Tunnel Ventilation at High Altitudes

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Motivation

- The “Agua Negra” Road Tunnel will be a 14 km long road tunnel situated at 3,700-4,000 m above sea level, in the province of San Juan, connecting Argentina to Chile.
- What are the ventilation requirements for this tunnel?

Limitations

- No design of “Agua Negra” Road Tunnel has been undertaken
- Statement of general principles only

Agenda

1. Altitude Conditions
2. General Ventilation Requirements
3. Tunnel Ventilation Systems
4. Air Quality Improvement
5. Conclusions

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1. Altitude Conditions

Atmospheric Conditions

Standard Atmosphere 1976					
Altitude (*m*)	**Temperature absolute (*K*)**	**Pressure (*hPa*)**	**Density (kg/m^3)**	**Dynamic viscosity ($Pa \cdot s$)**	**Sound velocity (*m/s*)**
0	288.15	1013.25	1.2250	1.79×10^{-5}	340.29
1000	281.65	898.76	1.1117	1.76×10^{-5}	336.44
5000	255.68	540.48	0.7364	1.63×10^{-5}	320.55

So at 4.000m density can be considered equal to 0,74 kg/m^3

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Fan Performance

- Due to the decrease in pressure, jetfan thrust will decrease proportionally
- However, the tunnel pressure drop will decrease in the same ratio
- Hence, the same number of jetfans will be required as at sea level
- However, operating point of axial fans will be different at high altitude – fan efficiency may be compromised

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2. General Ventilation Requirements

General Ventilation Requirements

- Tunnel ventilation generally required for:
  - Maintenance of air quality (concentration of CO, NOx, particulates)
  - Control of smoke in case of fire
- Both of these issues are influenced by tunnel altitude

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Air Quality Standards

- CO, NOx and other air quality standards would be influenced. Instead of designing to 70 ppm (CO), this limit could be 40-50 ppm due to altitude influences.

Altitude Effects on Humans

- Proposed altitude would approach hypoxic conditions for the human.
  - Tunnel workers, emergency personnel etc.. would have to be acclimated to the air or their functions are at risk of not being performed correctly.
  - Average tunnel driver may be impaired and not be aware of it due to the bodies difficulty in getting oxygen. Poor decision making, black outs etc...

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Temperature Effects

- If the projected vehicle usage of the tunnel is substantial, in-tunnel temperatures could become an issue.
- Analyses on long road tunnels (in excess of 6 km) indicate that tunnel heating could drive the ventilation requirements.

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Vehicle Emissions

- Passenger vehicles using the tunnel would emit higher levels of carbon monoxide unless the vehicle was tuned to the atmosphere. Passenger vehicles would have reduced performance under these circumstances.

Altitude Factor

Table 1 : Altitude factor (fh) for 2000 m over sea, passenger cars and LDV up to 3.5 t, technology standard A

fh	CO		NOx		Turbidity
Passenger cars	Gasoline	Diesel	Gasoline	Diesel	Diesel
2010	2.6	1.0	1.0	1.0	1.0
2015	2.0	1.0	1.0	1.0	1.0
2020	1.6	1.0	1.0	1.0	1.0
2025	1.0	1.0	1.0	1.0	1.0
2030	1.0	1.0	1.0	1.0	1.0

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Design for Air Quality

- Key design criteria for air quality are increasingly recognised as NOx and particulate matter
- Fortunately, these emissions are not influenced by altitude
- Underlying issues of how to maintain air quality for 14 km long tunnel remain

Smoke Ventilation

- In case of fire, smoke ventilation is required to allow evacuation of motorists in the opposite direction
- The likelihood of fires starting at high altitude, and their subsequent development, are reduced at high altitude
- Design for tunnel smoke ventilation is still required

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Fire Suppression

- World Road Association recommends a feasibility study, cost/benefit analysis and risk assessment prior to installation of a fixed fire suppression system
- For long road tunnels, fire suppression may allow longer sections between ventilation/escape shafts
- Fire heat release rates can be significantly reduced

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Fire Suppression – Water Mist

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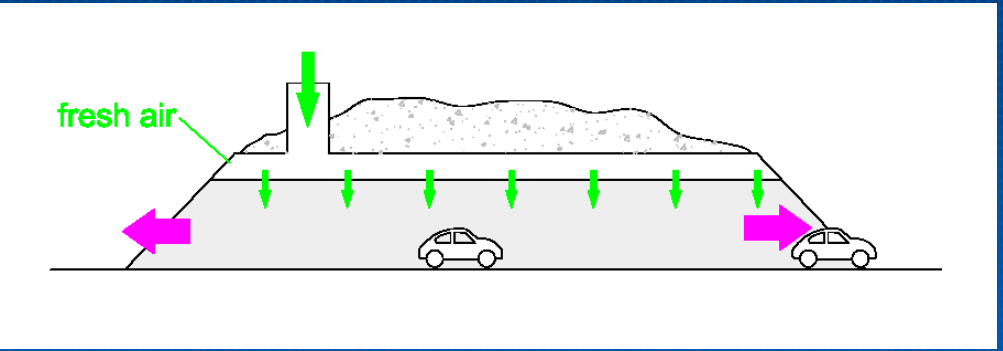
Overall Ventilation Requirements

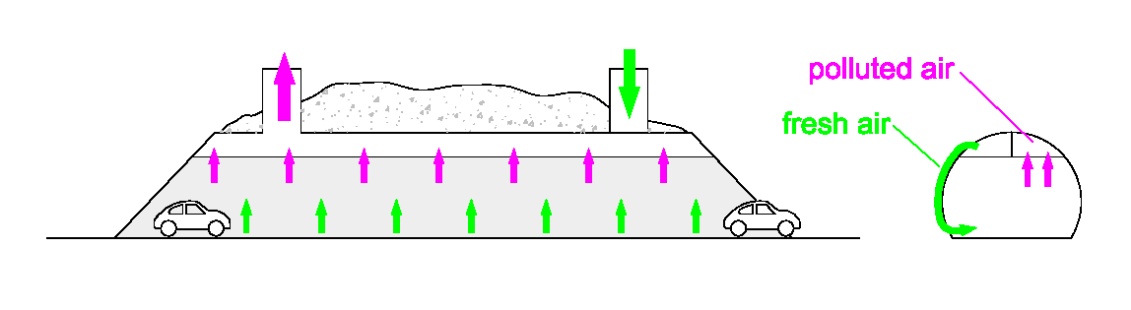
- For usual tunnel applications, smoke control requirements set the ventilation design
- For the “Agua Negra” Road Tunnel, this may not be the case – particularly if fire suppression is employed

3. Tunnel Ventilation Systems

Choice of Tunnel Ventilation System

- For long road tunnels, the only realistic choices of tunnel ventilation are
  - Semi-transverse
  - Transverse





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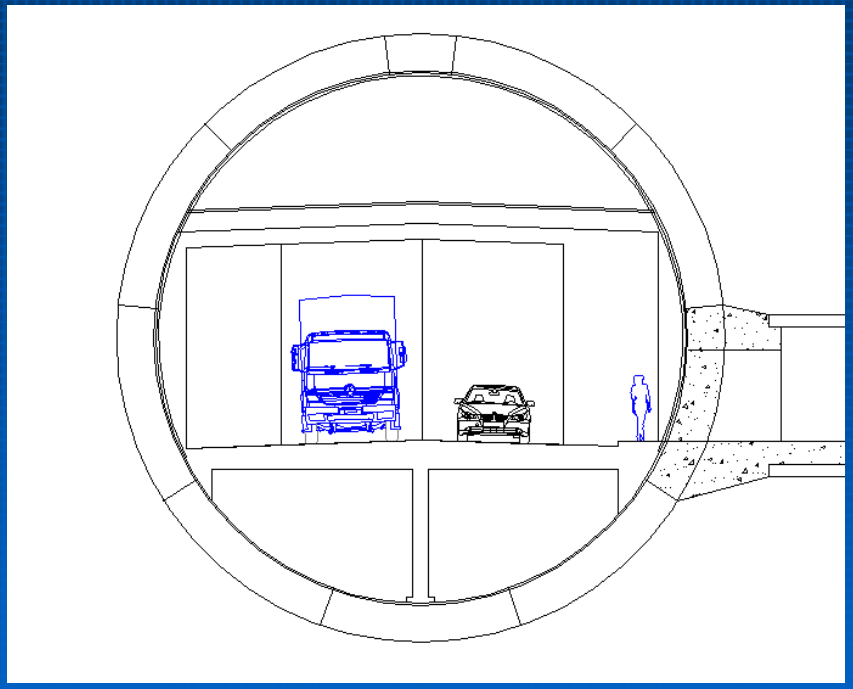
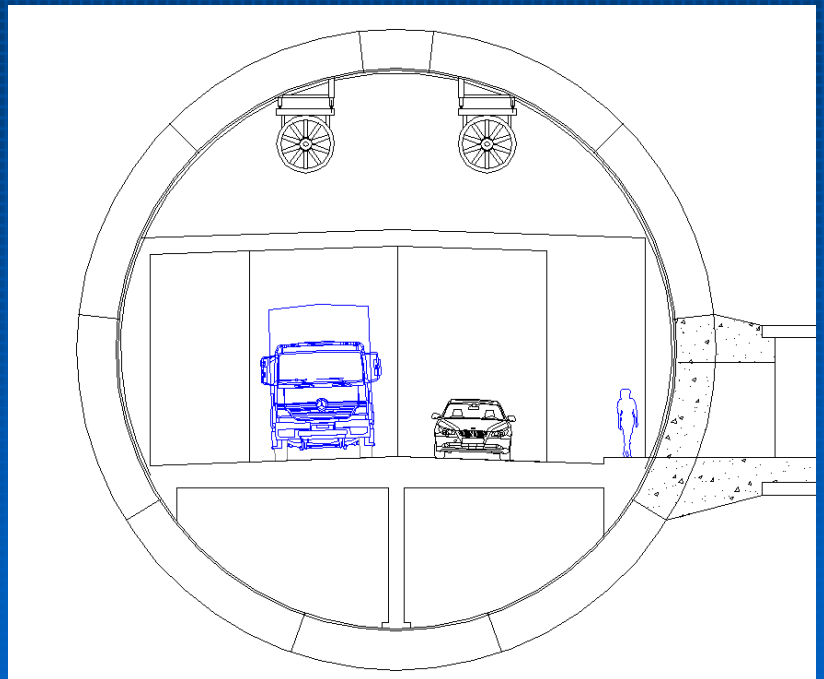
Riverside – Orange County Tunnel, USA (15 km)

Typical cross-sections



‘Normal’ section showing exhaust duct (upper, 28m^2) & fresh air supply duct (below roadway, 26m^2)



Near portals – showing booster (jet) fans in tunnel ceiling

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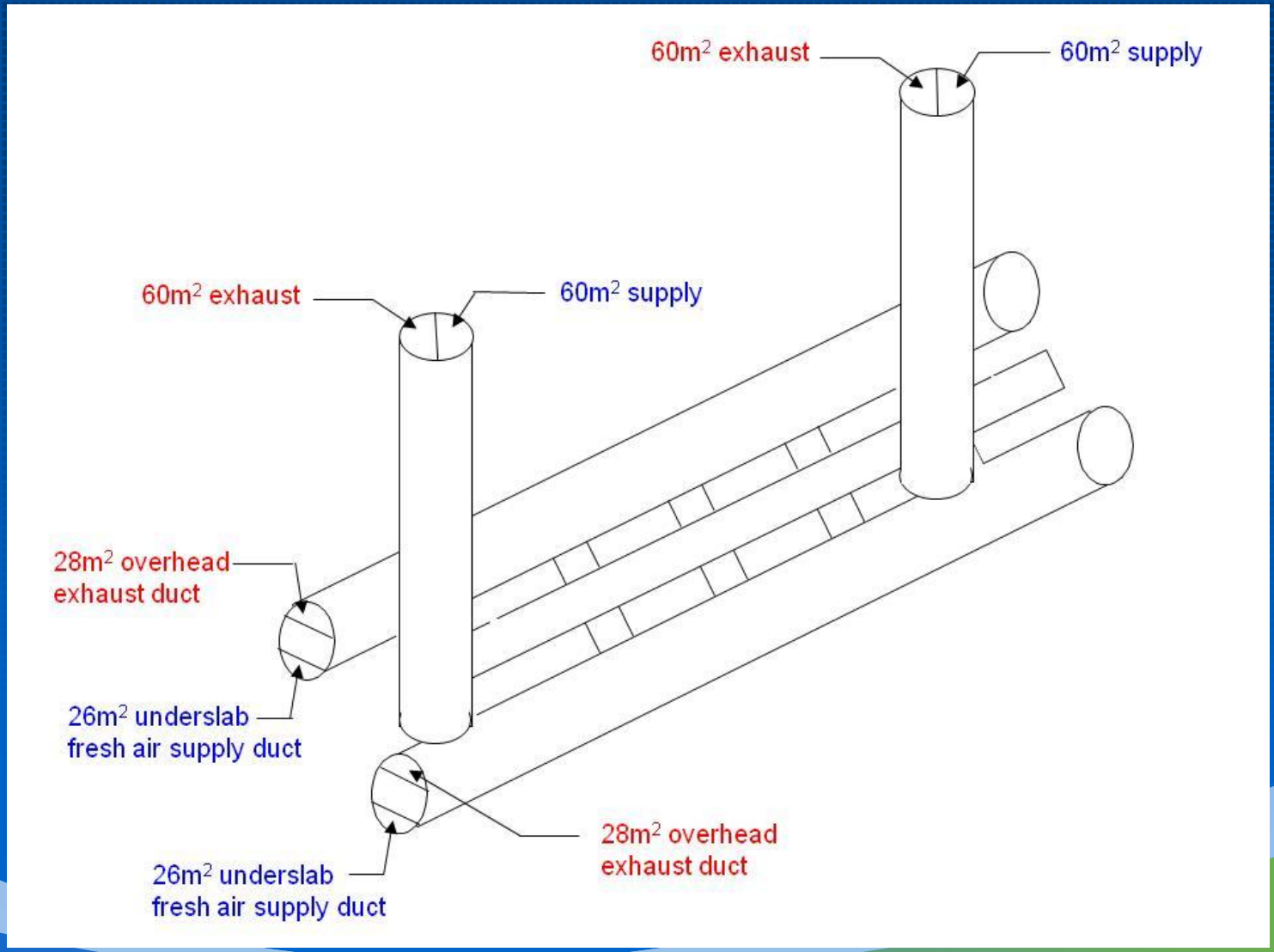
Riverside – Orange County Tunnel



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4. Air Quality Improvement

Air Quality Improvement

- Currently, there are not many choices for air quality improvement in tunnels:
  - Enhanced ventilation rate
  - Reduced distance between ventilation shafts
  - Reduced traffic speed
  - In-tunnel air filtration (expensive in terms of power consumption and space requirements)
- To maintain air quality outside portals, high-level discharge can be used

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Stockholm Bypass Tunnel

- 17km tunnel, construction starting in 2012
- Issues with particulate matter in spring time, due to studded tyres

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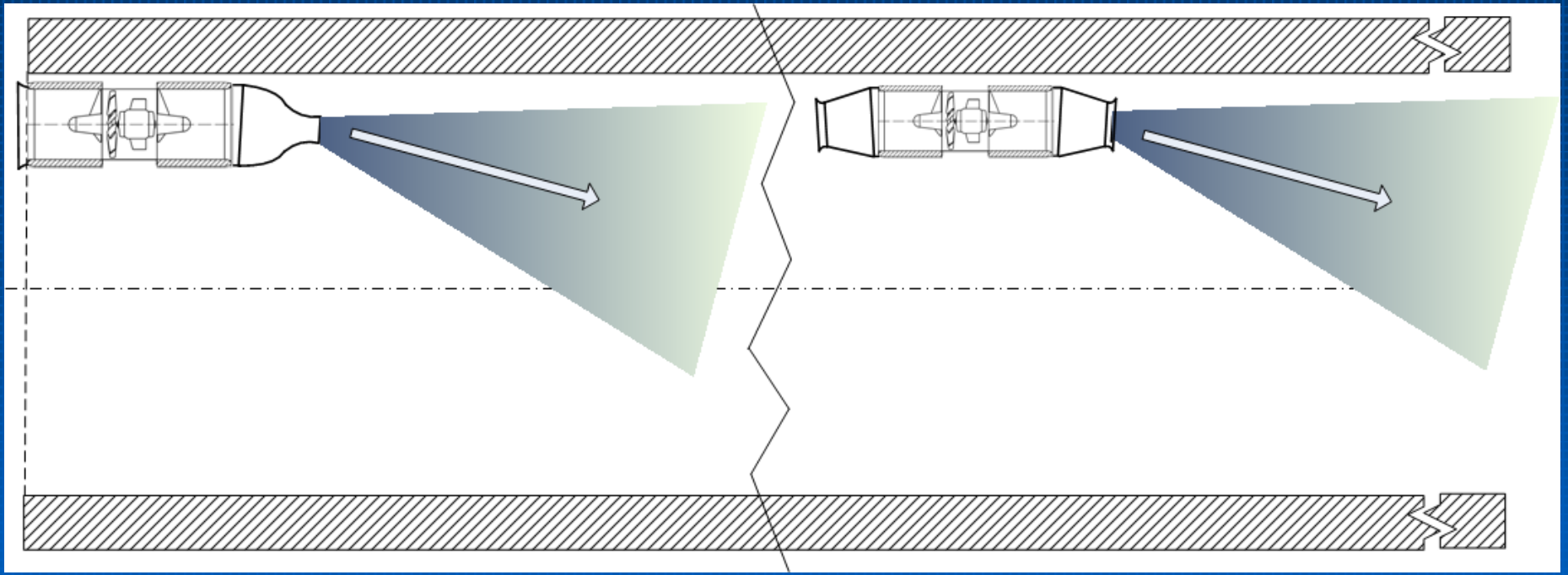
Option – Particulate 'Scrubber'



- MoJet technology
- Uses fine mist to reduce particulate concentrations
- Vitiated water to drain away

Mist Nozzles

5. Conclusions

Conclusions

- Ventilation challenges are difficult for any 14km tunnel, but are severe for such a tunnel in 4,000m altitude
- Design options exist to overcome these challenges:
  - For air quality: transverse ventilation, filtration, mist-based scrubbing
  - For smoke ventilation: fire suppression, smoke exhaust

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Review

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