Aspects of tunnel design directly related to safety in operations

Bernard Falconnat

Scetauroute Tunnels & Travaux Souterrains

tunnels are complex systems

- tunnels are become a more & more complex and involve following disciplines
  - geology, geotechnic, soil and rock mechanics
  - civil work and structure
  - more and more complex operating equipment
  - ventilation
  - air pollution - environment
  - safety
  - operation and training

tunnels are complex systems

- tunnels are also expansive
  - construction costs : one time
  - operating costs : all the tunnel live (higher than construction)
- value engineering and optimisation process
  - from the beginning of the design
  - a cross analysis of all topics mentioned above to:
    - optimise the alignment and length profile
      - geology – ventilation – tunnel traffic capacity …
    - optimise the functional cross section
      - excavation cost …
    - guarantee a high safety level

tunnels are complex systems

- value engineering & optimisation process (follow)
  - ventilation system and escape routes are essential parts in this process
  - this process may reach 15% of capital cost without to reduce the quality, comfort and safety level
- my presentation will focus on
  - ventilation
  - escape routes
  - tunnels in sever mountainous conditions


Ventilation

ventilation

- Art Bendelius will make a presentation concerning
  - ventilation system
  - fire and smoke control
- my presentation will focus on some particular aspects

ventilation target

- basic observations
  - fire fighting team are not able to intervene, if all the organisation is efficient (detection – alarm – mobilisation – transport to the site)
    - in less than 5 to 10 mn for dedicated team on the site
    - in less than 15 mn (much more if fire brigade is far away) for fire brigades out of the site
  - after starting of a fire
    - users have approx. 15 mn to save himself

ventilation target

- that means
  - the all information system (equipment – safety procedure - operator) has to inform very quickly the users trapped in tunnel
  - users must be in condition of self rescue without to wait on intervention teams
    - leaving their vehicles
    - using eventually the extinguishers
    - heading to escape routes or safety recesses
    - but for that, they:

o have to be aware of the danger
o need to know the basic safety equipments & the attitude to follow toward a fire

ventilation target

- that means
  - safety equipments of the tunnel have to be designed and managed to allow the self saving of the users immediately after the fire start
  - stakes for the all ventilation system
    - quick, efficient and reliable fire detection
    - operating procedures for a quick switch on of ventilation system
    - efficient smoke control:
      - avoid smoke spreading (bi-directional or urban tunnel)
      - keep layering – high-performance & focused extraction

to make users in condition to reach escape equipments

ventilation concept

- ventilation concept
  - must fulfil the stakes above
  - has to be adapted to particular tunnel conditions
    - urban or not (risk of jam or not)
    - bi-directional or uni-directional (one or two tubes)
    - traffic level - % of lorries – hazard goods transport
    - particular climatic conditions
    - operating and rescue organisation
    - eventually environmental conditions at portal
  - to the safety level required
    - standards and regulation
    - result of the risks and danger analysis

o essential to carry out risk analysis & preliminary emergency response plan at the very beginning of the design

ventilation design

- ventilation system
  - has usually a considerable impact on
    - the functional cross section
    - size of the cross section
    - additional structures like
      - building at portals – event. stacks for pollution dilution
      - underground caverns - ventilation shafts
      - ventilation ducts
    - energy supply and distribution
  - on construction costs and then operating costs

o optimisation of ventilation system is often an important target involving: tunnel geometry – ventilation & safety concept

mountain tunnels ventilation

- particular conditions for long mountain tunnels
  - bi-directional tunnel with an unique tube
  - high percentage of HGV traffic
  - medium daily traffic average volume (3.000 to 10.000 veh/day) but with a fast growth
  - difficult access conditions due to altitude
  - difficult climatic conditions – avalanches risk
  - rare opportunity to build shafts due to overburden
  - often isolated, fare from reliable energy supply (when existing) – from fire brigade and any village

mountain tunnels ventilation

- particular conditions relating to ventilation
  - mountain crossed by the tunnel is a climatic barrier
  - pressure difference between portals may be high, eventually very high
    - 700 to 800 Pa measured at Mont Blanc tunnel
    - sure similar figures for the long tunnels under project for crossing the Andes
  - natural air flow velocity in tunnel is close to 4m/s, but may reach 8 m/s
    - means that after 1mn, smoke will be naturally spread on a length of more than 250 m
  - natural air flow direction may also change

mountain tunnels ventilation

- ventilation concept & design must tackle these particular conditions
  - return of experience of Mont Blanc tunnel disaster
  - usual ventilation systems are not able to face up to these conditions
    - the air volume mass under motion is huge
    - and cannot be managed only by some adjustment on injected or extracted air quantity
    - the airflow control may be obtain only by applying forces with jet fans

o only a mix system is able to face up to these particular conditions

mountain tunnels ventilation

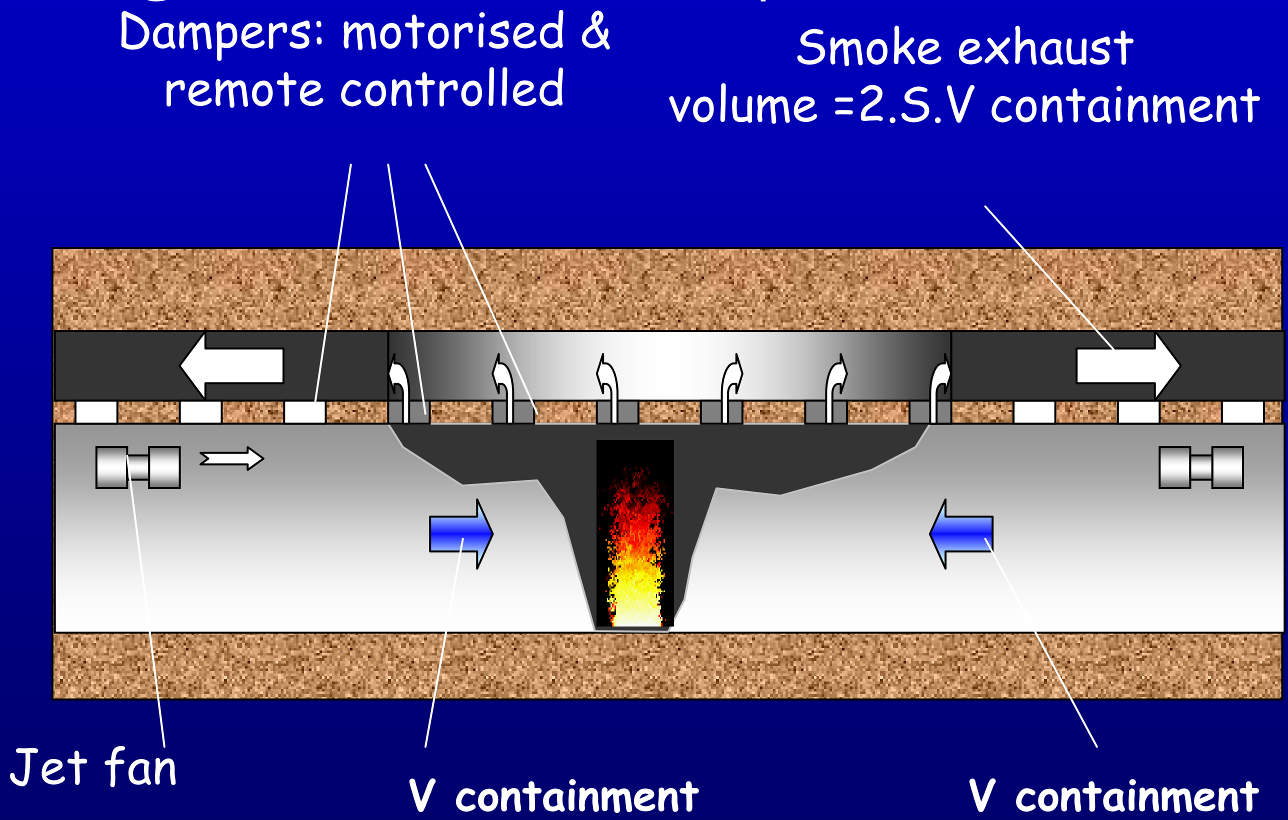
- description of a mix system
  - injection of fresh air from air ducts (health condition)
  - extraction of polluted air (health condition) and smoke extraction through remote and motorised dampers (spacing 100m), and an air duct
  - management and control of the air flow (and corollary the smoke) with jet fans installed in vault
- such a system has been developed and installed in Mont Blanc tunnel after disaster
  - numerous tests that have been done show
    - efficient air flow control even with high pressure difference
    - very good mastering of smoke layering

mix ventilation system concept

- concept based on R&D since 1990
  - manage the evolution of smoke
  - maintaining the stratification
  - stability of back layering
  - concept of air flow critical velocity
- principles
  - fire detection with redundant systems
  - reduce air flow velocity to 0m/s at fire place
  - confine the smoke & establish stratification
  - full automatic regulation of ventilation

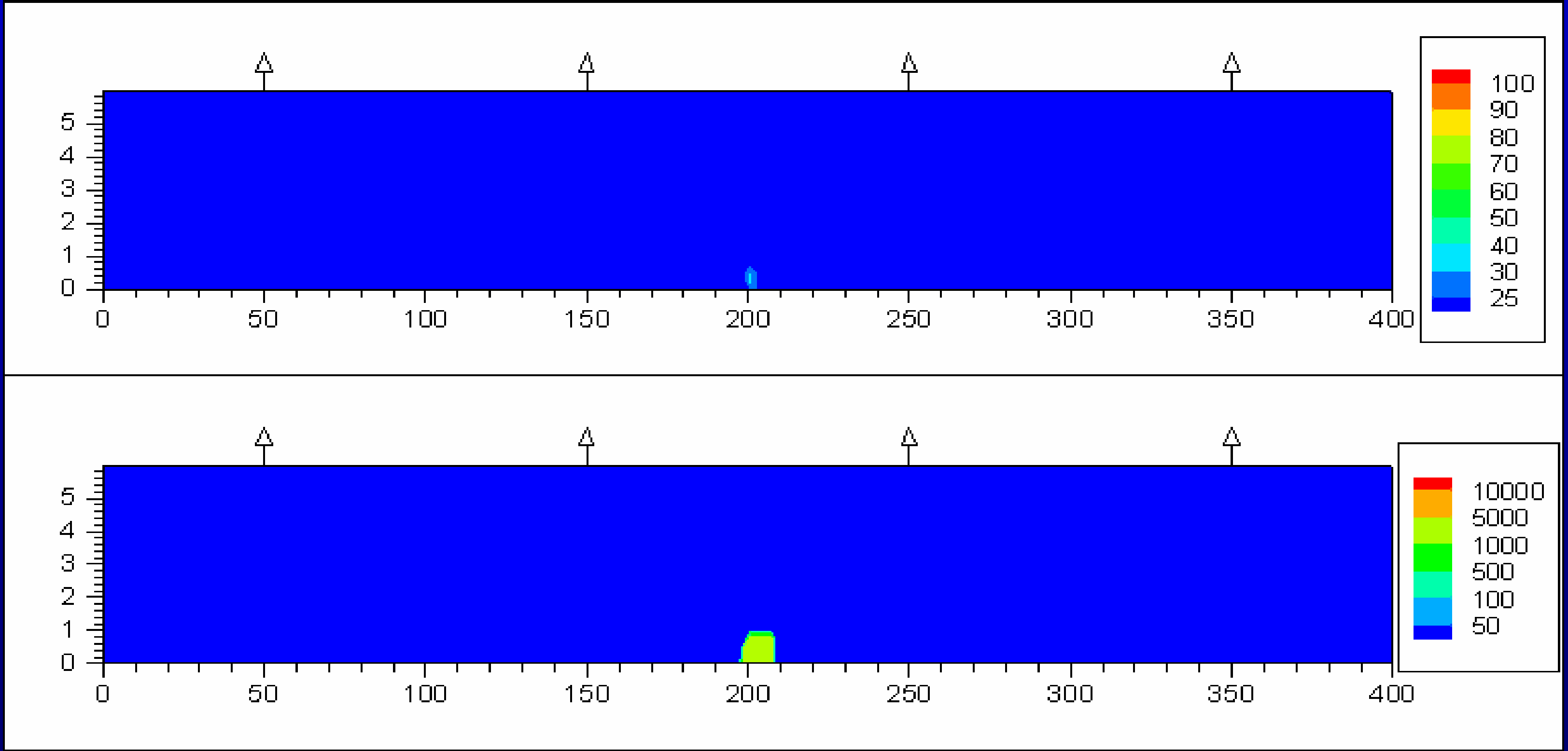
mix ventilation system concept

- control of longitudinal smoke spread

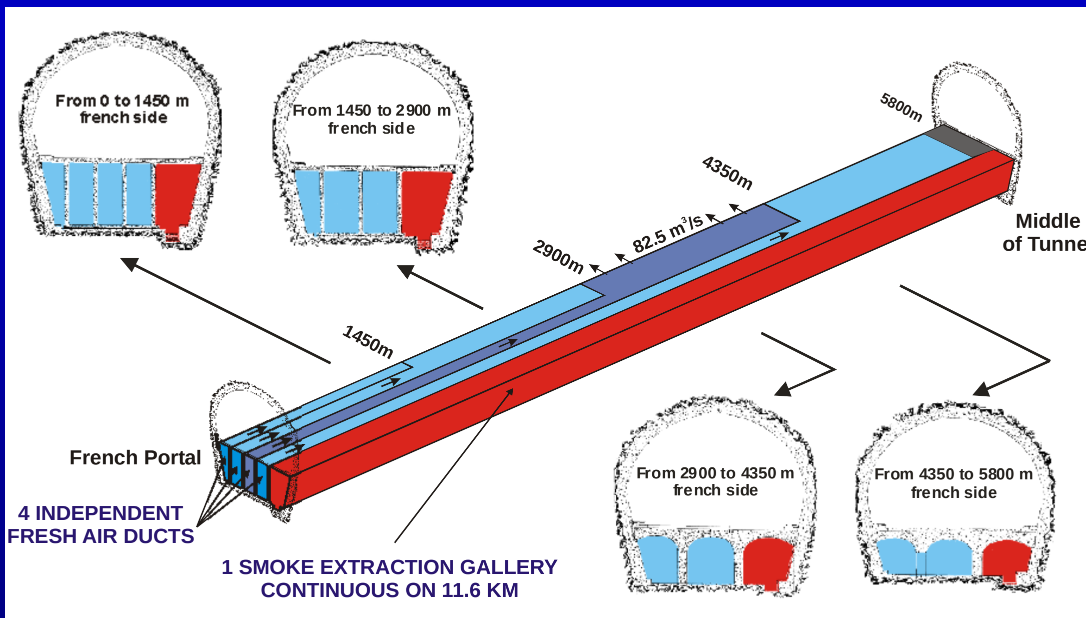


mix ventilation system concept

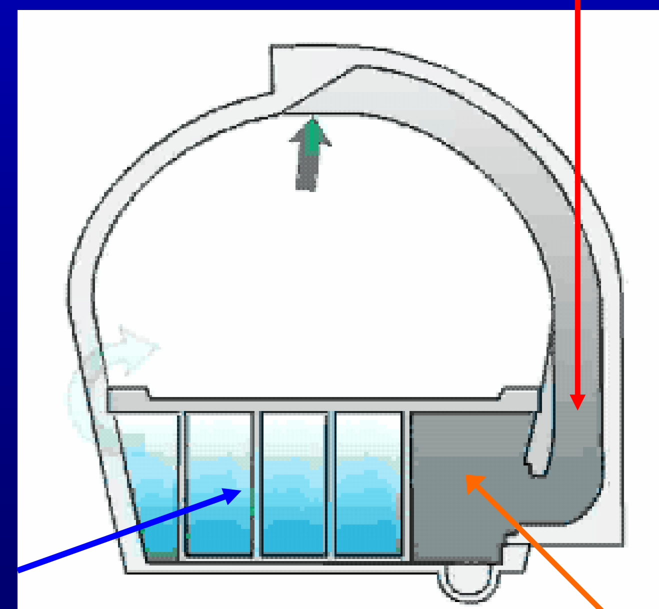
- Mont Blanc fire test modelisation



new Mont Blanc ventilation system



116 motorised & remote-controlled dampers



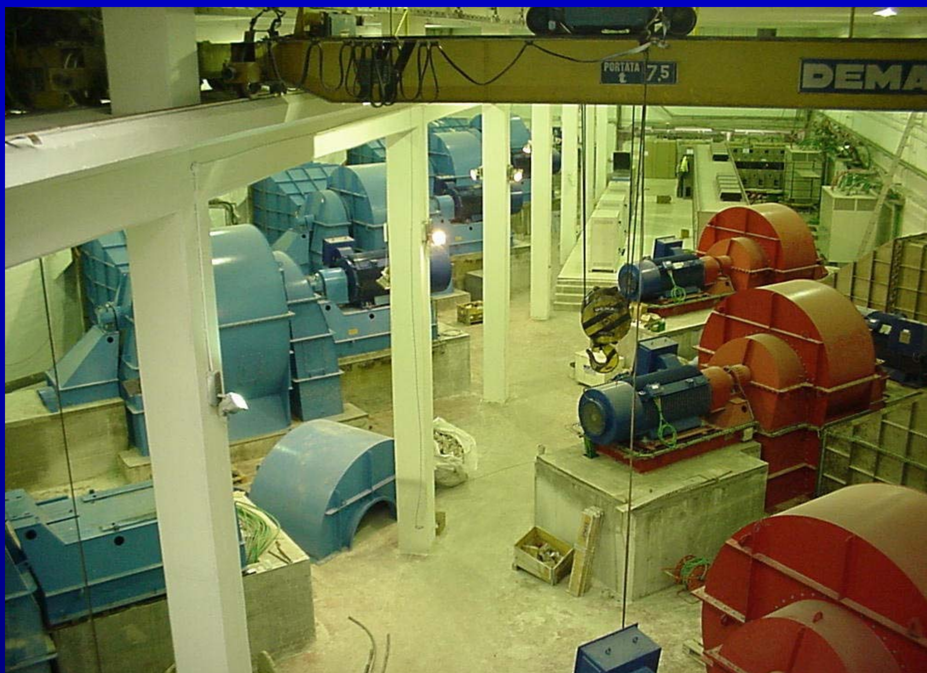
fresh air duct

smoke exhaust duct

new Mont Blanc ventilation system

- 76 jet fans in the vault
  - control the longitudinal draught
  - reduce it to 0 m/s within 2 min (500 Pa)
- smoke extraction dampers spacing 100 m
  - motorised & remote-controlled
- smoke extraction duct
  - 3 axial fans at both portals
  - 4 fans inside the duct to boost the pressure
  - volume: 150 m3/s for a 600-m long section
- captors: opacity and anemometers

new Mont Blanc ventilation system



2 plants with:

3 exhaust fans (1 stand by)

5 fresh air fans (1 stand by)

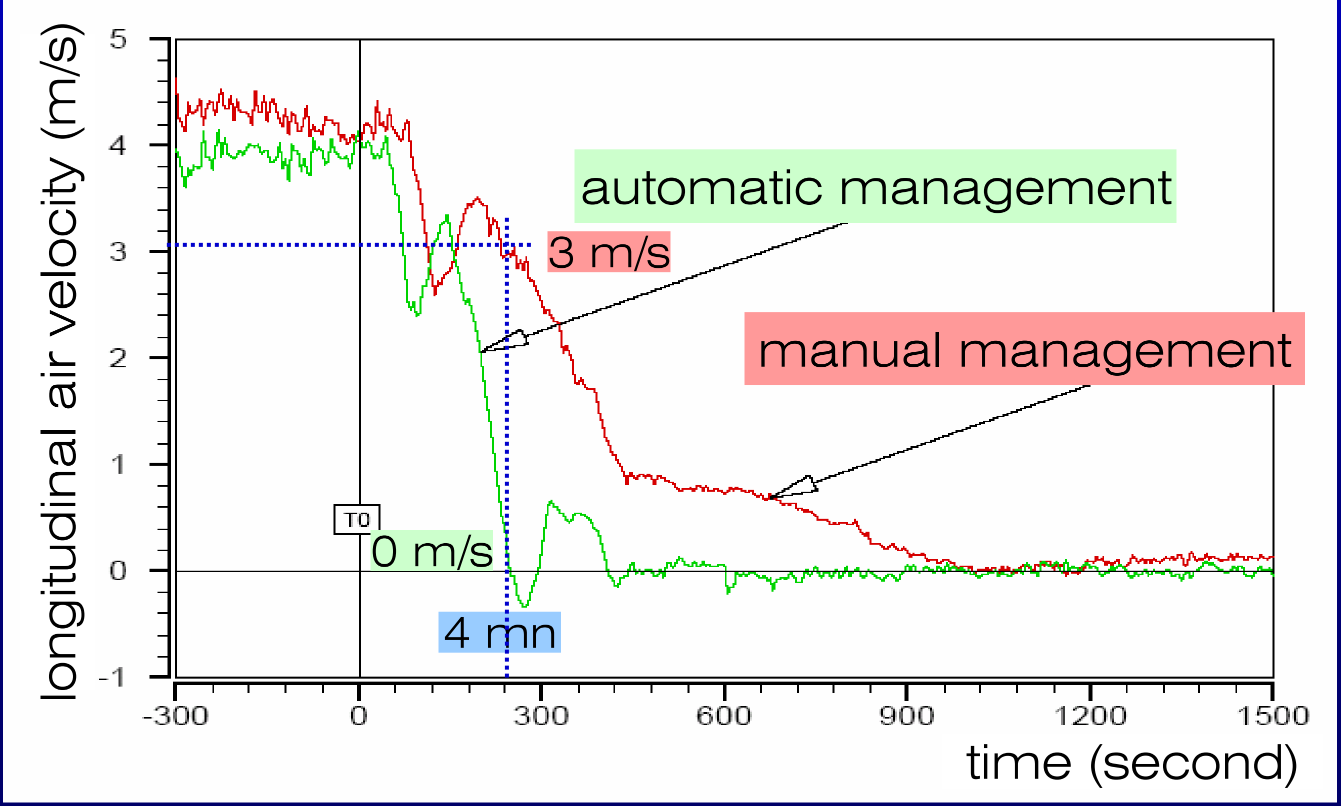
mix system management

- management of mix system is complex
  - numerous actions to be done on lot of equipments
    - set to a ready state when a fire is suspected
    - establish an initial numerical model according to the history before the fire started
    - start and full management of the jet fans except those near the fire place
    - start and management of exhaust fans
    - for a moving fire, track the vehicle & adapt the ventilation, opening / closing dampers etc
    - after vehicle is stopped, full regulation of the ventilation system
  - operator is under stress and very busy

mix system management

- fully automatic management required
  - much more better efficiency to perform the system

0 m/s air velocity after 4mn (automatic) instead 17mn (manual)



mix system management

- fire tests
  - numerous fires of 1 hour continuous power 15 MW
  - various initial conditions & pressures
  - excellent results
    - reactivity & capacity of the system
    - full control of stratification during 1 hour tests


Escape routes

escape routes

- regulation – standards
  - standards vary according to countries
  - EU Directive has introduced new common European standard for Trans European Network
    - obligation of escape route (max. spacing 500m) twin tubes tunnel
    - ditto for bi-directional tunnels class I & class II
    - no safety shelters without connection to an escape route

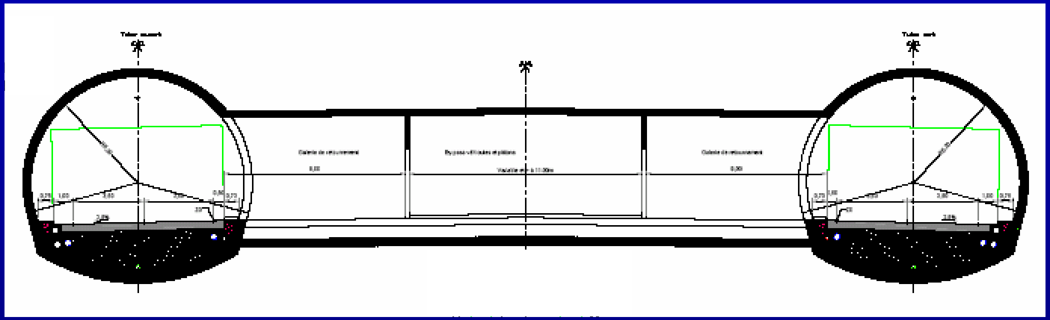
daily traffic per lane	length >
> 9.000	> 500m
4.500 < tunnel < 9.000	> 1 km
2.000 < tunnel < 4.500	> 3 km
500 < tunnel < 2.000	> 3 km
< 500	> 10 km

escape routes

- EU Directive (follow)
  - escape route
    - parallel to the tube
    - direct gallery connections to outside
- usual spacing design
  - twin tubes : 300 to 400 m
  - single tube : according to country and cost of connection gallery
  - urban tunnels : usually 200 m (but often 150 m)
    - lower spacing if needed by risk analysis conclusion
      - number of users to evacuate
      - evacuation flow rate according to geometric conditions

escape routes design

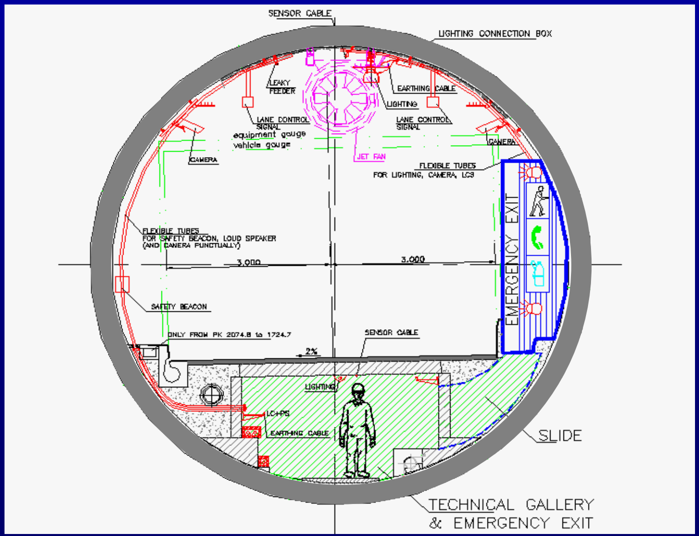
- escape routes are costly and design has to achieve best concept optimisation
- twin tubes tunnel
  - usual optimised solution is to build direct connection galleries between the both tubes



  - cross galleries are very expensive in case of bad geotechnical and hydro geological conditions (sand & gravel under water table), that may require grouting or soil freezing

escape routes design

- twin tubes tunnel in bad conditions
  - then tunnel excavation is driven with a shield and a circular profile
  - lower part of the circular profile may be used to install an escape route inside the profile, avoiding the construction of any very expensive connection



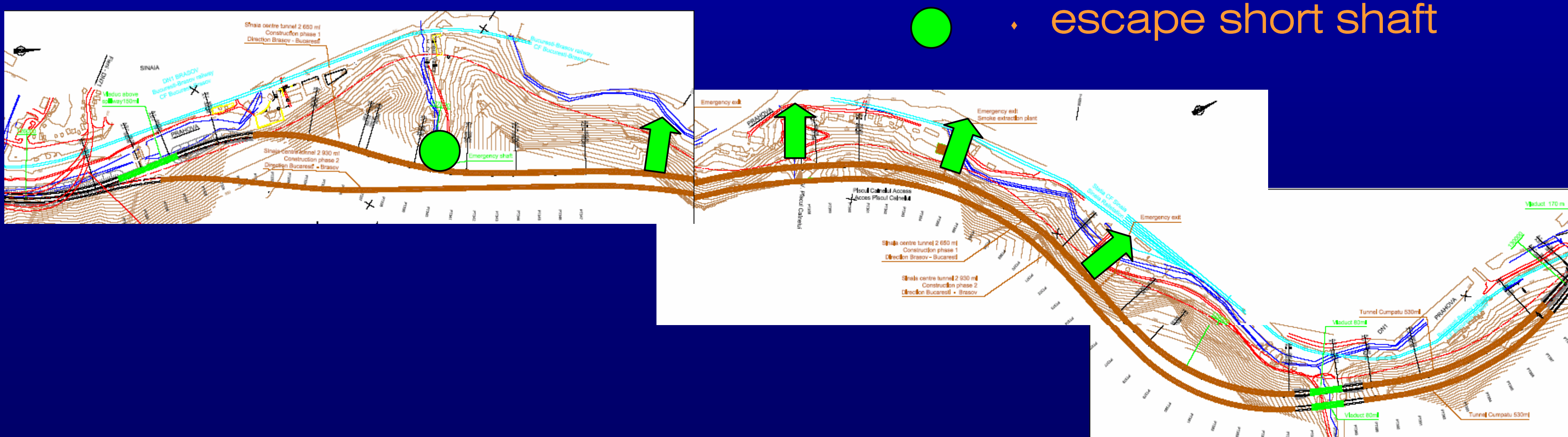
escape routes design

- unique tube
  - several dispositions are possible according to
    - geographic situation
    - ground conditions
    - construction methods

escape routes design

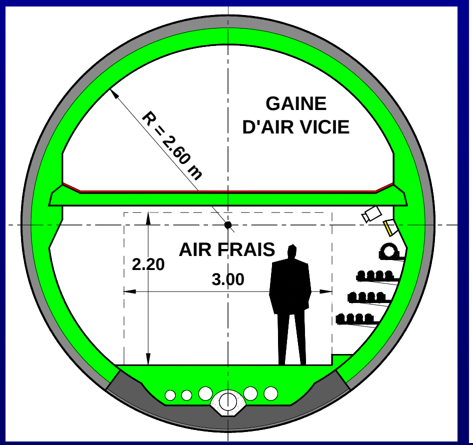
- escape route to the valley
  - by pass tunnel of a ski resort : length 2,9 km
  - one unique tube in a first construction stage
  - escape routes to the valley 100 to 150 m
  - alignment has been designed to make escape route possible

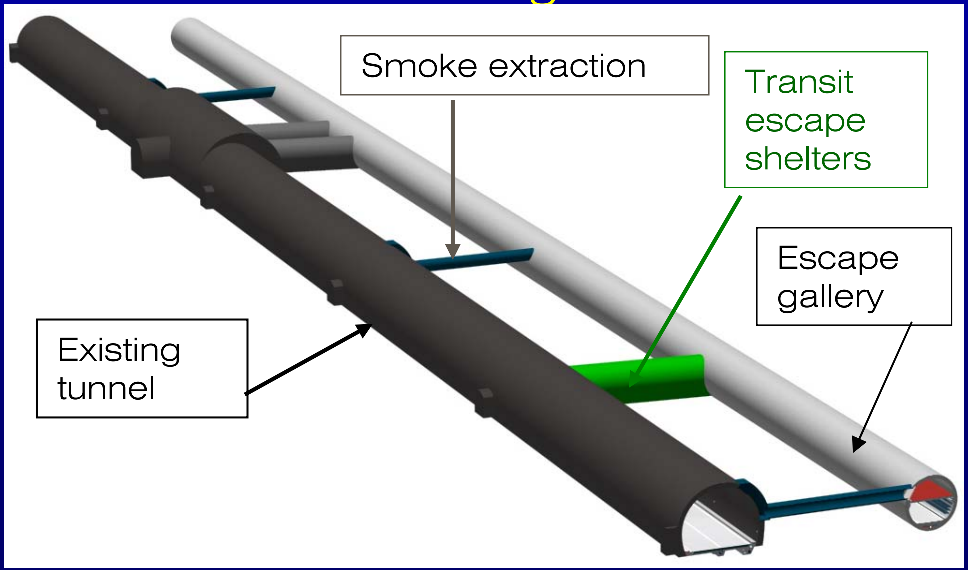
- escape routes
- escape short shaft



escape routes design

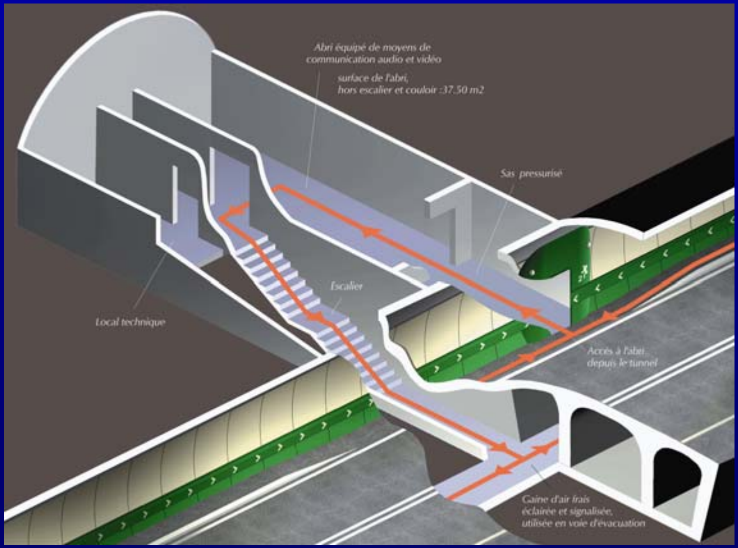
- escape route in a parallel gallery
  - used generally when renovation and safety improvement of an existing tunnel
  - for a new tunnel (even in good ground conditions), suppl. cost of approx. 12% in comparison with integrated escape gallery (new 9 km Pir Panjal tunnel in Kashmir)
  - example renovation Maurice Lemaire 7 km length





escape routes design

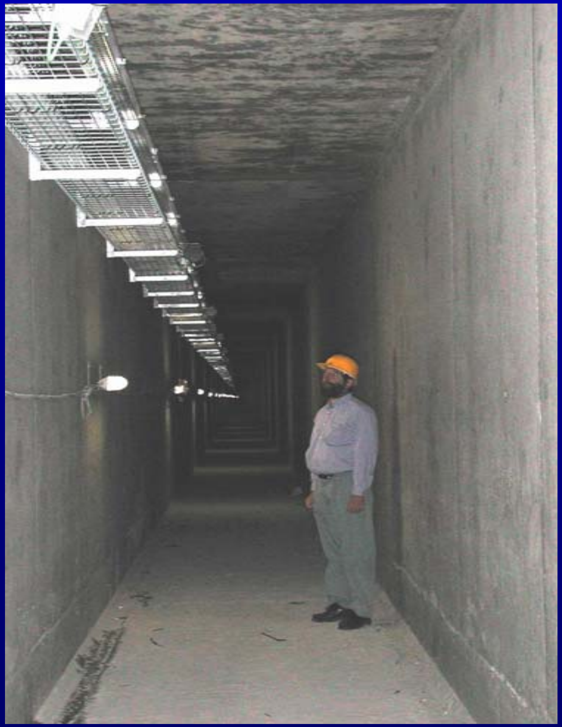
- escape route included in the cross section
  - principle is to used fresh air duct as escape route
  - to construct safety transit shelters with connection to escape route



escape routes design

- escape route included in the cross section (follow)

escape route

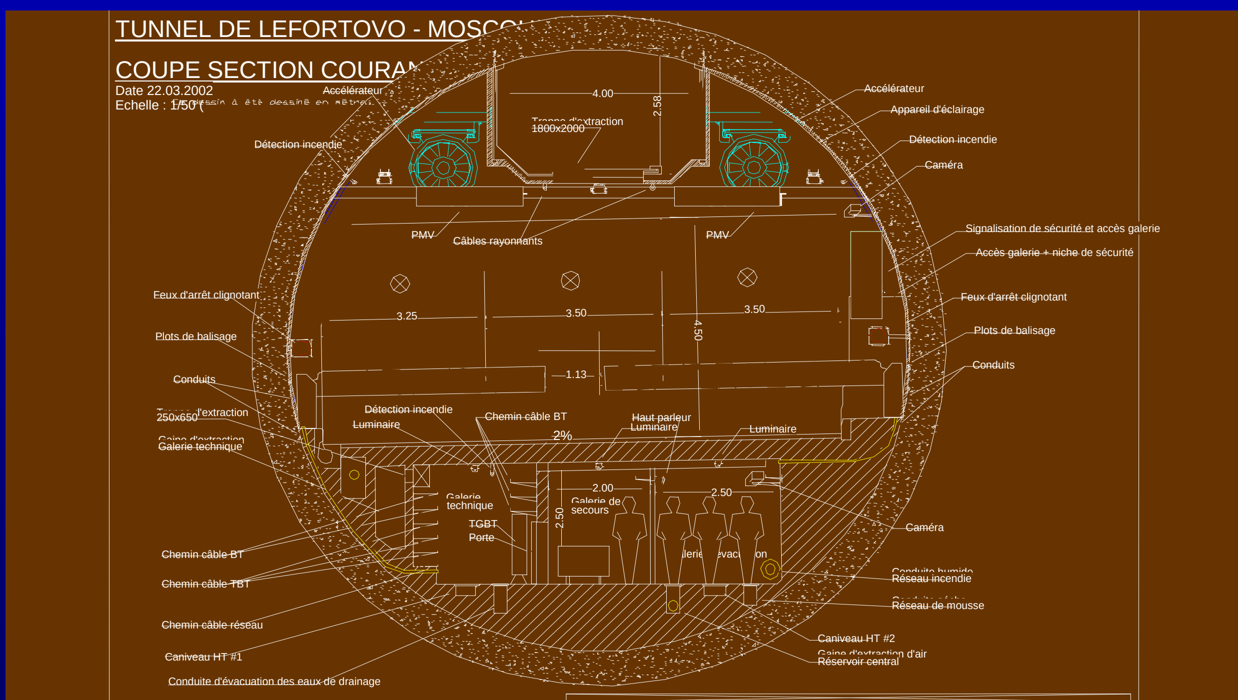


safety transit shelters

electric vehicle

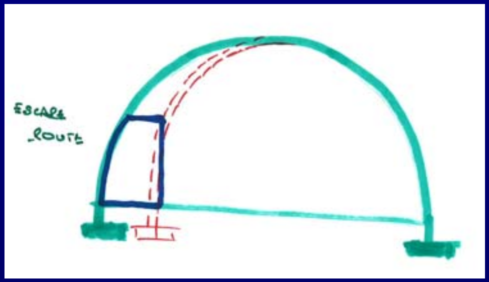
escape routes design

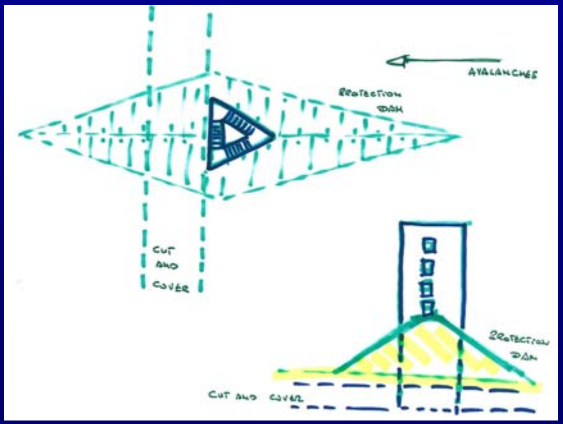
- tunnel in soft ground
  - cross value engineering process gives a saving of 100M€
    - by abandonment of parallel escape route and fully internal redesign of the cross section



escape routes design

- cut and cover escape in avalanches area
  - escape route inside the cross section by widening the cross section
  - escape tower
    - escape transit shelters at bottom
    - tower protected by earth dam
    - evacuation through stairs with exit level used according to snow thickness
    - possible use of the central duct for ventilation





escape routes design

- signalling of the escape route and the access to escape is essential

hand rail for the users

guide rail for fire brigade

beacons


tunnels in sever mountainous conditions

sever mountainous conditions

- particular conditions as for example
  - difficult access conditions due to altitude
  - difficult climatic conditions
  - avalanches risk at portal and along the access
  - often isolated, fare from reliable energy supply (when existing) – from fire brigade and any village
- risk analysis and a preliminary safety response plan are mandatory
  - before to start the design
  - to evaluate the risks
  - to choice design and operation concepts in order to mitigate the risks and make it acceptable

sever mountainous conditions

- some examples
  - difficult access conditions due to altitude
    - possible overheating for HGV and then burning in the tunnel
    - possible mitigations
      - heat control before to enter the tunnel
      - waiting parking in order to low the temperature

heat scanner

sever mountainous conditions

- some examples
  - difficult climatic conditions
    - efficient winter maintenance
    - risk evaluation for break down energy supply
    - emergency housing for people trapped
  - avalanches risk at portal and along the access
    - special protection structure
    - remote preventive start of avalanche : catex, gazex ...
    - particular safety procedures

sever mountainous conditions

- some examples
  - often isolated, fare from reliable energy supply
    - reliability analysis of all energy supply system
    - reinforcement or protection investigation
    - dedicated generators
  - far from fire brigade and any village
    - mandatory to organise a dedicated team, to have own intervention means
    - all these resources has to be sized according to the result of risk analysis and response plan
- results of this thinking process will be part of the action plan and base of design program


Thank for your attention