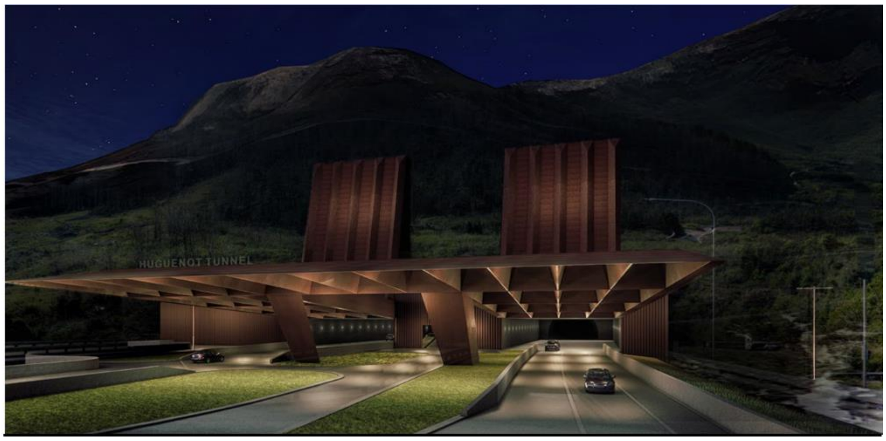
VENTILATION SYSTEM UPGRADE FOR HUGUENOT TUNNEL IN SOUTH AFRICA

Tiago Massingue[1], Julia Kearns[2]

[1]The South African National Roads Agency SOC Ltd, ZA
[2]SMEC South Africa (Pty) Ltd, ZA



DOI 10.3217/978-3-99161-087-8-031 (CC BY-NC 4.0)

ABSTRACT

Worldwide, tunnel operators increasingly adopt modern ventilation technologies to enhance safety and operational standards. This is the case for ventilation systems in the Huguenot Tunnel, South Africa, where the current ventilation system that has been in operation since 1982, is now inadequate and subject to immediate replacement.

The major drive for this effort is that the existing system, built in the 80s, no longer meets the requirements of a modern tunnel. A single 375 KVA axial fan in each 4km bore for both air inlet and extraction partnered with one for extraction at the portal of each bore cannot respond to the 100 MW fire load requirement. The two axial fans are located exactly at the ceiling portal at less than 5 m from the entry. 'While ventilation alone cannot fully mitigate fire risks, modern localized solutions significantly improve tunnel safety.

Figure 1: The Huguenot Tunnel in South Africa build in 1982

A semi-transverse system is being introduced to mitigate the current shortfalls. The proposed new system aims to introduce a single point extraction through the provision of air and smoke extraction dampers at approximately 80 m intervals. These new dampers above each existing ceiling slot will also block fresh air. Replacement of the exhaust fan bypass door with a damper system will increase the extraction capability to 200-250 m^3/s in line, with internationally acceptable standards, whilst the introduction of new jet and axial fans will enhance the air control and ability to extract air at a fire incident.

1. INTRODUCTION

The South African National Roads SOC Agency (SANRAL) has identified the need to upgrade the Huguenot Tunnel from a two-lane single bore to twin bore tunnel configuration with separated traffic flows. The proposed intervention will address traffic capacity issues, provide upgrades to the fire and ventilation resilience systems to respond to a 100MW fire, improve vehicle and pedestrian cross connections as well as provide a new concrete pavement structure. Currently, SANRAL is undertaking repair works to the existing Huguenot Tunnel South Bore, comprising the following activities: installation of a new back-up generator; replacement of variable message signs (VMS), electronic signage, fire detection and suppression systems; and installation of new radio and re-broadcast systems to enhance tunnel public announcement systems. The Huguenot Tunnel is the main transportation link between the coastal plains of the Western Cape and the interior. It eliminates a steep climb of 500m over the 23 km long Du Toits Kloof Pass and contributes significantly to the national economy in terms of savings in logistics, road user costs and accident costs. It is expected that once all works are complete not only will there be an enhanced tunnel safety environment but also it will also comply with international tunnel safety standards (EU Directive 2004 for Tunnel Operations). The South Bore, in operation alone for 37 years has carried a total of 110 million vehicles of which 90 million were light and 20 million Heavy Goods Vehicles. It is therefore of strategic significance for the South African National Roads Network.

2. VENTILATION SYSTEM

The current Huguenot Tunnel ventilation system is old and obsolete. It is therefore essential, as part of the major tunnel upgrade, to modernize this ventilation system. The single 375 KVA axial fan in each 4km bore for both air inlet and extraction partnered with one for extraction at the portal of each bore cannot respond to the 100 MW fire load requirement likely in the case of a major fire. Upgrading the tunnel to eliminate ventilation constraints has been prioritized by SANRAL.

2.1. Existing ventilation capability

Two modes of operation are currently in use. These two independent components operating separately aim to address possible opposing scenarios within the tunnel ventilation environment. The fresh air duct aims to supply fresh air into the tunnel. Then the smoke extraction system aims to exhaust fumes in case of fire or any other undesirable fumes in the tunnel. The two systems are facilitated by means of bypass doors which are used as deemed necessary. The bypass door is as important as any other system because its failure would mean the tunnel would be reduced to fresh air or exhaust air systems only.

Figure 2 A) below shows the day-to-day operation at the natural barometric pressure where the fresh air inlet is continuously made available through the ceiling and underneath the vertical wall panels along the tunnel length. The bypass door/valve used critically for extraction also contributes for enhanced air inlet in normal operation.
Operation in the event of a fire is shown in Figure 2 B) and demonstrates that, for operation in the event of fire, only the extraction capability is maximized. The lack of dampers is a major constraint for effective operation standards in the tunnel.

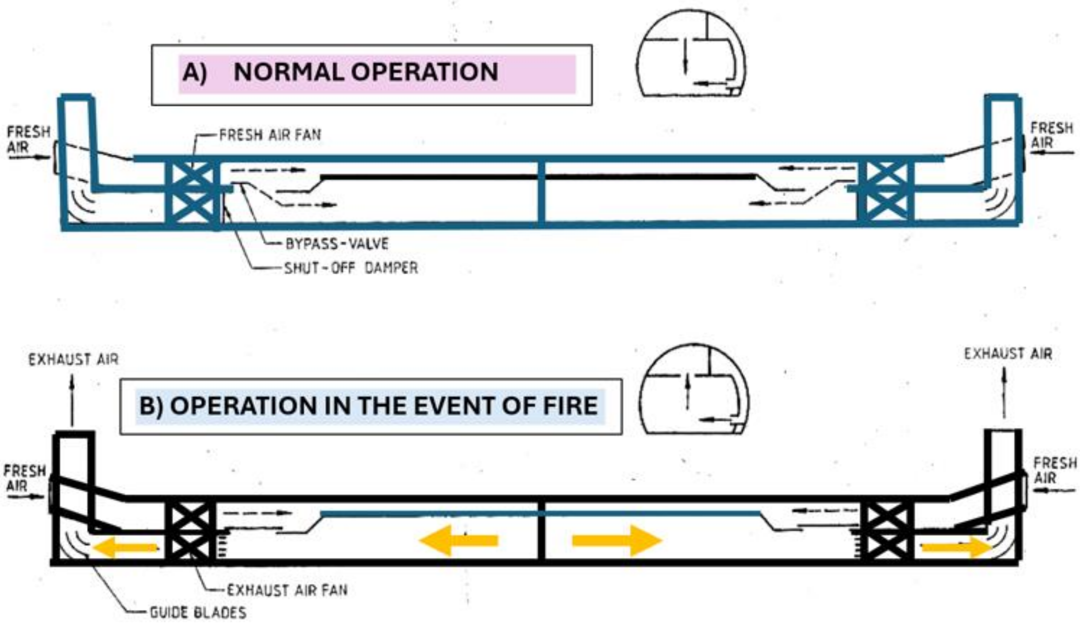


Figure 2: Normal Operation & Operation in the event of fire

3. VENTILATION IMPROVEMENT DESIGN CONCEPT

Several ventilation methods, namely longitudinal, transverse ventilation (including semi-transverse) and single point extraction were assessed for feasibility at the preliminary stage. Single point extraction was selected as most effective functionally for both bi-directional as well as unidirectional traffic flow scenarios. This option was found to offer the following benefits:

- Energy efficient – The system fully utilizes the fresh air and take full advantage natural air velocity for tunnel ventilation.
- Reduces portal air short circuiting.
- Fire Safety – The system can limit the fire affected zone to enable safe evacuation and firefighting. As a result, fire fighters can approach the fire from both sides.
- Operation Flexibility – The system can cater for bi-directional and unidirectional traffic without changing the system operational concept.
- Fast Response – As the exhaust fans are running for pollution ventilation, the exhaust location can be switched to the fire site within a shorter period. This can reduce movement and spread of smoke.
- Fast Recovery – Single point extraction system can limit the smoke affected zone to a reasonably short distance in the tunnel. This will limit the fire damage to a short distance, resulting in fast recovery and cost-effective repair/refurbishment after a fire incident.

3.1. Design Strategy

The Computational Fluid Dynamics (CFD) model developed for the project indicated that for a 100 MW fire load the axial fans would operate at 175 to 300m/second. New axial fans would be required to replace the old 375 KVA axial fan, but modernization of the existing fans would also be required. World Road Association (PIARC) guidelines on air quality parameters as well as the recommended CO levels were used for comparison. Based on the above, the pollution control ventilation rates were calculated for different project phases including bi-directional traffic and unidirectional traffic. For bi-directional traffic for year 2025, the peak airflow rates for East Bound and West Bound were 152.8m³/s (40kph) and 139.5m³/s (40kph) respectively. Similarly, for unidirectional traffic in year 2028, the peak airflow rates for East Bound and West Bound were 223.6m³/s (20kph) and 198.4m³/s (20kph) respectively. The limits of the airflow rates in Fig 2 below were therefore assumed at the range of 200m³/s to 300m³/s respectively.

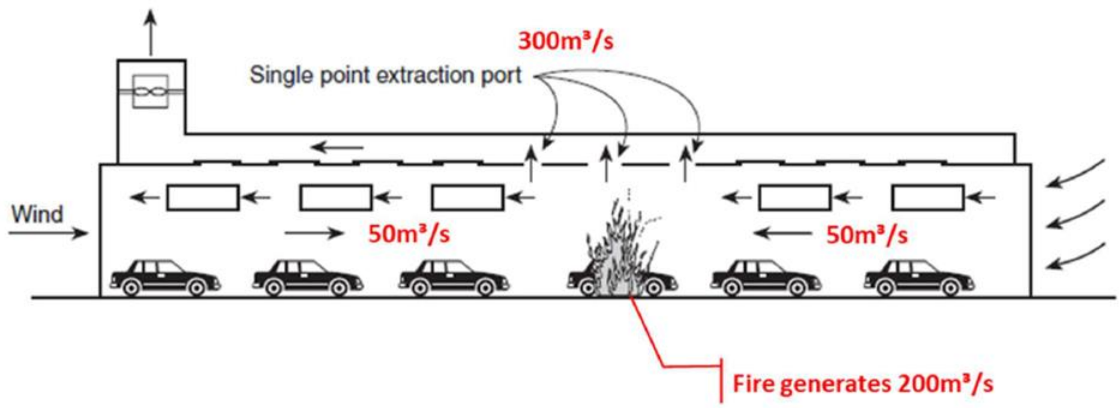


Figure 3: Limits of the airflow rates as per the CFD calculations

3.2. Key Equipment Components

The commissioning of the Huguenot Tunnel North Bore, and the upgrade of the Huguenot Tunnel South Bore has defined key equipment components to be used in line with CFD Models, previously discussed. These entail, the:

Provision of new axial fans,
- Provision of new jet fans,
- Introduction of new dampers, and,
- Retrofitting of the tunnel crown for the South Bore

a) New axial fans
Based on research of current suppliers, as well as supporting the (CFD) requirements, the following axial fans were selected for the North and South Bore Tunnels:

Table 1: Ventilation design requirements for new axial fans

Number of Tunnel Ventilation Buildings	2
Airflow rate per fan	100 m³/s
Total Tunnel Ventilation Fans in operation at peak load normal operation	3
Normal operation (Bi-directional traffic)	300 m³/s
Total Tunnel Ventilation Fans in operation for emergency	3
Emergency Operation	300 m³/s

b) New jet fans
The CFD model tested three different jet fans sizes of 900, 1200 and 1600 mm diameter to counter the natural air velocity during the emergency. Subsequently, the 1600 mm diameter fans were selected, and the summary of their output specifications was as follows:

Table 2: Ventilation design requirements for jet fans

Jet fan diameter	1600 mm
Thrust	2160 N
Number of fans per niche	3
Total duty fans	30
Standby fans	3
Total number of niches per tunnel	11

c) New dampers
The provision of dampers to effectively contribute to the extraction capability of smoke in normal and critical operations. The new improvement not only will provide working teams with proper fresh air in their normal activities, but it will be used also to exhaust fumes and gases that are detrimental to human lives and can be the major cause of fatalities in case of fires. This improvement is one of the most important technical contributions to a previously designed tunnel without ventilation dampers. The concluded design has established that the size of dampers will vary between 3 m³and 5 m³ for spacing intervals of 50 to 100 m. Due to high temperatures of the smoke in the extraction zone, the dampers will feature a heat resistance of at least 400 ℃ for 90 minutes. The time required for opening or closing the dampers should not exceed 25 seconds.

d) Reprofiling the tunnel crown

All design improvements being introduced at the Huguenot Tunnel North Bore must be replicated in the South Bore and for that purpose the tunnel crown of the south bore must be reprofiled to cater for the substantial 1600 mm diameter jet fans. This is an operation requirement which is made by specialist ventilation firms however it triggers a substantial level of new work in the currently operational bore.

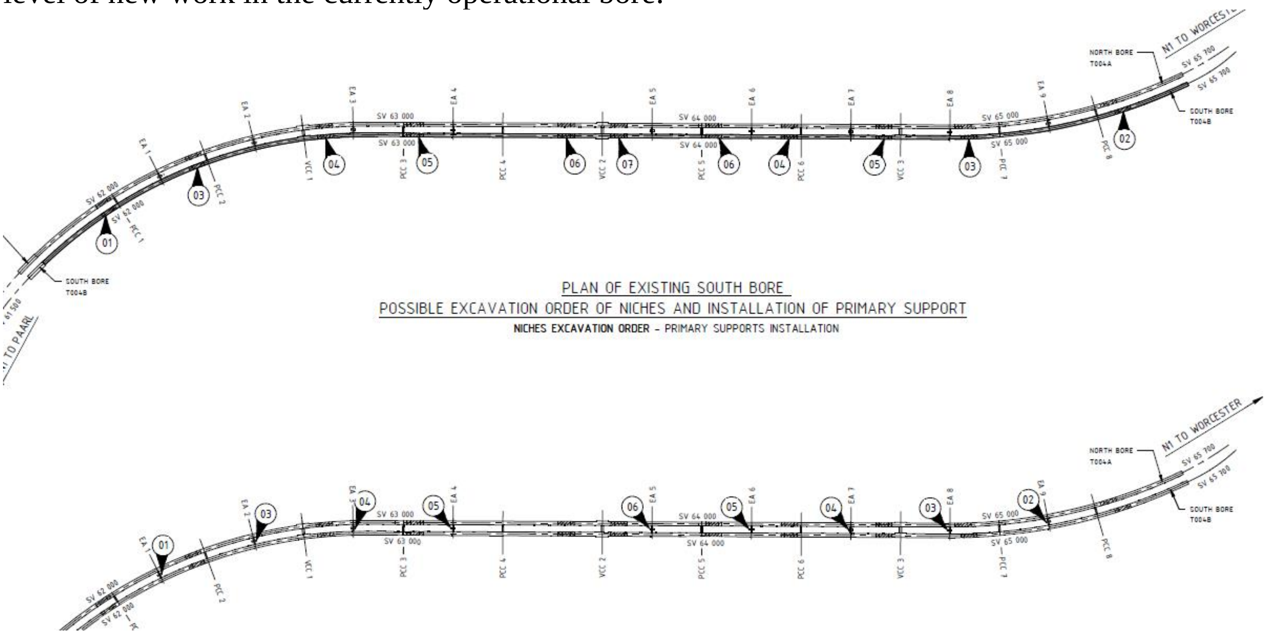


Figure 4: Niches layout

3.3. Retrofitting new design components

In terms of the ventilation design, 11 no. vertical niches are to be excavated into the roof of both tunnels to accommodate banks of jet fans. Niches are 56 m long and approximately 330 m apart. Vertical niches accommodate 11 banks of 3 no. reversible jet fans at each niche location, as shown in Fig 4 and Fig 5. Speed controls, including variable speed drives and power reticulation to jet fans is supplied from the 9-no. new cross connections and electrical adits. Fixed fire suppression system with misting nozzles will be installed to both North and South Bores. The misting system will be mounted to the underside of the tunnel ceiling. Monitoring will include cameras with 100% coverage (optical and thermal), heat detectors, sensors, all fully connected to Tunnel Supervisory Control System. Fig 4, 5 & 6 shows the design strategy applicable to North and South bores encompassing new niche locations, typical elevation and cross section as well as the expected final outcome.

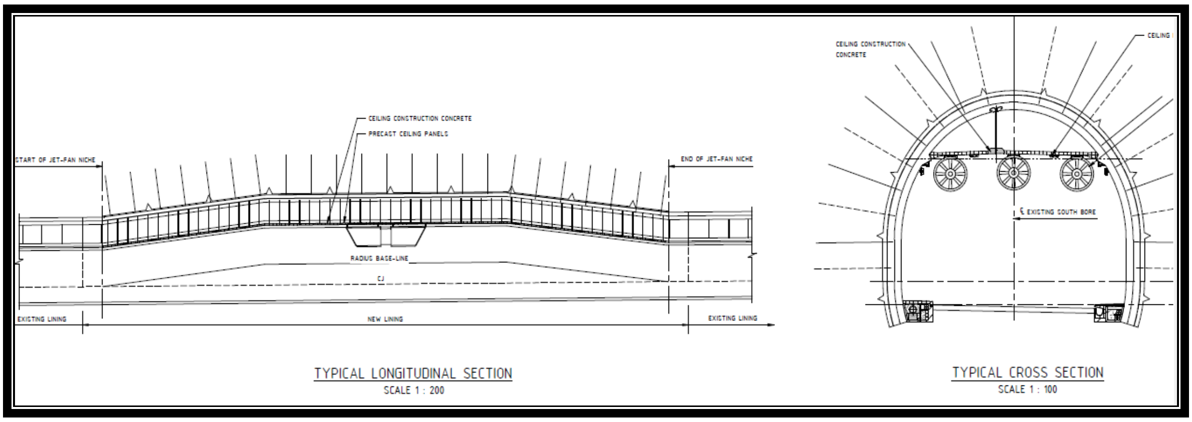


Figure 5: Niche longitudinal and cross sections

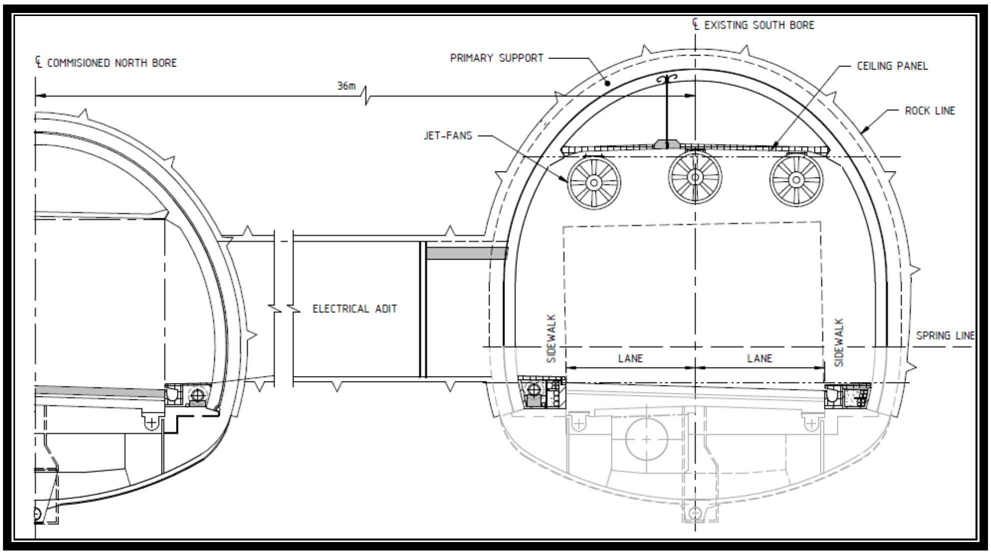


Figure 6: Design consideration for new niche after reprofiling tunnel crown

4. CONCLUSIONS

The South African National Road Agency is committed to develop the Huguenot tunnel as a twin bore mega infrastructure. All design steps for achieving this have been concluded and the appointment of contractors for civil work is at a final stage. The ventilation design and the retrofitting of its main components namely the new north bore, and the existing south bores are part of the scope of work that must be implemented for the safety of road users. As a project of unique complexity in the past 40 years one would expect some challenges related to experience of construction firms and possible implementation delays. The Huguenot Tunnel upgrade represents a significant advancement in South Africa's tunnel infrastructure, aligning with international safety standards and ensuring operational resilience. Fig 7 is the expected North and the South Bore tunnel portals as it is completed in 2029.

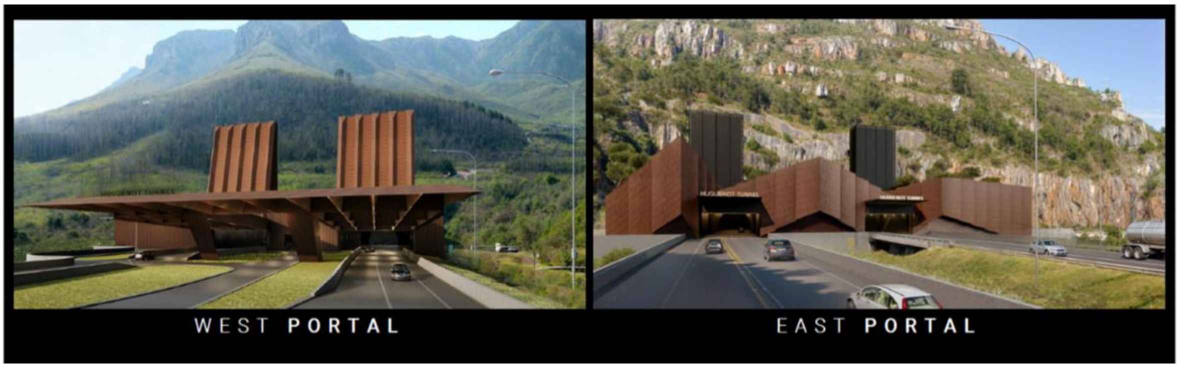


Figure 7: Architect's impression of tunnel portals after completion of the works

5. PLANNED UPGRADE WORKS

Based on the findings of the detailed design for the works, the upgrade of the Huguenot Tunnel has outlined the following activities beyond the topic discussed in this paper. These are:

- Upgrading of the N1/1 to a divided dual carriageway between km 56.430 and km 69.290 (12.86 km) with concrete-lined median drain on both approaches to the Huguenot Tunnel.
- Upgrading of the Southern Bore of the Huguenot Tunnel, including associated upgrades to the electrical, electronic, ventilation and fire suppression systems.
- Commissioning of the Northern Bore of the Huguenot Tunnel, designed for a 100 MW fire load; and including an international best practice point extraction ventilation system.
- Upgrading of the Southern Bore of the Huguenot Tunnel, to allow for a 100 MW fire load; and include an international best practice point extraction ventilation system.
- Installation of a low-pressure mist-type fixed fire-fighting system.
- Upgrading of the Main Control Centre Building, Portal Building East and Portal Building West to accommodate the upgrade of the Huguenot Tunnel.
- Upgrading of the power supply through construction of a new (132/11kV) Newland
- Substation and a back-up supply system for South Africa's state-owned electricity utility (Eskom).
- Upgrading of the tunnel electronic and control systems.
- Pavement rehabilitation of the existing N1/1 within the Planning Limits to cater for future attracted traffic.
- Providing 5 No. new bridge structures: Hugos River Viaduct Bridge A at km 60.180, Elands River Bridge at 65.690, Molenaars.
- Bridge 1A at 66.040, Molenaars Bridge 2B at 67.980 and a grade separation of the N1/R101 at 68.100.
- Incorporate findings of further geotechnical investigations in detailed design.