulation of evacuation (1)

1. computer aided methods e.g.: Aseri, Pedgo, BuildingExodus

Advantages:

a) self-explanatory
b) simulation with variations of mobility and obstacles
c) merging of passenger streams

Simulation of evacuation (2)

(example Aseri)
Simulation of evacuation (3)
(example Aseri)

Simulation of evacuation (4)
(2) non-computer aided methods
  a) NFPA 130
  b) Predtetschenski / Milinski

advantage: easy control of results

Time schedule
before start of evacuation

(1) vehicle starts burning in tunnel
(2) fire detection: after min 1
(3) arrival in station: after min 2
(4) call for leaving the vehicle: after min 3
(5) beginning of evacuation: after min 4
(reaction time of passengers: 1 min)

Benchmarks for fixed stairways

(1) width of escape lane: 60 cm
(2) capacity: 33 persons / min / lane
(according to NFPA 130 for fixed stairways used upwards)

Benchmarks for escalators

(1) width of escape lane: 60 cm although escalator 1m wide (reserve on safe side)
(2) all escalators switched off
(3) capacity only: 25 persons/min/lane
(4) 1 escalator not available (because of maintenance)

Simulation of evacuation (5)

evacuation time
= time before start of evacuation (4 min)
+ walking time
+ all waiting times
must be shorter than the critical smoke build-up time
Basic requirements for metros

- 2 independent exits
- In older facilities not meeting this condition: improved escape way through running tunnel

Influence of vehicle construction on dimensions of damage

- Steel
- Aluminium
- Plastic

(downwards increase of damage)

Basic requirement

An effective fire safety concept requires a holistic view considering:
- Construction of tunnel
- Rolling stock
- Operational organisation
- Rescue and fire fighting service
Fire simulation

(1) geometry of station
(2) structural fire protection measures
   (e.g. smoke curtains, extraction shafts)
(3) dimensions of railway car
(4) fire relevant data of vehicle (e.g. heat and
    smoke release rates)

Acceptance test of underground metro station for validation
   (loud speakers, emergency lighting, control of lifts and
    escalators, fire detectors, propagation of smoke)

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lay-by:

Acceptance test of operational equipment in the Markusberg road tunnel, Luxemburg (ventilation, loudspeakers, emergency lighting, signing, closing barrier)

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Closing
Fire and smoke compartmentalisation

Not appropriate in the main tunnel are:
• gates
• inflatable barriers
• one-piece textile curtains

In contrast appropriate are:
• multilayer water curtains
• vertical blinds

There is no doubt: In our daily life we need tunnels!

Therefore:
Let us build them!
Let us make them safe!
Let us use them!

Thanks for your attention!