ROCKFALL PROTECTION ALONG SIDDHABABA SECTION OF SIDDHARTHA HIGHWAY
Ch. 28+200 km – Ch. 30+600 km

TENDER DOCUMENTS

VOLUME 3 – ANNEX D

TECHNICAL REQUIREMENTS
VENTILATION SYSTEM - TECHNICAL REPORT AND DESIGN BASIS

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1 Introduction

The 1130 m long Siddhababa Tunnel is located on the H10 road at the foothills of the Himalaya about 30 km north of the Nepali-Indian boarder. It lies in a valley with an approximate north-south orientation and is planned to bypass an area prone to landslides.
The length of tunnel requires a ventilation system for safety purposes.

This report constitutes the documentation of the preliminary design of the tunnel-ventilation system.

2 Objectives of report

This report summarises the boundary conditions, geometric input and results of the dimensioning of the ventilation system for the tunnel. Moreover, the report summarises the quantity of necessary ventilation equipment and gives guidance on how the equipment shall be installed in the tunnel to function properly.

3 Methodology and tools

The dimensioning of the ventilation system of the Siddhababa Tunnel was performed applying HBI internal calculation tools which are based on the Swiss guideline FEDRO for tunnel ventilation [3].

4 Fundamentals, assumptions and further details

4.1 Overview

The Siddhababa Tunnel is located on the H10 road at the foothills of the Himalaya about 30 km north of the Nepali-Indian boarder, lies in a valley with an approximate north-south orientation and is planned to bypass an area prone to landslides, see Figure 4.1.

The tunnel opening is forecasted for 2023 (design year).

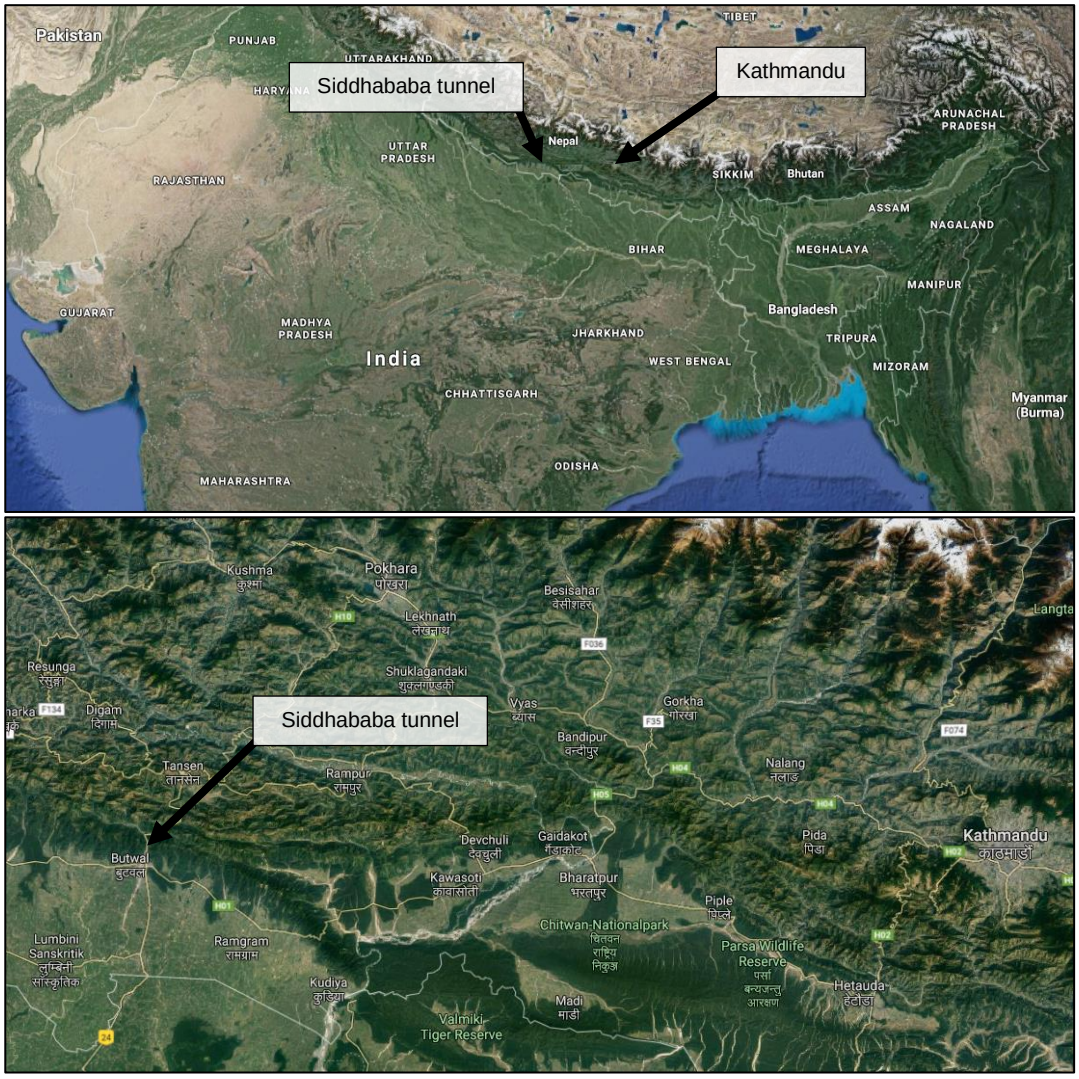


Figure 4.1: Overview location

The tunnel:

- will be operated with bidirectional traffic with one lane in each direction,
- is 1’130 m long,
- rises from the southern portal to the northern portal with about 35 m,
- and provides 3 bypass tunnels (escape tunnels) towards a parallel road, see Figure 4.2.
- The tunnel is located approx. 210 m above sea level

The lengths of the bypass tunnels are about 155 m, 129 m and 125 m.

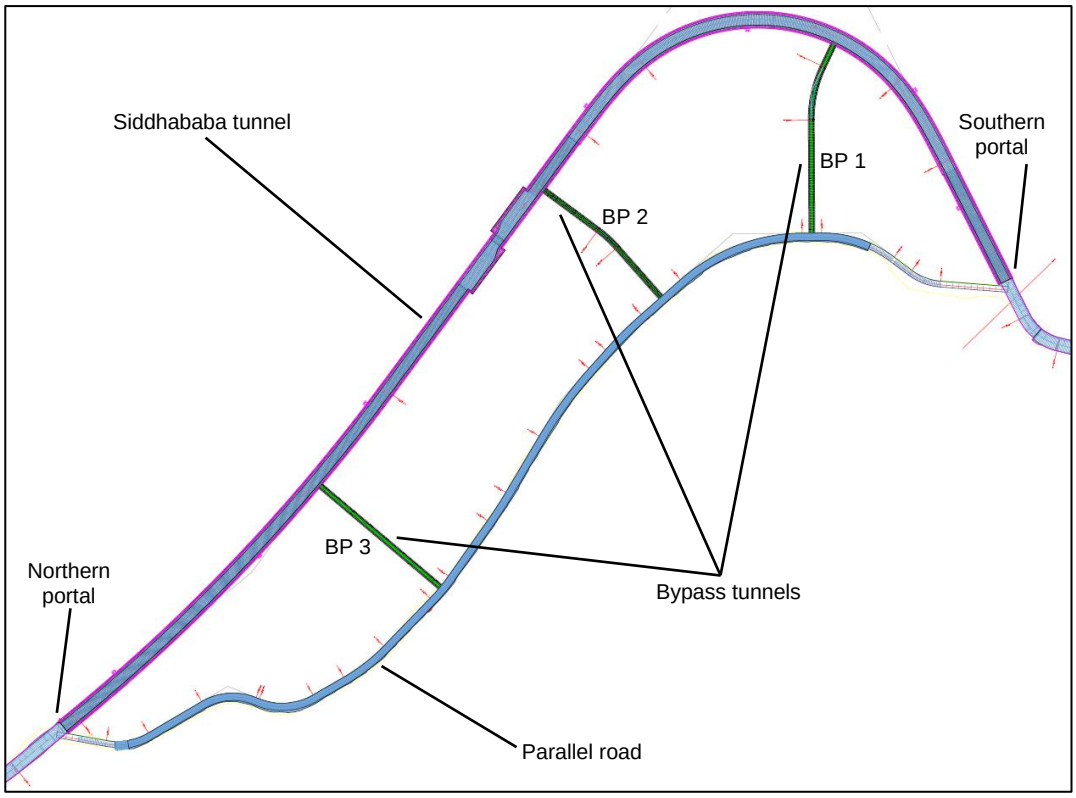


Figure 4.2: Overview Siddhababa tunnel with the bypass tunnels (towards the parallel road)

Emergency exits inside the tunnel are provided every 300 m, which means that an emergency exit is 245 m from the southern portal and another 285 m from the northern portal, see Figure 4.3.

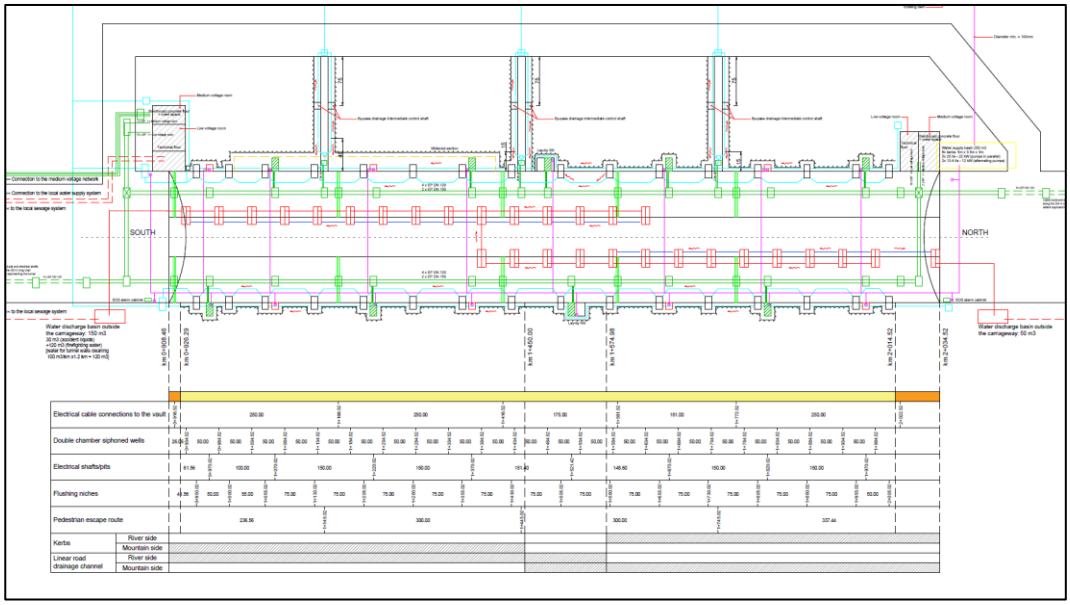


Figure 4.3: Layout of the Siddhababa tunnel

4.2 Geometry

4.2.1 Road tunnel

The longitudinal profile of the Siddhababa tunnel is given in Table 4.1

Table 4.1: Longitudinal tunnel profile from south to north

Section number	Section length	Section slope	Tunnel km	Chainage	Altitude
1	50 m	1.3%	0 m	1’600 m	200 m
			50 m	1’650 m	201 m
2	484 m	4.0%			
			534 m	2’134 m	219 m
3	133 m	0.53%			
			667 m	2’267 m	221 m
4	371 m	4.0%			
			1’038 m	2’638 m	235 m
5	92 m	-0.5%			
			1’130 m	2’730 m	235 m
Total length and difference in altitude:			1’130 m		35 m

Three types of cross sections were provided for the road tunnel, see Figure 4.4 to Figure 4.6. The information regarding the tunnel areas and the perimeters of the different cross sections is given in Table 4.2.

Table 4.2: Information of cross sections for the road tunnel

	Excavation area	Tunnel area (measured)	Perimeter (measured)
Cross section type 1	111 m^2	70 m^2	33 m
Cross section type 2	117 m^2	75 m^2	34 m
Cross section type 3	148 m^2	97 m^2	39 m

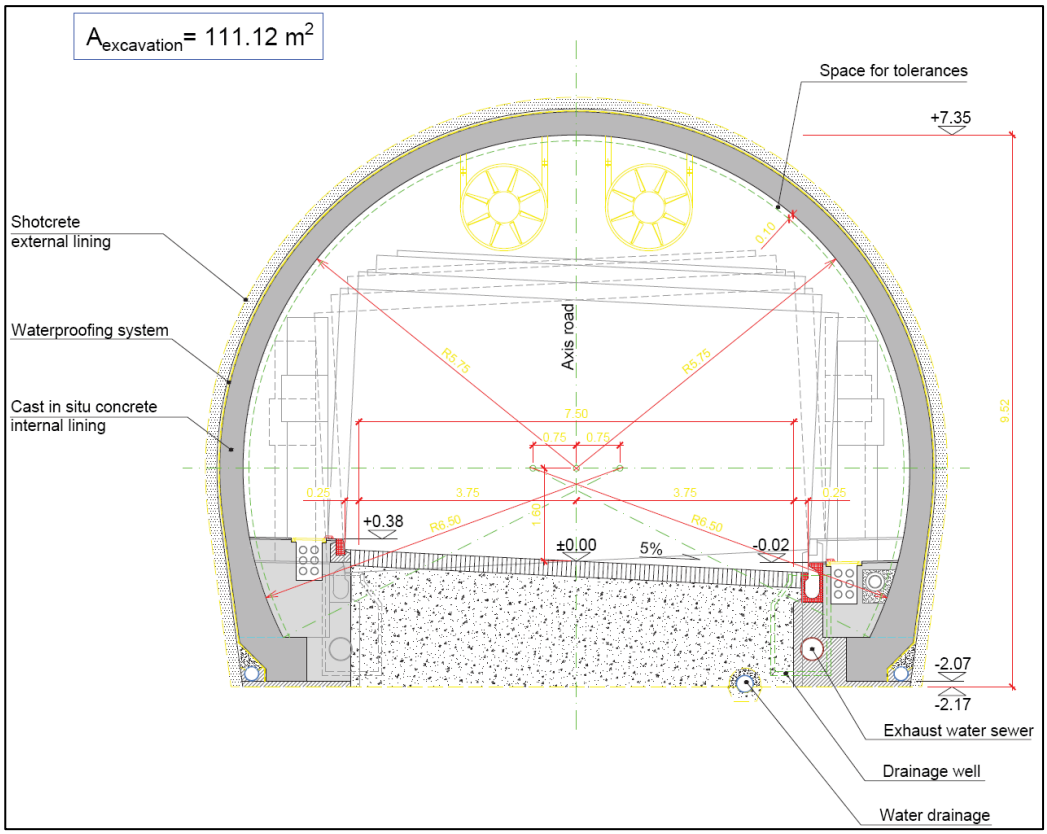


Figure 4.4: Road tunnel cross section type 1

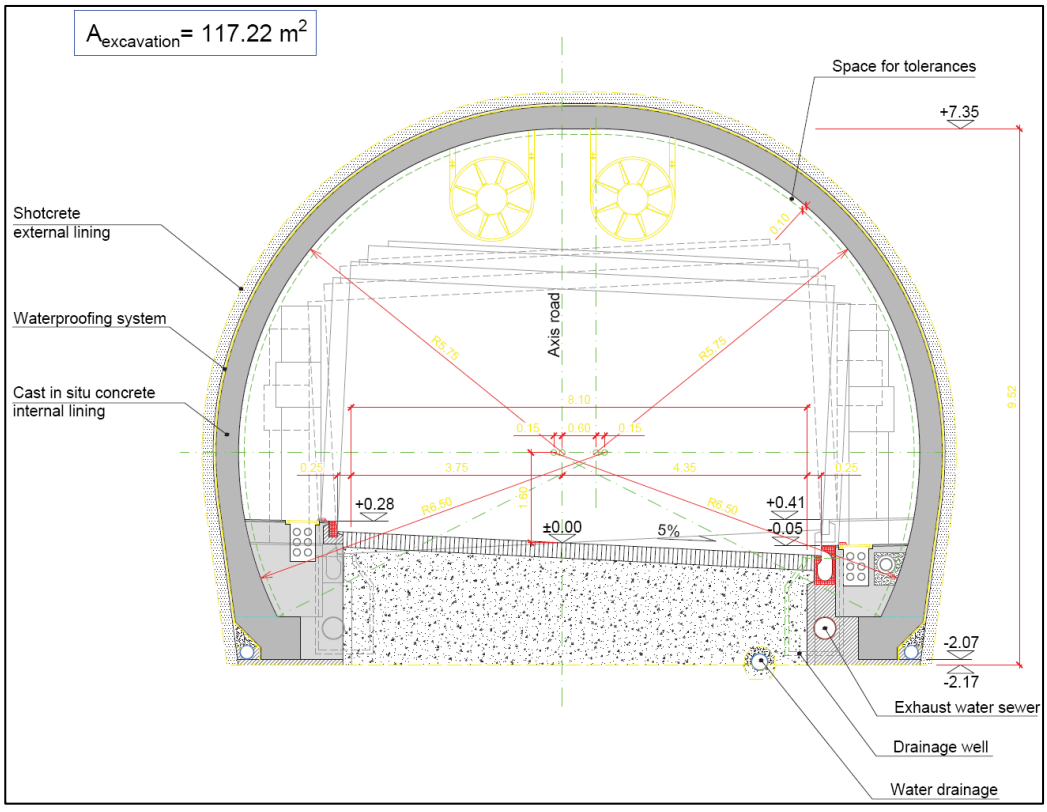


Figure 4.5: Road tunnel cross section type 2

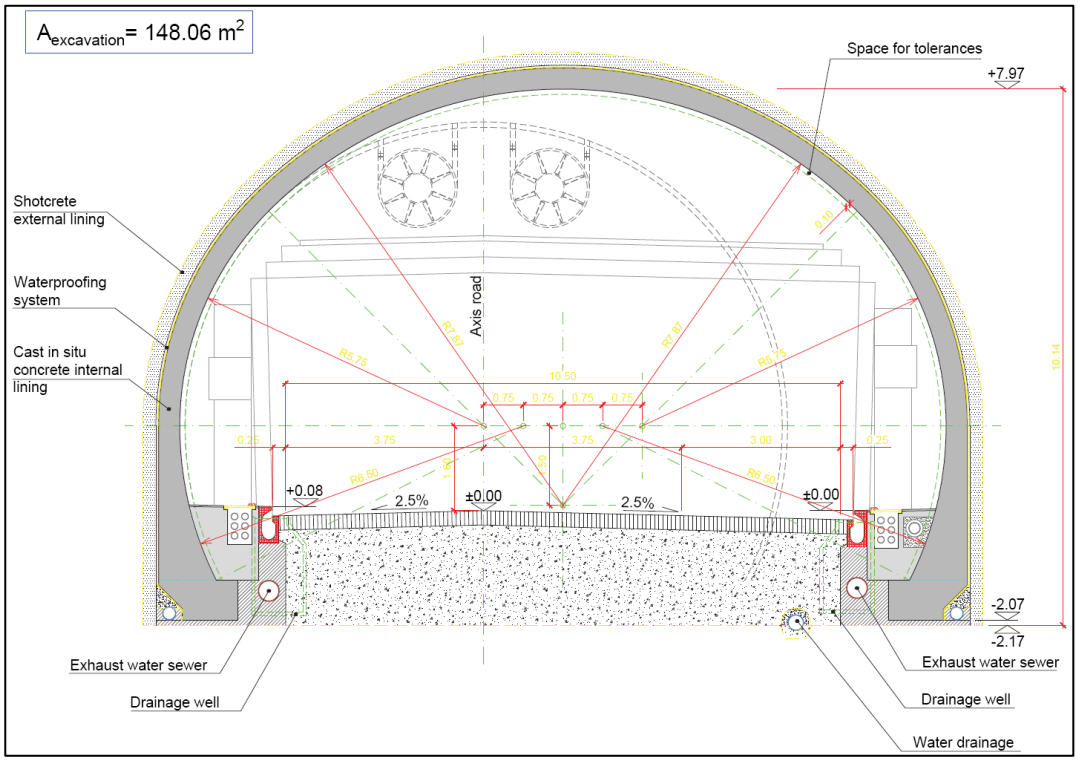


Figure 4.6: Road tunnel cross section type 3

Generally, the cross section type 1 is applied. The cross section type 2 is constructed in the area of long curve in the southern part of the Siddhababa tunnel. For the 42 m long break-down bays, the cross section type 3 is used. This information is summarised in Table 4.3.

Table 4.3: Tunnel sections with different cross section types (see also Figure 4.3)

Sections with different cross sections	Section length	Cross section type	Tunnel km	Chainage
1	95 m	Type 1	0 m	1’600 m
2	430 m	Type 2	95 m	1’695 m
3	33 m	Type 1	525 m	2’125 m
4	42 m	Type 3	558 m	2’158 m
5	3 m	Type 1	600 m	2’200 m
6	42 m	Type 3	603 m	2’203 m
7	485 m	Type 1	645 m	2’245 m
			1’130 m	2’730 m

4.2.2 Bypass tunnels

The longitudinal profiles of the bypass tunnels are given in Table 4.4 to Table 4.6.

Table 4.4: Longitudinal profile of the bypass tunnel 1 (bypass tunnel south), from the parallel road to the Siddhababa tunnel

Section number	Section length	Section slope	Tunnel km	Chainage	Altitude
1	127 m	1.0%	0 m	6 m	208 m
			127 m	133 m	209 m
5	28 m	-2.0%			
			155 m	161 m	207 m
Total length and difference in altitude:			155 m		1 m

Table 4.5: Longitudinal profile of the bypass tunnel 2 (bypass tunnel south), from the parallel road to the Siddhababa tunnel

Section number	Section length	Section slope	Tunnel km	Chainage	Altitude
1	21 m	1.0%	0 m	6 m	212 m
			21 m	27 m	213 m
2	88 m	9.1%			
			109 m	115 m	220 m
3	20 m	-2.0%			
			129 m	135 m	220 m
Total length and difference in altitude:			129 m		8 m

Table 4.6: Longitudinal profile of the bypass tunnel 3 (bypass tunnel south), from the parallel road to the Siddhababa tunnel

Section number	Section length	Section slope	Tunnel km	Chainage	Altitude
1	13 m	1.0%	0 m	6 m	217 m
			19 m	25 m	218 m
2	89 m	12.4%			
			107 m	113 m	228 m
3	23 m	-2.0%			
			125 m	131 m	228 m
Total length and difference in altitude:			125 m		11 m

The given cross section for the bypass tunnels is shown in Figure 4.7 and the information regarding the bypass tunnel area and the perimeters is summarised in Table 4.7.

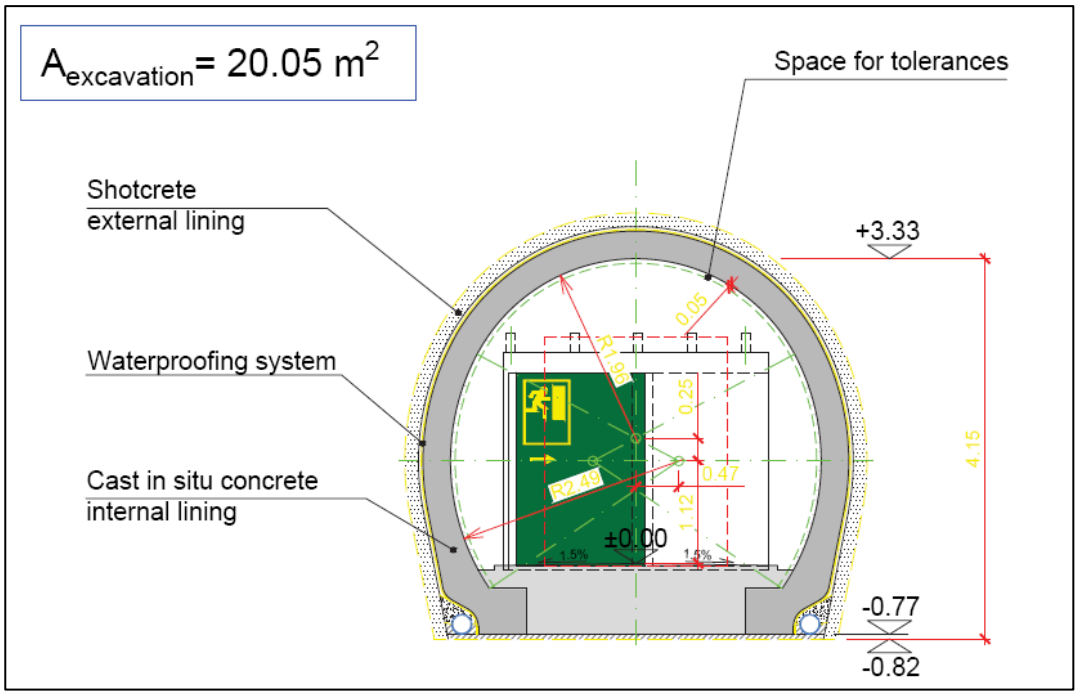


Figure 4.7: Cross section of bypass tunnels

Table 4.7: Information of cross section for the bypass tunnels

	Excavation area	Tunnel area (measured)	Perimeter (measured)
Cross section	20.05 m²	12 m²	13 m

4.3 Traffic

The Siddhababa tunnel has to be designed for forecasted traffic for the following years (according to [1]):

- Design year (i.e. tunnel opening year): 2023
- Design year + 20 years: 2043

It was informed that the yearly traffic increase of 7% is not to be applied to this project.

According to traffic counts, following data was provided to us:

- Average Annual Daily Traffic (AADT) for both traffic directions: 12'444
- Thereof:
  - Heavy goods vehicles (trucks, busses, utility vehicles, tractor): 1'474
  - Passenger cars (car/taxi/motorised three, rickshaw, bullock): 1'886
  - Motorcycles: 9'084

Irrespectively of the traffic forecast, the tunnel ventilation is dimensioned to cater for traffic of up to 20'000 PCU.

For the calculation of the piston effect in of the vehicles and the blockage by standing vehicles, only heavy goods vehicles and passenger cars are being considered. Based on this, it can be concluded that 44% of genuine vehicles are heavy good vehicles.

Table 4.8: Vehicle types and equivalent factors, [1], section 4.2

SN	Vehicle Type	Equivalency Factor
4	Bicycle,Motorcycle	0.5
1	Car, Auto Rickshaw, SUV,Light Van and Pick Up	1.0
2	Light (Mini) Truck, Tractor, Rickshaw	1.5
3	Truck,Bus,Minibus,Tractor with trailer	3.0
5	Non-motorized carts	6

4.4 Meteorology

4.4.1 Wind

Ten numbers of txt-Files with wind measurements are provided. Table 4.9 shows the summary of the analysis of the data.

Table 4.9: Analysis of provided wind data

	AW070720.03.txt	AW070720.04.txt	AW070720.05.txt	AW070720.06.txt	AW070720.07.txt	AW070720.10.txt	AW070720.11.txt	AW070720.12.txt	AW070720.13.txt	AW070720.14.txt
Minimum	0.0	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0
Maximum	9.4	21.7	11.0	13.5	11.1	5.4	6.1	7.2	5.6	5.5
Average	2.5	2.8	2.5	2.7	3.2	0.2	0.5	0.6	0.7	0.4
90-percentile	4.9	5.7	5.5	5.5	6.2	0.5	1.3	1.8	2.1	1.5
95-percentile	5.9	6.9	6.8	7.5	8.1	1.2	2.2	2.4	3.0	2.3
98-percentile	6.7	9.3	7.8	8.9	10.1	3.4	3.3	2.9	3.6	3.1

→

	Minimum	Average	Maximum
Minimum	0.0	0.0	0.1
Maximum	5.4	9.7	21.7
Average	0.2	1.6	3.2
90-percentile	0.5	3.5	6.2
95-percentile	1.2	4.6	8.1
98-percentile	2.9	5.9	10.1

↓

The above values are in [km/h] and the correspondig values in [m/s] are as follows:

	Minimum	Average	Maximum
Minimum	0.0	0.0	0.0
Maximum	1.5	2.7	6.0
Average	0.1	0.5	0.9
90-percentile	0.1	1.0	1.7
95-percentile	0.3	1.3	2.3
98-percentile	0.8	1.6	2.8

Upon request, it was informed that the unit of the values is km/h. Further, information with regard to the wind direction is not given. However, as a worst-case scenario the given data can be applied to the direction of the portals.

The wind data was measured in the years 2003 till 2014 at Bhairahawa (Lat. 27.529030555556, Lon. 83.4581166666669), which is about 20 km south of the tunnel location, see Figure 4.8. It was confirmed that the provided wind data was measured 10 m above ground level.

As the wind data shows fairly low air velocities, the typical maximum value for mountain regions of 30 Pa, was implemented as portal pressure for the dimensioning.

Figure 4.8: Comparison of location of tunnel and location of given wind data

4.4.2 Temperature

Ten numbers of txt-Files with temperature measurements are provided. Table 4.10 shows the summary of the analysis of the data.

Table 4.10: Analysis of provided temperature data

	TA070320.08.txt		TA070320.09.txt		TA070320.10.txt		TA070320.11.txt		TA070320.12.txt		TA070320.013.txt		TA070320.14.txt		TA070320.15.txt		TA070320.16.txt		TA070320.17.txt	
	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin
Minimum	16.2	7.0	13.5	7.0	11.5	7.0	11.0	6.0	12.5	6.5	8.0	5.2	11.4	7.0	12.0	5.6	12.6	4.5	19.5	5.0
Maximum	39.0	29.0	41.5	30.0	43.0	32.0	39.4	24.0	42.0	28.5	25.4	14.6	42.5	29.4	535.5	29.5	42.6	28.0	41.5	29.6
Average	30.6	21.3	31.4	21.4	31.0	21.4	31.7	16.7	30.7	18.8	19.7	8.8	30.0	19.6	31.7	19.6	31.7	18.9	31.7	19.3
90-percentile	36.5	26.5	37.4	27.5	38.0	27.5	37.0	20.2	39.3	23.9	24.8	12.6	38.0	25.6	36.6	26.0	38.0	24.5	37.0	25.5
95-percentile	37.8	27.2	38.5	28.0	39.5	28.0	38.0	21.0	40.2	24.2	25.0	13.1	39.0	26.6	38.0	26.8	40.5	25.0	39.2	26.5
98-percentile	38.5	27.6	39.8	28.5	40.5	29.0	38.4	22.0	41.0	25.0	25.2	13.8	40.4	27.5	39.9	27.5	41.6	26.0	39.9	27.5

Tmax			
	Min.	Av.	Max.
Minimum	8.0	12.8	19.5
Maximum	25.4	89.2	535.5
Average	19.7	30.0	31.7
90-percentile	24.8	36.3	39.3
95-percentile	25.0	37.6	40.5
98-percentile	25.2	38.5	41.6

Tmin			
	Min.	Av.	Max.
Minimum	4.5	6.1	7.0
Maximum	14.6	27.5	32.0
Average	8.8	18.6	21.4
90-percentile	12.6	24.0	27.5
95-percentile	13.1	24.6	28.0
98-percentile	13.8	25.4	29.0

According the Swiss guideline [3], it can be assumed that the temperature in the tunnel differs from the ambient temperature by 2°C for 450 m of tunnel length for tunnels in mountainous areas. Applying this relation, a temperature difference between inside and ambient of about 5°C can be assumed for the Siddhababa tunnel.

4.4.3 Barometric pressures

The Siddhababa tunnel does not underpass a mountain chain, hence the same meteorological conditions for both portals can be assumed. However, the height difference of the portals of about 35 m shall be accounted for:

- Southern portal: Chainage 1'600 m: 200 ASL
- Northern portal: Chainage 2'730 m: 235 ASL

4.5 Ventilation requirements by the Nepali Road Standard

Irrespectively of the traffic forecast, the tunnel ventilation is dimensioned to cater for traffic of up to 20'000 PCU. The design speed of the tunnel is 60 km/h.

Figure 4.9 shows a note on the dependence of the ventilation costs.

k. Ventilation costs depend on length, grades, natural and vehicle-induced ventilation, type of system, and air quality constraints.

Figure 4.9: Note regarding the dependence of the ventilation costs, [1], section 17.3

Tunnels of more than 150 m length should be provided with artificial ventilation. It is assumed that this requirement applies to road tunnels and not to bypass tunnels.

n. Tunnels of more than 150m length should be provided with artificial ventilation.

Figure 4.10: Requirement regarding mechanical ventilation, [1], section 17.3

The maximum air speed within the tunnel from mechanical ventilation shall not be more than 6 m/s, see Figure 4.11.

o. Maximum speed of air inside the tunnels(without considering the motion of air due to movement of vehicles) from artificial ventilation should be 6m/s.

Figure 4.11: Limitation of air speed due to mechanical ventilation, [1], section 17.3

4.6 Other guidelines for the ventilation design

In addition to the requirements by section 4.5 and [1], the tunnel ventilation design of the Siddhababa tunnel is based on the Swiss tunnel ventilation design code.

4.7 Constraints on equipment

It was informed that jet fans with an outer diameter of 1.5 m comply with the required distances to the tunnel and the traffic envelope according the Swiss standards and guidelines.

5 Tunnel-ventilation concept and dimensioning

5.1 Selection of ventilation system

The Swiss design guideline provides a methodology to determine the ventilation system based on the tunnel length and secondary tunnel characteristics, see Figure 5.1.

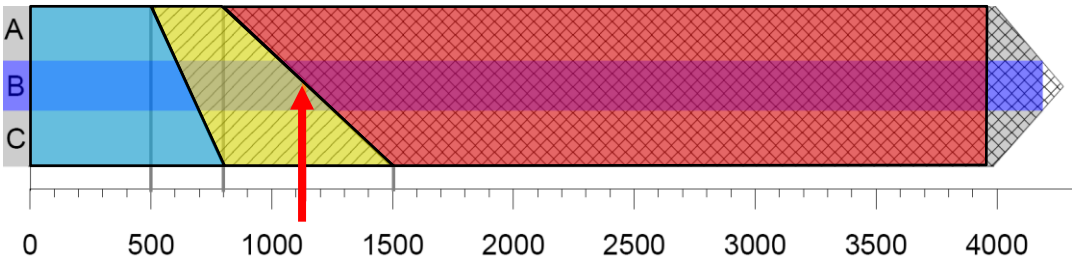


Figure 5.1: Comparison of location of tunnel and location of given wind data
blue: no mechanical ventilation;
yellow: longitudinal ventilation;
red: with smoke duct

After the evaluation of the total traffic data, the percentage of HGV and the level of inclination of the tunnel, the category of the Siddhababa was set to category “B”. In combination with the tunnel length of 1’130 m, the Siddhababa is in the region where longitudinal ventilation system is acceptable

5.2 Dimensioning for the fire case

The fire case is dimensioned for a fire size of 30 MW and the tunnel filled 50% with vehicles, as vehicles stop on both sides of the fire.

Details of the computations are documented in Appendix A: Dimensioning cases for fire ventilation.

5.3 Ventilation system for normal operation

The tunnel ventilation system dimensioned for the fire case can achieve fresh-air supply of 285 m³/s i.e. 252 m³/s per kilometre, which with a comfortable margin is judged to be more than adequate for normal operation.

5.4 Ventilation equipment

5.4.1 Jet fans

Calculations were performed assuming standard jet fans with the largest possible impeller diameters i.e. 900 mm, 1000 mm and 1120 mm. The results showed that the largest jet fan was the most suitable.

The jet fans shall be of reversible type. As the tunnel is short and the space to fit jet fan groups is limited, the largest jet fan that will fit into the tunnel cross section shall be used. This results in a jet fan with an impeller diameter of 1120 mm. The following table summarises the main specifications of the jet fans that were used for the dimensioning.

Table 5.1: Main jet-fan specifications at standard condition with air density 1.20 kg/m^3

Jet Fan Specifications		
Type		Reversible
Outer diameter, max	[mm]	1500
Impeller diameter	[mm]	1120
Outlet velocity	[m/s]	32.7
Minimum thrust in still air at ρ=1,20 kg/m^3	[N]	1011
Power	[kW]	35
Voltage	[V]	400/690
Thrust efficiency	[-]	0.8
Installation factor	[-]	1.2

Table 5.2: Resulting number of jet fans

Results, number of jet fans, impeller diameter 1120 mm		
Number of jet fans per group	[-]	2
Resulting number of groups incl. one redundant group	[-]	7
Total resulting number of jet fans	**[-]**	**14**

For further details on how the dimensioning was performed, please refer to Appendix A.

5.4.2 Anemometers AVD

The AVDs are vital the airflow control during emergencies (smoke control), as the ventilation control system needs to rely on the accuracy of their measurements. Therefore, we recommend:

- the ultrasonic measurement principle (2 ultrasonic transducers typically installed at an angle of 45° to 60° to the tunnel axis operate alternately as sender and receiver), see Figure 5.2
- each indicated (and overall) measurement consists of 3 independent single measurements (which allow for a plausibility check performed by the control system) with a distance of 10 m to each other

If the space requirements shown in chapter 5.4.4.1 cannot be met and the spacing has to be reduced the measurement may be faulty. An individual check of this situation is then required.

Based on the length of the tunnel, 2 locations with groups of 3 AVDs are required to handle the fire cases in the Siddhababa Tunnel

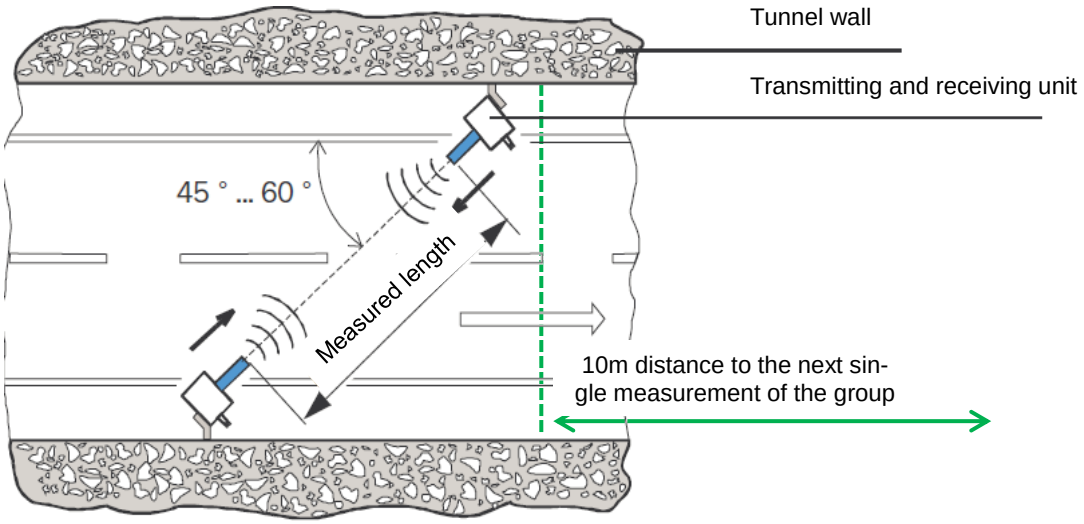


Figure 5.2: AVD-measurement point within the tunnel.

5.4.3 Air quality meters

To survey the air quality during normal operation, two air quality monitors shall be installed. The Air quality monitor shall monitor the turbidity and the CO concentration.

5.4.4 Installation requirements

5.4.4.1 Jet Fans

Jet fans shall be positioned according to the following minimum spacing [3], [4].

- Distance to the portal (vent. direction to environment): min. 100 m
- Distance between two jet fan groups: min. 100 m
- Distance to large signs: min. 100 m
- Distance to medium signs min. 60 m
- Distance to small signs: min. 30 m

The definition of the traffic sign size for ventilation purposes is based on the overall area of the sign (including frame) and is as follows:

- Large = 2.5 m^2 ≤ A_sign
- Medium = 1.0 m^2 < A_sign < 2.5 m^2
- Small = A_sign ≤ 1.0 m^2

Note: If two or more signs are located at the same location, the sign area for ventilation purposes is then determined by the overall area of all signs at that location.

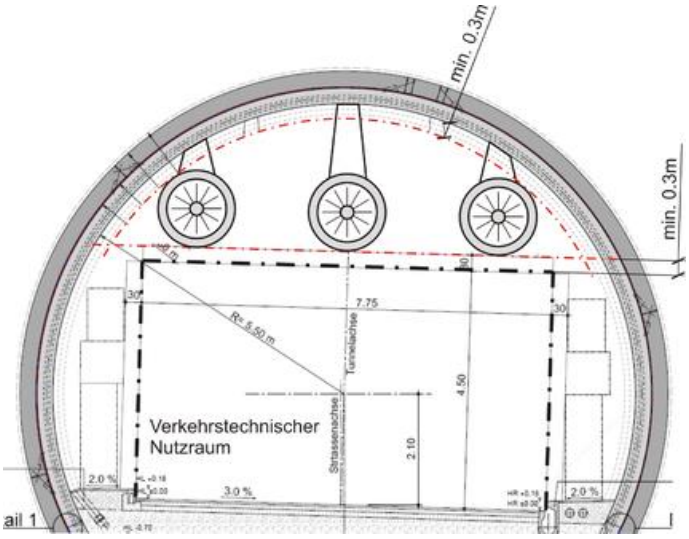


Figure 5.3: Example of jet fan installation distances to tunnel wall and traffic envelope.

Distance between casing and tunnel ceiling or side wall	min. 0.3 m
Distance between casing and traffic envelope	min. 0.3 m
Distance between the jet fans of a group	min. 1 inner fan diameter

5.4.4.2 Air Velocity and Direction Monitors

For a correct measurement of the airspeed and direction, the air-velocity and direction (AVD) monitors shall be installed in tunnel sections with a developed airflow. Depending on the size of the obstruction the airflow may need up to 7-8 hydraulic tunnel diameters to fully develop. This leads to the following space provisions for the positioning of the AVDs:

- Distance to adjacent jet fan groups: min. 100 m
- Distance to changes in cross section (breakdown bays): min. 60 m
- Distance between two AVDs of one group: min. 10 m
- Distance to large signs: min. 40 m
- Distance to medium signs: min. 20 m
- Distance to small signs: min. 5 m

The definition of the traffic sign size for ventilation purposes is based on the overall area of the sign (including frame) and is as follows:

- Large = 2.5 m² ≤ A_sign
- Medium = 1.0 m² < A_sign < 2.5 m²
- Small = A_sign ≤ 1.0 m²

Note: If two or more signs are located at the same location the sign area for ventilation purposes is then determined by the overall area of all signs at that location.

For the installation of the AVDs within the tunnel cross-section, the space provisions as shown in Figure 4 2 shall be provided.

If the AVDs are installed too close to the tunnel ceiling, reflections may occur which falsify the measurement. Interferences with other equipment have to be checked.

If these space requirements cannot be met and the AVDs have to be positioned at a lower height within the cross section, the measurement may be disturbed by high vehicles passing or interrupted in case of congestion.

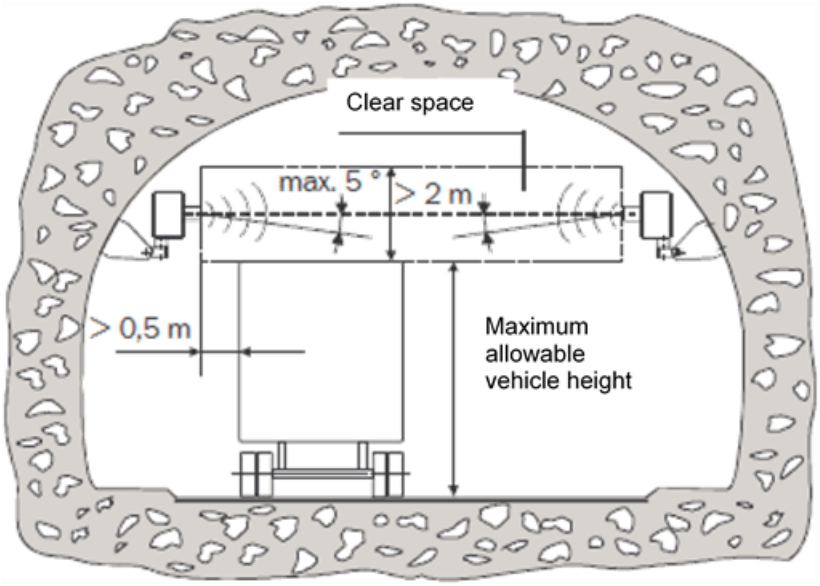


Figure 5.4: Minimum clearances for AVDs within the tunnel section.

5.4.4.3 Air quality meters

The two air-quality meters shall be located between 200 and 300 m from each portal.

5.4.5 Equipment schedule

The following table summarizes the equipment required for the ventilation of the Siddhababa Tunnel:

Table 5.3: Equipment schedule of in-tunnel equipment

Equipment Schedule	Number
Jet fans ,1120 mm impeller, 1011 N, 35 kW	14
Air velocity and direction measuring devices (ultrasonic measurements across the traffic space)	6
Air quality meters e.g. turbidity and CO combined	2

6 Egress tunnel ventilation concept and dimensioning

6.1 Overview

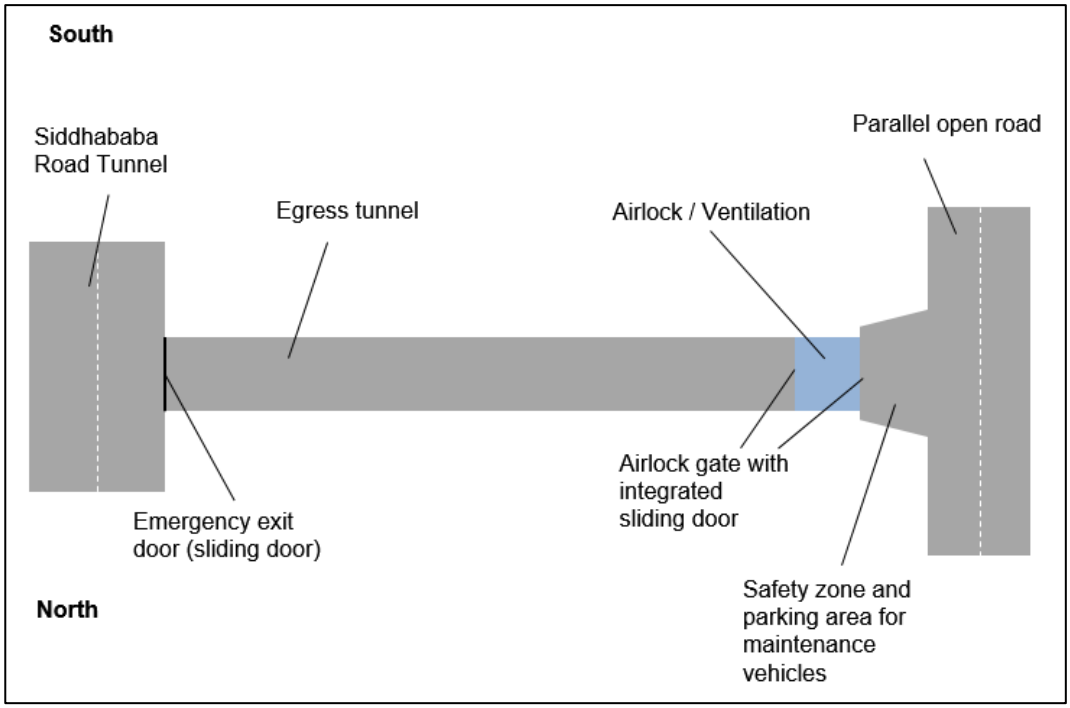


Figure 6.1: Egress tunnel with airlock at portal.

Each egress tunnel is equipped with a sliding emergency exit door at the intersection with the road tunnel. At the portal, each egress tunnel is equipped with an airlock with sliding doors on each side of the airlock. The ventilation of the egress tunnels is provided by two axial fans at the portal of each egress tunnel. The fans are installed parallel to the airlock.

6.2 Assumptions

- For the dimensioning of the fans of the egress ventilation an air speed of at least 2 m/s through open doors toward the tunnel was assumed. This value must be achieved also if one fan fails.
- For normal operation a leakage flow rate of 0.15 m³/s per door is assumed.
- The overpressure in the egress tunnel is set to 300 Pa with a pressure relief damper.

6.3 Normal operation

During normal operation, the ventilation of the egress tunnel ensures a defined overpressure relative to the traffic area. The operation of a fan at low speed (50% speed) is sufficient. The fan in operation (green in Figure 6.2) is changed periodically depending on the number of operating hours. The fan that is not in operation (grey in Figure 6.2) is shut off with a damper.

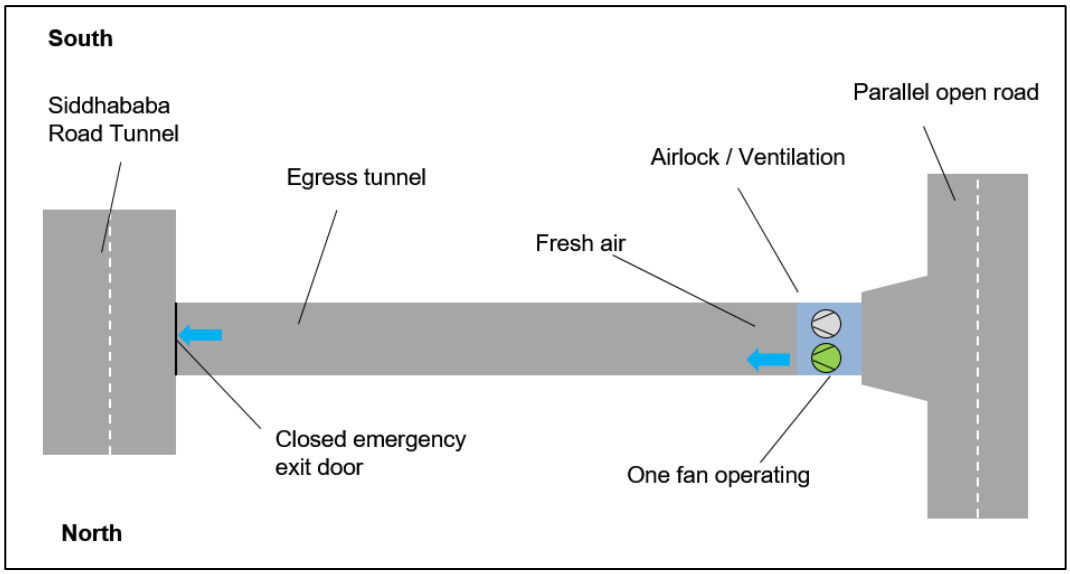


Figure 6.2: Ventilation concept for normal operation

6.4 Emergency operation

The ventilation concept for emergency operation is shown schematically in Figure 6.3. In the event of an emergency, both fans (green in Figure 6.3) operate at the full speed (100% speed). This way, the greatest possible flow is achieved through the open door and an over-pressure is built up relative to the traffic area when the door is closed.

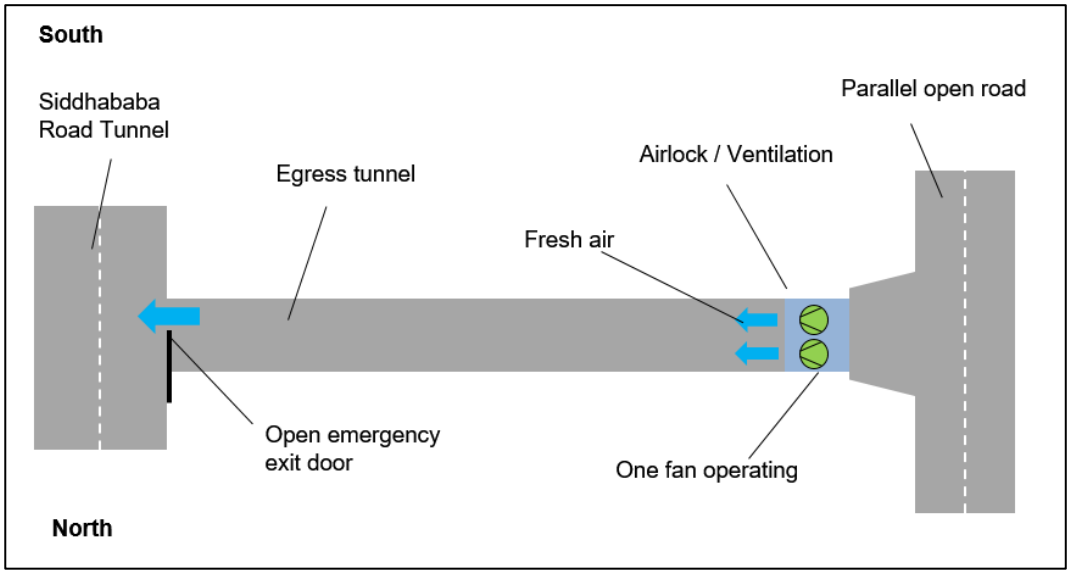


Figure 6.3: Ventilation concept for emergency operation with open door.

In order to avoid excessive pressure in the egress tunnel, a pressure relief damper is provided parallel to the fans. The damper closes as soon as the emergency exit door to the tunnel is opened and the pressure in the egress tunnel drops. In the event of a fan failure, the shut-off damper of the affected fan is closed. The egress tunnel is then ventilated with the remaining fan.

6.4.1 Redundancy

All fans of the egress tunnel ventilation system shall ideally be supplied via two independent electrical feeds.

The redundancy of the system is designed to ensure that 100% flow is achieved if one fan fails during emergency operation.

6.5 Egress tunnel ventilation equipment

6.5.1 Overview

Each ventilation system of an egress path consists of 2 axial fans with VSDs (variable speed drive), motorised shut-off dampers and flow meters. For excess pressure, a pressure relief damper with duct to the ambient is installed.

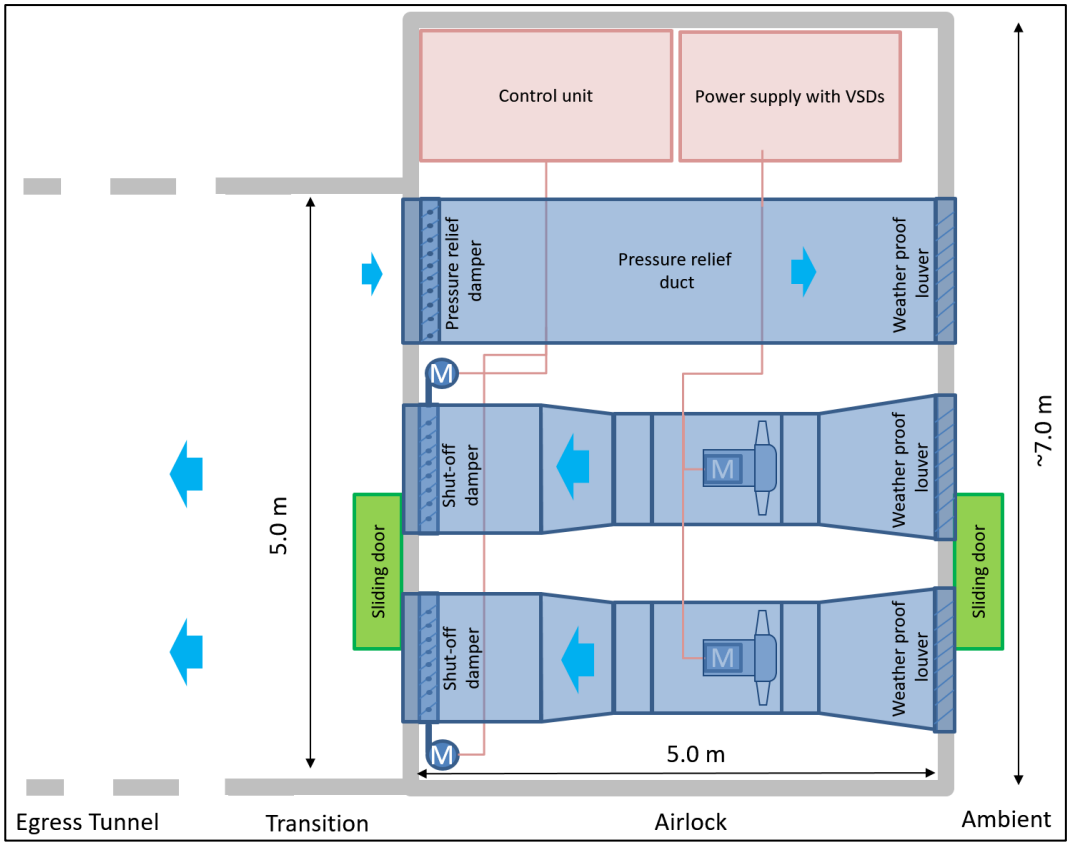


Figure 6.4: Airlock with ventilation equipment setup.

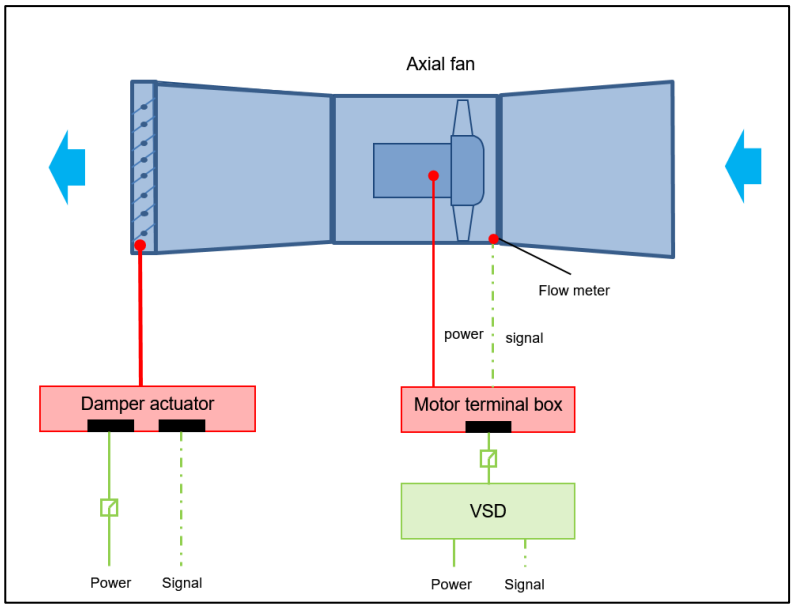


Figure 6.5: Fan unit with shut-off damper of the egress-tunnel ventilation.

In Figure 6.6, the estimated dimensions are given for the airlock including space for the ventilation equipment and electrical equipment.

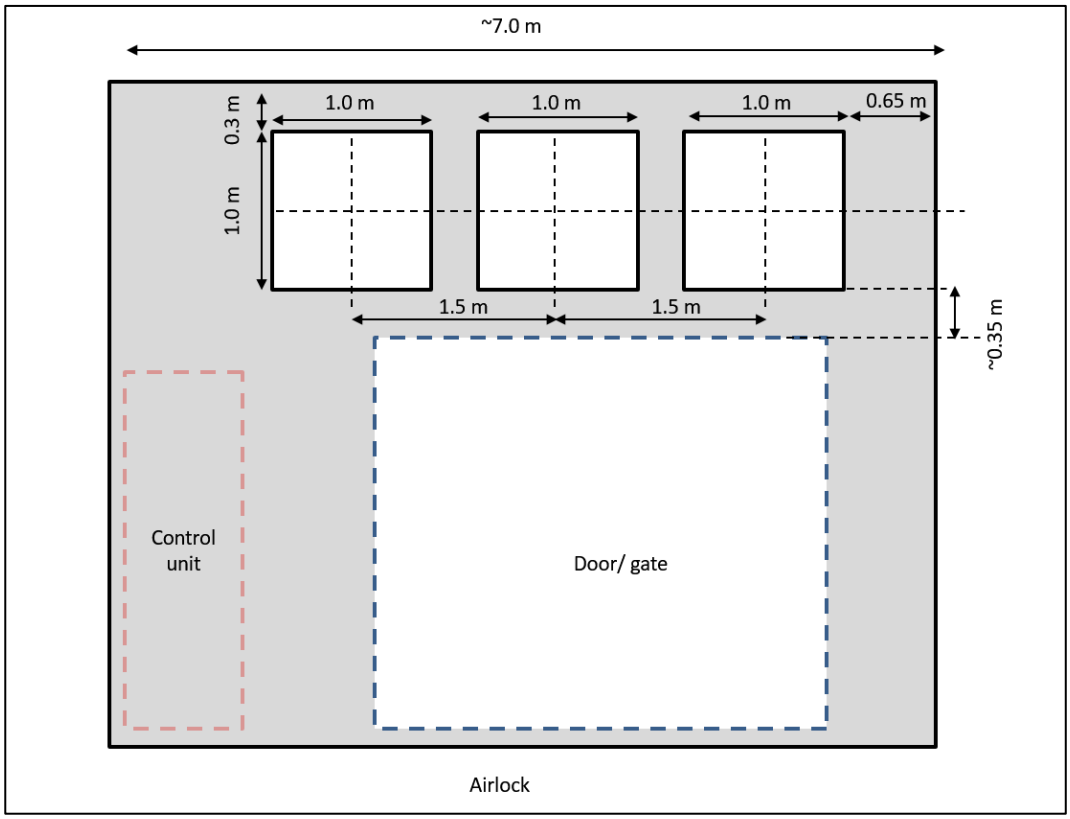


Figure 6.6: Airlock front view wall openings for ventilation equipment.

6.5.2 Monitoring devices

6.5.2.1 Damper limit switches

Each fan shut-off damper shall be equipped with a limit switch to monitor whether the damper is open or closed.

6.5.2.2 Flow meter

Each fan shall be equipped with a flow meter to determine that the fan is functioning properly.

6.5.2.3 Supervision of egress doors

Each egress door has to be supervised in such a manner that when the door is not closed, the associated egress tunnel ventilation automatically engages in emergency mode.

6.6 Equipment schedule of egress tunnel ventilation

Table 6.1: Ventilation equipment schedule of egress tunnels

Equipment Schedule considering all 3 egress tunnels	Number
Axial fans with VSD*, 800 mm impeller, 5.5 kW 6.0 m^3/s @ 280 Pa with stall-free fan curve	6
Flow meters	6
Shut-off dampers with actuators and limit switch, 0.3 kW	6
Pressure relief dampers	3

*VSD (variable speed drive)

7 References

[1] Nepal Road Standard 2070, Government of Nepal, Ministry of Physical Infrastructure & Transport, Department of Roads, Planning and Design Branch, Road and Traffic Unit, Babarmahal, Kathmandu, July 2013

[2] Road Tunnels: Vehicle Emissions and Air Demand for Ventilation, Technical Committee D.5 Road Tunnels, PIARC, World Road Association, 2018R038EN

[3] Swiss Tunnel Ventilation Design Code (Federal Roads Office “FEDRO”; Richtlinie Lüftung der Strassentunnel, Systemwahl, Dimensionierung und Ausstattung), V2.03, 2008

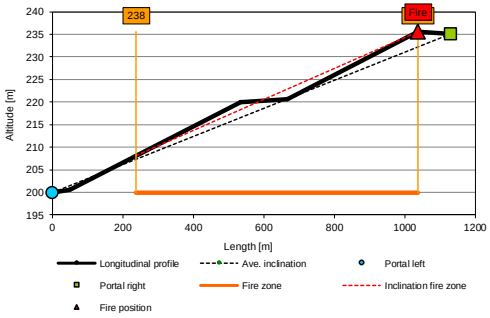
[4] Strahlventilatoren bei Portalen und in Nischen, Anordnung und Wirkungsgrad, CFD, Franz Zumsteg, 2007

Appendix A: Dimensioning cases for fire ventilation

Calculation of buoyancy due to fire and determination of the number of jet fans for longitudinal ventilation without exhaust

Project:	Siddhababa Tunnel Nepal	Reference year:	2031	Name:	NKR/RBR
Tunnel:	Siddhababa	File name:	KAL_18-304_001_V1-2_2019-06-02 - Siddhababa - SV_Längslüftung_mitAbsaugun	Date:	06.02.2019

Longitudial section of the tunnel



Geometry

Tunnel lenght L	1130 m
Gradient i (l -> r)	3,11 %
Altitude H	217,5 amsl
Tunnel cross-section A	75,00 m^2
Cross-section at jetfan positions	75,00 m^2
Hydraulic diameter Dh	8,82 m
Wall friction coefficient	0,015

Traffic

Significant traffic per hour STH	1000 Veh./h
HGV fraction	44,0 %
Mean cw*A vehic.	2,79 m^2
Travel speed	60 km/h
Detection time	15 min
Traffic density	150 PCU/km,lane
Degree of admission	100%
Vehicles inside the tunnel	118 Veh

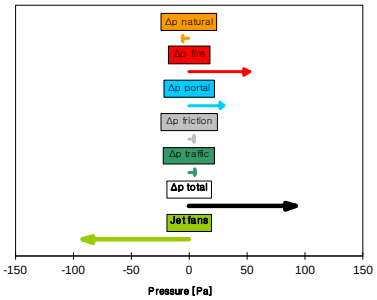
Meteorology and fire

Atmospheric pressure p(h)	98747 Pa
Atmospheric pressure p(h)	98974 Pa
External temperature (5th percentile)	13,10 °C
External temperature (95th percentile)	40,50 °C
Internal temperature	35,48 °C
Heat-release rate HRR	30 MW
Fire location (from the left portal)	1038 m
Lenght of the fire section	800 m
ΔT fire	65 K
Gradient of the fire section	3,42 %

Calculation bases

Category of traffic [OWT1, OWT2, TWT]	TWT
Extraction capacity	0 m^3/s
Required flow velocity left of fire	-1,5 m/s
Required flow velocity right of fire	-1,5 m/s

Pressures at T_{A_95}



Pressure differences

Δp fire	52,20 Pa
Δp natural	-6,16 Pa
Δp portal due to wind	30,00 Pa
Δp portal effective	30,00 Pa
Δp friction	4,43 Pa
Δp traffic	5,51 Pa
Total pressure difference	**92,13 Pa**
Required thrust	**-6910 N**

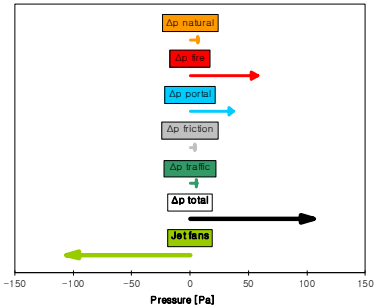
Jet fans

Specifications

Internal diameter D	900 mm	1000 mm	1120 mm
Jet velocity	30,20 m/s	32,70 m/s	32,70 m/s
Volume flow rate	17,18 m^3/s	22,24 m^3/s	28,82 m^3/s
Installation factor	1,2	1,2	1,2
Static thrust	557 N	756 N	1011 N
Results			
Thrust of 1 jet fan	**-363 N**	**-477 N**	**-662 N**
No. of jet fans	**19,1**	**14,5**	**10,4**
Min. no. of jet fans*	**17,2**	**13,0**	**9,4**

*Redundancy case

Pressures at T_{A_5}



Pressure differences

Δp fire	57,87 Pa
Δp natural	7,13 Pa
Δp portal due to wind	30,00 Pa
Δp portal effective	37,13 Pa
Δp friction	4,68 Pa
Δp traffic	5,82 Pa
Total pressure difference	**105,50 Pa**
Required thrust	**-7913 N**

Jet fans

Specifications

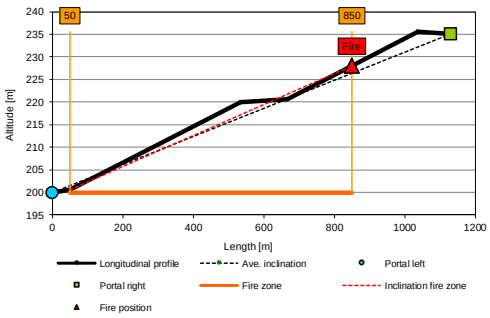
Internal diameter D	900 mm	1000 mm	1120 mm
Jet velocity	30,20 m/s	32,70 m/s	32,70 m/s
Volume flow rate	17,18 m^3/s	22,24 m^3/s	28,82 m^3/s
Installation factor	1,2	1,2	1,2
Static thrust	557 N	756 N	1011 N
Results			
Thrust of 1 jet fan	**-383 N**	**-504 N**	**-699 N**
No. of jet fans	**20,6**	**15,7**	**11,3**
Min. no. of jet fans*	**18,6**	**14,1**	**10,2**

*Redundancy case

Calculation of buoyancy due to fire and determination of the number of jet fans for longitudinal ventilation without exhaust

Project:	Siddhababa Tunnel Nepal	Reference year:	2031	Name:	NKR/RBR
Tunnel:	Siddhababa	File name:	KAL_18-304_001_V1-2_2019-06-02 - Siddhababa - SV_Längslüftung_mitAbsaugun	Date:	06.02.2019

Longitudial section of the tunnel



Geometry

Tunnel lenght L	1130 m
Gradient i (l -> r)	3,11 %
Altitude H	217,5 amsl
Tunnel cross-section A	75,00 m^2
Cross-section at jetfan positions	75,00 m^2
Hydraulic diameter Dh	8,82 m
Wall friction coefficient	0,015

Traffic

Significant traffic per hour STH	1000 Veh./h
HGV fraction	44,0 %
Mean cw*A vehic.	2,79 m^2
Travel speed	60 km/h
Detection time	15 min
Traffic density	150 PCU/km,lane
Degree of admission	100%
Vehicles inside the tunnel	118 Veh

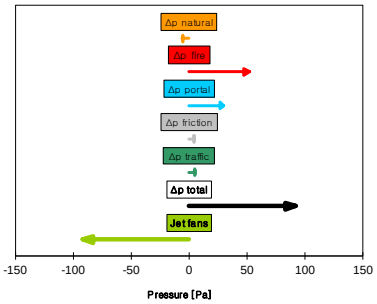
Meteorology and fire

Atmospheric pressure p(h)	98747 Pa
Atmospheric pressure p(h)	98974 Pa
External temperature (5th percentile)	13,10 °C
External temperature (95th percentile)	40,50 °C
Internal temperature	35,48 °C
Heat-release rate HRR	30 MW
Fire location (from the left portal)	850 m
Lenght of the fire section	800 m
ΔT fire	65 K
Gradient of the fire section	3,42 %

Calculation bases

Category of traffic [OWT1, OWT2, TWT]	TWT
Extraction capacity	0 m^3/s
Required flow velocity left of fire	-1,5 m/s
Required flow velocity right of fire	-1,5 m/s

Pressures at T_{A_95}



Pressure differences

Δp fire	52,20 Pa
Δp natural	-6,16 Pa
Δp portal due to wind	30,00 Pa
Δp portal effective	30,00 Pa
Δp friction	4,43 Pa
Δp traffic	5,51 Pa
Total pressure difference	**92,13 Pa**
Required thrust	**-6910 N**

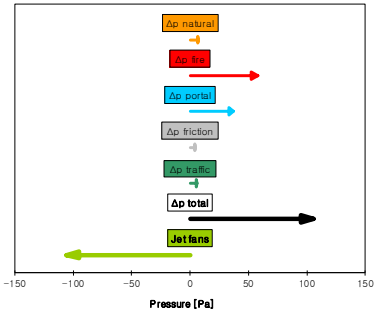
Jet fans

Specifications

Internal diameter D	900 mm	1000 mm	1120 mm
Jet velocity	30,20 m/s	32,70 m/s	32,70 m/s
Volume flow rate	17,18 m^3/s	22,24 m^3/s	28,82 m^3/s
Installation factor	1,2	1,2	1,2
Static thrust	557 N	756 N	1011 N
Results			
Thrust of 1 jet fan	**-363 N**	**-477 N**	**-662 N**
No. of jet fans	**19,1**	**14,5**	**10,4**
Min. no. of jet fans*	**17,2**	**13,0**	**9,4**

*Redundancy case

Pressures at T_{A_5}



Pressure differences

Δp fire	57,87 Pa
Δp natural	7,13 Pa
Δp portal due to wind	30,00 Pa
Δp portal effective	37,13 Pa
Δp friction	4,68 Pa
Δp traffic	5,82 Pa
Total pressure difference	**105,50 Pa**
Required thrust	**-7913 N**

Jet fans

Specifications

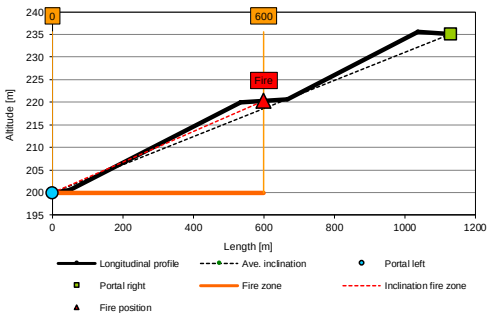
Internal diameter D	900 mm	1000 mm	1120 mm
Jet velocity	30,20 m/s	32,70 m/s	32,70 m/s
Volume flow rate	17,18 m^3/s	22,24 m^3/s	28,82 m^3/s
Installation factor	1,2	1,2	1,2
Static thrust	557 N	756 N	1011 N
Results			
Thrust of 1 jet fan	**-383 N**	**-504 N**	**-699 N**
No. of jet fans	**20,6**	**15,7**	**11,3**
Min. no. of jet fans*	**18,6**	**14,1**	**10,2**

*Redundancy case

Calculation of buoyancy due to fire and determination of the number of jet fans for longitudinal ventilation without exhaust

Project:	Siddhababa Tunnel Nepal	Reference year:	2031	Name:	NKR/RBR
Tunnel:	Siddhababa	File name:	KAL_18-304_001_V1-2_2019-06-02 - Siddhababa - SV_Längslüftung_mitAbsaugung	Date:	06.02.2019

Longitudial section of the tunnel



Geometry

Tunnel lenght L	1130 m
Gradient i (l -> r)	3,11 %
Altitude H	217,5 amsl
Tunnel cross-section A	75,00 m^2
Cross-section at jetfan positions	75,00 m^2
Hydraulic diameter Dh	8,82 m
Wall friction coefficient	0,015

Traffic

Significant traffic per hour STH	1000 Veh./h
HGV fraction	44,0 %
Mean cw*A vehic.	2,79 m^2
Travel speed	60 km/h
Detection time	15 min
Traffic density	150 PCU/km,lane
Degree of admission	100%
Vehicles inside the tunnel	118 Veh

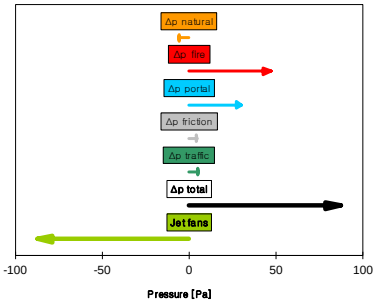
Meteorology and fire

Atmospheric pressure p(h)	98747 Pa
Atmospheric pressure p(h)	98974 Pa
External temperature (5th percentile)	13,10 °C
External temperature (95th percentile)	40,50 °C
Internal temperature	35,48 °C
Heat-release rate HRR	30 MW
Fire location (from the left portal)	600 m
Lenght of the fire section	600 m
ΔT fire	65 K
Gradient of the fire section	3,40 %

Calculation bases

Category of traffic [OWT1, OWT2, TWT]	TWT
Extraction capacity	0 m^3/s
Required flow velocity left of fire	-1,5 m/s
Required flow velocity right of fire	-1,5 m/s

Pressures at T_{A_95}



Pressure differences

Δp fire	47,39 Pa
Δp natural	-6,16 Pa
Δp portal due to wind	30,00 Pa
Δp portal effective	30,00 Pa
Δp friction	4,43 Pa
Δp traffic	5,51 Pa
Total pressure difference	**87,32 Pa**
Required thrust	**-6549 N**

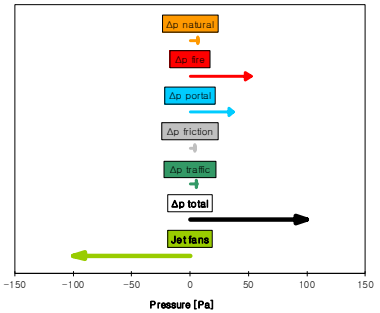
Jet fans

Specifications

Internal diameter D	900 mm	1000 mm	1120 mm
Jet velocity	30,20 m/s	32,70 m/s	32,70 m/s
Volume flow rate	17,18 m^3/s	22,24 m^3/s	28,82 m^3/s
Installation factor	1,2	1,2	1,2
Static thrust	557 N	756 N	1011 N
Results			
Thrust of 1 jet fan	**-363 N**	**-477 N**	**-662 N**
No. of jet fans	**18,1**	**13,7**	**9,9**
Min. no. of jet fans*	**16,3**	**12,4**	**8,9**

*Redundancy case

Pressures at T_{A_5}



Pressure differences

Δp fire	52,54 Pa
Δp natural	7,13 Pa
Δp portal due to wind	30,00 Pa
Δp portal effective	37,13 Pa
Δp friction	4,68 Pa
Δp traffic	5,82 Pa
Total pressure difference	**100,18 Pa**
Required thrust	**-7513 N**

Jet fans

Specifications

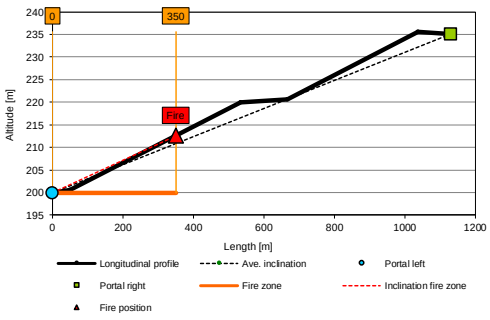
Internal diameter D	900 mm	1000 mm	1120 mm
Jet velocity	30,20 m/s	32,70 m/s	32,70 m/s
Volume flow rate	17,18 m^3/s	22,24 m^3/s	28,82 m^3/s
Installation factor	1,2	1,2	1,2
Static thrust	557 N	756 N	1011 N
Results			
Thrust of 1 jet fan	**-383 N**	**-504 N**	**-699 N**
No. of jet fans	**19,6**	**14,9**	**10,7**
Min. no. of jet fans*	**17,6**	**13,4**	**9,7**

*Redundancy case

Calculation of buoyancy due to fire and determination of the number of jet fans for longitudinal ventilation without exhaust

Project:	Siddhababa Tunnel Nepal	Reference year:	2031	Name:	NKR/RBR
Tunnel:	Siddhababa	File name:	KAL_18-304_001_V1-2_2019-06-02 - Siddhababa - SV_Längslüftung_mitAbsaugung	Date:	06.02.2019

Longitudial section of the tunnel



Geometry

Tunnel lenght L	1130 m
Gradient i (l -> r)	3,11 %
Altitude H	217,5 amsl
Tunnel cross-section A	75,00 m^2
Cross-section at jetfan positions	75,00 m^2
Hydraulic diameter Dh	8,82 m
Wall friction coefficient	0,015

Traffic

Significant traffic per hour STH	1000 Veh./h
HGV fraction	44,0 %
Mean cw*A vehic.	2,79 m^2
Travel speed	60 km/h
Detection time	15 min
Traffic density	150 PCU/km,lane
Degree of admission	100%
Vehicles inside the tunnel	118 Veh

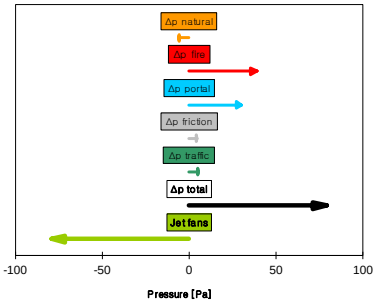
Meteorology and fire

Atmospheric pressure p(h)	98747 Pa
Atmospheric pressure p(h)	98974 Pa
External temperature (5th percentile)	13,10 °C
External temperature (95th percentile)	40,50 °C
Internal temperature	35,48 °C
Heat-release rate HRR	30 MW
Fire location (from the left portal)	350 m
Lenght of the fire section	350 m
ΔT fire	65 K
Gradient of the fire section	3,62 %

Calculation bases

Category of traffic [OWT1, OWT2, TWT]	TWT
Extraction capacity	0 m^3/s
Required flow velocity left of fire	-1,5 m/s
Required flow velocity right of fire	-1,5 m/s

Pressures at T_{A_95}



Pressure differences

Δp fire	39,29 Pa
Δp natural	-6,16 Pa
Δp portal due to wind	30,00 Pa
Δp portal effective	30,00 Pa
Δp friction	4,43 Pa
Δp traffic	5,51 Pa
Total pressure difference	**79,22 Pa**
Required thrust	**-5941 N**

Jet fans

Specifications

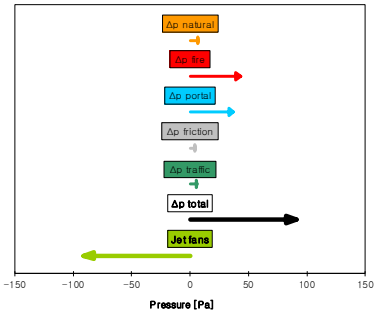
Internal diameter D	900 mm	1000 mm	1120 mm
Jet velocity	30,20 m/s	32,70 m/s	32,70 m/s
Volume flow rate	17,18 m^3/s	22,24 m^3/s	28,82 m^3/s
Installation factor	1,2	1,2	1,2
Static thrust	557 N	756 N	1011 N

Results

Thrust of 1 jet fan	**-363 N**	**-477 N**	**-662 N**
No. of jet fans	**16,4**	**12,5**	**9,0**
Min. no. of jet fans*	**14,8**	**11,2**	**8,1**

*Redundancy case

Pressures at T_{A_5}



Pressure differences

Δp fire	43,56 Pa
Δp natural	7,13 Pa
Δp portal due to wind	30,00 Pa
Δp portal effective	37,13 Pa
Δp friction	4,68 Pa
Δp traffic	5,82 Pa
Total pressure difference	**91,19 Pa**
Required thrust	**-6839 N**

Jet fans

Specifications

Internal diameter D	900 mm	1000 mm	1120 mm
Jet velocity	30,20 m/s	32,70 m/s	32,70 m/s
Volume flow rate	17,18 m^3/s	22,24 m^3/s	28,82 m^3/s
Installation factor	1,2	1,2	1,2
Static thrust	557 N	756 N	1011 N

Results

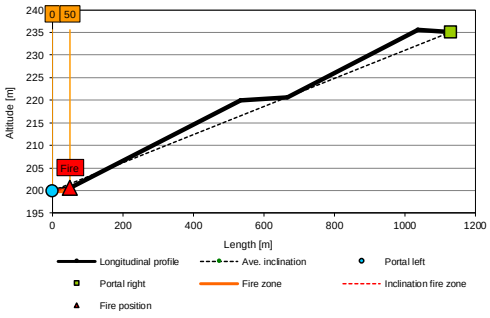
Thrust of 1 jet fan	**-383 N**	**-504 N**	**-699 N**
No. of jet fans	**17,8**	**13,6**	**9,8**
Min. no. of jet fans*	**16,1**	**12,2**	**8,8**

*Redundancy case

Calculation of buoyancy due to fire and determination of the number of jet fans for longitudinal ventilation without exhaust

Project:	Siddhababa Tunnel Nepal	Reference year:	2031	Name:	NKR/RBR
Tunnel:	Siddhababa	File name:	KAL_18-304_001_V1-2_2019-06-02 - Siddhababa - SV_Längslüftung_mitAbsaugung	Date:	06.02.2019

Longitudial section of the tunnel



Geometry

Tunnel lenght L	1130 m
Gradient i (l -> r)	3,11 %
Altitude H	217,5 amsl
Tunnel cross-section A	75,00 m^2
Cross-section at jetfan positions	75,00 m^2
Hydraulic diameter Dh	8,82 m
Wall friction coefficient	0,015

Traffic

Significant traffic per hour STH	1000 Veh./h
HGV fraction	44,0 %
Mean cw*A vehic.	2,79 m^2
Travel speed	60 km/h
Detection time	15 min
Traffic density	150 PCU/km,lane
Degree of admission	100%
Vehicles inside the tunnel	118 Veh

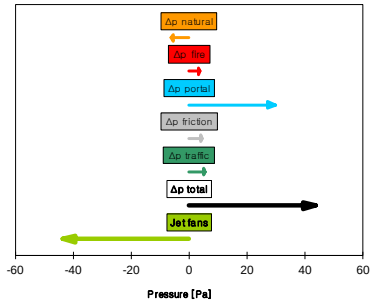
Meteorology and fire

Atmospheric pressure p(h)	98747 Pa
Atmospheric pressure p(h)	98974 Pa
External temperature (5th percentile)	13,10 °C
External temperature (95th percentile)	40,50 °C
Internal temperature	35,48 °C
Heat-release rate HRR	30 MW
Fire location (from the left portal)	50 m
Lenght of the fire section	50 m
ΔT fire	65 K
Gradient of the fire section	1,33 %

Calculation bases

Category of traffic [OWT1, OWT2, TWT]	TWT
Extraction capacity	0 m^3/s
Required flow velocity left of fire	-1,5 m/s
Required flow velocity right of fire	-1,5 m/s

Pressures at T_{A_95}



Pressure differences

Δp fire	3,70 Pa
Δp natural	-6,16 Pa
Δp portal due to wind	30,00 Pa
Δp portal effective	30,00 Pa
Δp friction	4,43 Pa
Δp traffic	5,51 Pa
Total pressure difference	**43,64 Pa**
Required thrust	**-3273 N**

Jet fans

Specifications

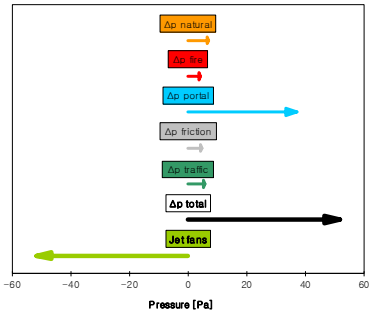
Internal diameter D	900 mm	1000 mm	1120 mm
Jet velocity	30,20 m/s	32,70 m/s	32,70 m/s
Volume flow rate	17,18 m^3/s	22,24 m^3/s	28,82 m^3/s
Installation factor	1,2	1,2	1,2
Static thrust	557 N	756 N	1011 N

Results

Thrust of 1 jet fan	**-363 N**	**-477 N**	**-662 N**
No. of jet fans	**9,0**	**6,9**	**4,9**
Min. no. of jet fans*	**8,1**	**6,2**	**4,5**

*Redundancy case

Pressures at T_{A_5}



Pressure differences

Δp fire	4,11 Pa
Δp natural	7,13 Pa
Δp portal due to wind	30,00 Pa
Δp portal effective	37,13 Pa
Δp friction	4,68 Pa
Δp traffic	5,82 Pa
Total pressure difference	**51,74 Pa**
Required thrust	**-3881 N**

Jet fans

Specifications

Internal diameter D	900 mm	1000 mm	1120 mm
Jet velocity	30,20 m/s	32,70 m/s	32,70 m/s
Volume flow rate	17,18 m^3/s	22,24 m^3/s	28,82 m^3/s
Installation factor	1,2	1,2	1,2
Static thrust	557 N	756 N	1011 N

Results

Thrust of 1 jet fan	**-383 N**	**-504 N**	**-699 N**
No. of jet fans	**10,1**	**7,7**	**5,5**
Min. no. of jet fans*	**9,1**	**6,9**	**5,0**

*Redundancy case