Performance based design approach in smoke evacuation in existing Belgian railway tunnels

Bart De Pauw, Lead Design Engineer, Expert Structures, TUC RAIL NV
Introduction

More attention to the level of safety in existing tunnels
• Fire in railway tunnel:
  • Channel tunnel:
    – 17 November 1996
    – 21 August 2006
    – 11 September 2008
  • Kaprun Austria
    – 11 November 2000
Outline of the presentation

• Introduction
• Performance based design
• Case studies – new railway tunnels
• Case studies – renovation of existing tunnels
• Tunnel Schuman - Josaphat
• North–South Link Brussels
• Next steps
• Conclusions
Introduction

Codes and guidelines

Interfaces

Calamities

Risk analysis

Design requirements
Introduction
Tunnel as a system - Interfaces
Introduction

CALAMITIES
- FIRE / EXPLOSION
- DERAILMENT
- COLLISION
- STRUCTURAL
- spontaneous EVACUATION

RISK-ANALYSIS & OPTIMALIZATION
« manageable risk »

Additional design requirements
- Structural
  • Cross Passages & Evacuation shafts
  • Evacuation paths (f.e. Innostrails)
  • Accesses
- Subsystems
  • Fire detection – Ventilation – Communication – etc.
Introduction – tunnel in normal exploitation
Introduction – tunnel in mode maintenance
Introduction – tunnel in calamity (fire)
Introduction – tunnel in calamity (gas leak)
Introduction – renovation of railway tunnels

EXISTING SITUATION OF The TUNNEL

ACTUAL SAFETY LEVEL

Verification regarding codes and guidelines
- Structural
- Fire resistance
- Calamity
- Subsystems
- Different Interfaces

Work out and define project requirements and possible solutions

Choice of best solution (cost – safety – impact on tunnel in service – risks – deadlines) Choice
Introduction – Interoperability

Interoperability

• the capacity of the various national networks to interact, without interruption, with the adjoining networks, enabling a passenger or goods train to circulate without distinction on any section of the large trans-European railway network

<table>
<thead>
<tr>
<th>Land</th>
<th>Spoorbreedte [mm]</th>
<th>Elektrische voeding</th>
<th>Seininrichtingssyste em</th>
<th>Type HST-treinen</th>
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<tbody>
<tr>
<td>België</td>
<td>1435</td>
<td>3kV DC – 25kV AC (HST)</td>
<td>TBL</td>
<td>Eurostar, Thalys, TGV, ICE</td>
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<tr>
<td>Denemarken</td>
<td>1435</td>
<td>1,5kV DC – 25kV 50Hz AC</td>
<td>ZUB</td>
<td>IC3, ICE, SJ2000</td>
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<td>Frankrijk</td>
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<td>25kV 50Hz AC</td>
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<td>Duitsland</td>
<td>1435</td>
<td>15kV 16.2/3 Hz AC</td>
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<td>ICE, Thalys, TGV</td>
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<td>Verenigd Koninkrijk</td>
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<td>750 V DC - 25kV 50Hz AC</td>
<td>AWS, Selcab, TBL</td>
<td>Eurostar – IC225</td>
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<td>1435</td>
<td>1,5 kV DC</td>
<td>ATB</td>
<td>Thalys, ICE</td>
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<tr>
<td>Spanje</td>
<td>1668 (HST:1435)</td>
<td>3kV DC – 25kV 50Hz DC</td>
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<td>ZUB</td>
<td>TGV, SJ 2000, ETR470, ICE</td>
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</table>
Introduction – Interoperability

Interoperability

European legislation

Safety

Regulation 2008/57/CE

Technical Specifications for interoperability (TSI)

Regulation 2004/49/CE

Common Safety Method (CSM)
Introduction – Interoperability

Structural
- Infrastructure (INF): track, civil engineering

Functional
- Energie (ENE): catenary, power supply
- Signaling (CCS)
- Rolling stock (RST)
- Operation and traffic management (OPE)
- Maintenance (MAI)
- Telematic services for “passengers” and “goods” (TAP/TAF)
- Safety in railway tunnels
- People with reduced mobility

Essential requirements

Specific requirements per subsystem
- Safety (RAMS) (Reliability, Availability, Maintainability, Safety)
- Health
- Environmental protection
- Technical compatibility

Other requirements
- Local environment
- Legislator authorities
## Performance based design

<table>
<thead>
<tr>
<th>PERFORMANCE REQUIREMENTS</th>
<th>PRESCRIPTIVE REQUIREMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>PURPOSE</td>
<td></td>
</tr>
<tr>
<td>&quot;To ensure the activity structure conforms with a set of minimum design governing force, form, durability and serviceability&quot;</td>
<td>&quot;To ensure adequate control over the impacts (materials, space etc.) and processes (placing, compaction, curing etc.) of construction, in order to avoid construction to achieve the performance&quot;</td>
</tr>
</tbody>
</table>

### INPUTS & ELEMENTS

- **Determine the governing mode of deterioration**
- **Identify the exposure environment**
- **Observe visible transport or other parameter (e.g. chloride ingress parameter, movement parameter)**
- **Consider possible range of binder types available**

### MATERIALS & MIXES: e.g. limits on materials, susceptible materials, limits on proportion, alkali content & fibre of binding, setting time, bond limits, maximum water content, etc.

### CONSTRUCTION PRACTICES: e.g. suspension of placing, required compaction, plastic defects, specified curing, maximum delay times before placing, finishing, additional or early protection

### OUTPUTS

- **Specify limiting value(s) in relation to above factors (i.e. "maintained" with environment and binder type)**
- **Check on other construction-related requirements such as need for adequate curing air, check on area achieved, etc.**
- **Provide clear procedure for non-compliance with specifications, e.g. possible remediation**
- **Clearly prescribed limitations on materials, space, and construction processes, such that known harmful or detrimental factor are excluded**

- **Provide suitable narrative guiding construction in how to achieve performance requirements**
Performance based design

“**Performance-based engineering** is the design, evaluation and construction of engineered facilities that meet, as economically as possible, the uncertain future demands that both owner-users and nature will put upon them. The premise is that performance levels and objectives can be quantified, that performance can be predicted analytically, and that the cost of improved performance can be evaluated, so that rational trade-offs can be made based on life-cycle considerations rather than construction costs alone.”

(structural engineering en geomechanics)
Performance based design
Figure 1: Overview of railway risks and mitigation measures (from [1])
Performance-based design

Eight key steps are defined as follows:
1. Specification of basic fire design
2. System and problem definition,
3. Identification of relevant scenarios,
4. Definition of fire safety measures,
5. Preliminary screening of scenarios and identification of critical scenarios,
6. Detailed analysis of critical scenarios,
7. Evaluation of possibly adapted safety measures based on detailed scenarios,
8. Assessment and conclusions.

Figure 2: Overview of methodology
Performance-based design

FESG
Performance-based design
Case studies new railway tunnels

- Kennedytunnel
- Liefkenshoek spoorverbinding
- Diabolo
- Soumagne
- Noord-Zuid verbinding Antwerpen

renovation
North-South Link Antwerp

Tunnel layout in general
• evacuation shafts (ES) en cross-passages (CP)
  – Every +/- 300m
• Evacuation paths

- Protection against collision and derailment
- Structural resistance tunnel and material
Tunnel Soumagne

Tunnel layout in general
Tunnel van Soumagne

- 2 Evacuation shafts (ES)
  - Bay-Bonnet
  - Bouny

structural measures

Schéma du tunnel de Soumagne avec ses sorties de secours
Tunnel van Soumagne

- **Evacuation paths – double track**
  - « Strails « every 500 m
  - Protection against collision and derailment
  - Structural resistance tunnel and material
1. Nieuwe HSL Brussel - Antwerpen
2. Noordelijke en zuidelijke toegangshelling
3. Cut & covertunnel (560m)
4. 2 enkelsporige boortunnels (1075m)
5. Uitbreiding van het bestaande station

Tunnel layout in general
Diabolo

- **evacuationshaft** (ES) and **cross-passages** (CP)
• Evacuation paths

Dubbelsporige sectie
1/ spoor - 1,60 m breed - 0,50 m t.o.v. de rails

Enkelsporige geboorde tunnel
2/ spoor -1m breed op vloersteen niveau - 0,65 m t.o.v. de rail
Diabolo

- Protection against collision and derailment
- Structural resistance tunnel and material
Liefkenshoek Railway Tunnel

Tunnel layout in general

Aanleg spoorbedding van Bundel Zuid tot Beverenspoor-tunnel (1-3)

Renovatie en aanpassing van de bestaande Beverenspoortunnel (3-4)

Bouw van twee enkelsporige boortunnels onder Schelde en kanaaldok B1-B2 (5-6)

Bouw van gesloten tunnelconstructie en open toegangsheiling op Rechteroever (6-7)

Aanpassing van bestaande spoortunnel onder R2 (7→)

Noord-Zuid verbinding Antwerpen

Bouw van toegangs-tunnel tussen Beverenspoortunnel en boortunnels (4-5)

6,7 km

1,2 km

6 km

75 m
Liefkenshoek Railway Tunnel

- **ES and CP**
  - Evacuationshafts: 13 in total; +/- every 600m
  - Cross-passages at every ES and 13 independent; +/- every 300 m
Liefkenshoek Railway Tunnel

Life time assessment (Ugent)
Liefkenshoek Railway Tunnel

Fire test in situ
Kennedytunnel

Tunnel layout in general
Kennedytunnel

- Additional evacuatieshaft (ES)

structural measures
Kennedytunnel

structural measures
# Overview structural measures / requirements

<table>
<thead>
<tr>
<th></th>
<th>Noord-zuid Antwerpen</th>
<th>Soumagne</th>
<th>Diabolo</th>
<th>Liefkenshoek-spoorverbinding</th>
<th>Kennedy-spoortunnel</th>
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<tr>
<td><strong>Type vervoer</strong></td>
<td>Reizigers</td>
<td>Reizigers</td>
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<td>Gemengd</td>
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<td>Drill&amp;Blast</td>
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<td>1.4m breed</td>
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<td><strong>Ontsporing en botsing</strong></td>
<td>-</td>
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<td>-</td>
<td>-</td>
<td>Geleidingsrail</td>
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<td><strong>Evaucatie-mogelijkheden</strong></td>
<td>~ 300m</td>
<td>~ 2.1km</td>
<td>~ 300m</td>
<td>~ 300m</td>
<td>~ 150m</td>
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<td><strong>Brandweerstand</strong></td>
<td>ISO + brandwerende bespuiting boortunnel</td>
<td>Onbrandbare omhulling met d=30cm</td>
<td>Eureka</td>
<td>RWS + brandwerende bespuiting</td>
<td>RWS + brandwerende bekleding</td>
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<td><strong>Branddetectie</strong></td>
<td>Punctueel in station</td>
<td>Lineair</td>
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<td><strong>Ventilatie</strong></td>
<td>Omkeerbaar HRR = 14MW</td>
<td>Omkeerbaar HRR = 14MW</td>
<td>Omkeerbaar HRR = 14MW</td>
<td>Enkel push HRR = 200MW</td>
<td>In studie</td>
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<td><strong>Brandbestrijdingsmiddelen</strong></td>
<td>Hydranten (60m) natte leiding sprinklers in station</td>
<td>Hydranten (100m) natte leiding spoor-weg voertuig</td>
<td>Hydranten (100m) natte leiding spoor-weg voertuig sprinklers in station</td>
<td>AFS hydranten natte leiding</td>
<td>Natte leiding met hydranten</td>
</tr>
<tr>
<td><strong>Communicatiemiddelen</strong></td>
<td>GSM-R ASTRID</td>
<td>GSM-R ASTRID</td>
<td>GSM-R ASTRID</td>
<td>GSM-R ASTRID</td>
<td>GSM-R ASTRID</td>
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<td><strong>Verlichting</strong></td>
<td>Normaal uit 10lux / 50lux lokaal, remote</td>
<td>Normaal 4-6lux 20lux lokaal, remote</td>
<td>Normaal uit 10lux / 50lux lokaal, remote</td>
<td>Normaal uit 10lux lokaal, remote</td>
<td>Normaal uit 10lux lokaal, remote</td>
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<td>Geen</td>
<td>Aanwezig</td>
<td>Geen</td>
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<td><strong>Evacuatiesignaaltechnica</strong></td>
<td>DEG (pijlen) vaste signaletica</td>
<td>Vaste signaletica</td>
<td>DEG (LED) vaste signaletica</td>
<td>Vaste signaletica</td>
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<td><strong>Toegangscontrole en CCTV</strong></td>
<td>Badgelezers CCTV (60m)</td>
<td>Camera’s aan toegangen</td>
<td>Camera’s (50m) badgelezers</td>
<td>Camera’s (200m) badgelezers</td>
<td>Badgelezers camera’s toegangen</td>
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<td><strong>Scenario’s</strong></td>
<td>Vooralarm/alarm operator komt tussen</td>
<td>Bestuurder en operator komen tussen</td>
<td>Operator bevestigt</td>
<td>Automatisch</td>
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</tbody>
</table>

**Overview techniques / equipement**
Tunnel Schuman - Josaphat
Tunnel Schuman - Josaphat

<table>
<thead>
<tr>
<th>Scenario</th>
<th>$V_{AD}$ (m/s)</th>
<th>$V_{G1}$ (m/s)</th>
<th>$V_{G2}$ (m/s)</th>
<th>$V_{V_{{\text{max}}}}$ (m/s)</th>
<th>$V_{AD}$ (m/s)</th>
<th>Performance</th>
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<tbody>
<tr>
<td>Scenario 1</td>
<td>5.66 ($V_{\text{max}}$)</td>
<td>2.59 (+0)</td>
<td>2.4 (+0)</td>
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<td>Scenario 5</td>
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<td>/ (+0)</td>
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<td>4.57 ($V_{\text{max}}$)</td>
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</table>
Tunnel Schuman - Josaphat
North-South Link Brussels

Existing situation
North-South Link Brussels

Existing situation
North-South Link Brussels

Existing situation
North-South Link Brussels

Existing situation
North-South Link Brussels

Existing situation

A1, A2
Operating Periods

<table>
<thead>
<tr>
<th>Start</th>
<th>End</th>
<th>Type L1</th>
<th>Type L3</th>
<th>Type T5</th>
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<tbody>
<tr>
<td>5 h</td>
<td>24 h</td>
<td>Monday, Tuesday, Wednesday</td>
<td>Thursday, Friday</td>
<td></td>
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<tr>
<td>6 h</td>
<td>22 h</td>
<td>Saturday, Sunday</td>
<td></td>
<td>7 days/7</td>
</tr>
</tbody>
</table>

2 operating modes

Basis mode
CO₂ < 1000 ppm
CO < 30 ppm

Detection mode
CO₂ ≥ 1000 ppm
CO ≥ 30 ppm

North-South Link Brussels

Existing situation
North-South Link Brussels

Design parameters
- Type of the train: M6
- Length: 280 m (10 wagons)
- Section: 12 m²

Pressure losses:
- Friction on the walls of trains (λ train)
- Punctual Obstacles (K)

Number of trains:
- Incident tube: one in fire, one train blocked
- Non-incident: none
- In station: one train in fire

Power
<table>
<thead>
<tr>
<th>35 MW</th>
</tr>
</thead>
</table>

Convective
| 66.66 % |

[Graph: HRR [kW]]
North-South Link Brussels

3 operating modes:
- Ventilation of smoke extraction (+ overpressure ventilation)
- Daily ventilation
- Maintenance Ventilation

<table>
<thead>
<tr>
<th>Vermogen [MW]</th>
<th>Kritische ontsnelpnelheid [m/s]</th>
</tr>
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<tbody>
<tr>
<td>14</td>
<td>2.5</td>
</tr>
<tr>
<td>35</td>
<td>2.95</td>
</tr>
<tr>
<td>70</td>
<td>3.45</td>
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</tbody>
</table>
North-South Link Brussels

Diagram showing the layout of the tubes (A1, A2, A3) with scenarios 1 to 10. The diagram includes symbols for ventilatietestation (ventilation station) and straalventilator (blow vent). The legend indicates that 'O' represents a door open and 'X' represents a door closed.

Scenario 0 shows all doors open, while scenario X shows all doors closed.
North-South Link Brussels

Reference design – Tuc Rail / FESG

plenums

Saccardo
Extractie opening
Geluidsdemper
North-South Link Brussels

Reference design – Tuc Rail / FESG
North-South Link Brussels

Reference design – Tuc Rail / FESG

station
North-South Link Brussels

Reference design – Tuc Rail / FESG

station
North-South Link Brussels

Reference design – Tuc Rail / FESG
North-South Link Brussels

Reference design – Tuc Rail / FESG

Daily ventilation

The devices are located at two different heights:
1. At 5.5 m height (50 cm above the train).
2. At 2 m above the platform.
Do not blindly trust codes but trust on calculated and validated results

M6 – Fire with stop in the tunnel

Ignition, Train stop & evac. start, Evacuation complete

Time [min]

HTT [MW]

Adequate integration of evacuation time in the structural approach
Conclusions

• A strong performance based design approach
  – Stimulates creativity in the design
  – Impact on the solutions within the economical context
  – Intensive process designers – owners, even re-orientation relationship owner - designer
  – Impact on the full design process
  – Stimulates meaningful integration of RAMS in the design
  – Better description of design versus degraded modes

Next steps
  – Adequate integration of evacuation time in the structural approach (future)
  – TSI needs to be reoriented to the performance based design approach