Appendix 4.6b Detailed Calculation of In-Tunnel Air Quality for the Short Section of the Underpass

Tunnel Parameter

One way, One lane

Length L	=	48 m	
Height H	=	9 m	
Width W	=	8 m	
Cross-sectional area A_T = H x W =			72 m^2
Perimeter P	=	34 m	

Emission Data

Traffic flow = 627 veh/hr

Traffic Breakdown	M/C	Car/Taxi	Minibus	LGV	HGV	Bus
% vehicle	3	67	6	11	5	8
NO_x Emission Factor (EURO 3)	0.46	0.8	1.67	1.35	4.67	8.44 g/km

Total NO_x emission factor = 1.707 g/km/veh

Total NO_2 emission rate = total NO_X emission factor x traffic flow x tunnel length x NO_2 conversion factor where conversion factor = 12.5% (including tailpipe NO_2 emission taken as 7.5% of NO_X and 5% of NO_2/NO_X for tunnel air)

= 0.001784 g/sec

Vehicle Data

Nominal dimensions of vehicles are given in Transport Planning and Design Manual, Vol. 2 as:

	W /m	H /m	L /m
Cars and Taxi	1.7	1.5	4.6
Light Bus	2	3	6.5
LGV	2.1	1.6	5.2
HGV	2.5	4.6	16
Bus	2.5	4.6	12

* No dimensions for motor cycle are provided.

* For the purpose of this study, the dimensions of motor cycle are assumed to be the same as private car.

Nominal cross-sectional area A_C = (0.03+0.67)*1.7*1.5+0.06*2*3+0.11*2.1*1.6+(0.05+0.08)*2.5*4.6

= 4.0096 m^2

Tunnel Airflow

For Uni-directional Traffic,

Push Force by vehicles:

$$F_C = \frac{1}{2}\rho\,(V_C - V_T)^2\,C_d\,A_C\,N$$

Resisting Force by tunnel:

$$F_T = \frac{1}{2}\rho\,V_T^2\,(K_{in} + K_{out} + \frac{f\,L}{D})\,A_T$$

External Wind at the Entrance and Exit Portals:

$$F_W = \frac{1}{2}\rho\,C_W(V_W\cos\theta)^2\,A_T$$

where ρ = Air density = 1.2 kg/m³

V_C = Velocity of vehicle, m/s

V_T = Velocity of air flow in tunnel, m/s

C_d	= Vehicle drag coefficient	=	0.645
A_C	= Vehicle frontal area	=	4.0096 m^2
N	= No. of vehicles in tunnel		
K_{in}	= Inlet loss coefficient	=	0.5
K_{out}	= Outlet loss coefficient	=	1.0
f	= Tunnel friction factor	=	0.0155
L	= Length of tunnel	=	48 m
D	= Hydraulic diameter of tunnel =	$4A_T/P$ =	8.470588 m, P is the Perimeter of tunnel
A_T	= Cross-sectional area of tunnel	=	72 m^2
C_W	= External wind coefficient	=	0.3
V_W	= Velocity of wind	=	2.38 m/s (Weighted average of 1994 Junk Bay Station data)
θ	= Angle of the wind velocity component parallel to the roadway		

For the worst scenario, only external wind at the exit portal is considered and the wind is parallel to the roadway.

Force balance : $F_C - F_T - F_W = 0$ (1)

Solving the equation, $a V_T^2 + b V_T + c = 0$

where

$$a = C_d A_c N - (K_{in} + K_{out} + \frac{fL}{D}) A_T$$

$$b = -2 C_d A_c N V_c$$

$$c = C_d A_c N V_c^2 - C_w V_w^2 A_T$$

For normal traffic condition

traffic flow Q = 0.174167 veh/s
Vehicle speed V_C = 50 km/h
= 13.88889 m/s
Number of vehicles in tunnel N = QL/V_C
= 0.60192

Solving for V_T by equation (1)
a = -112.77
b = -43.24
c = 177.93

tunnel air flow velocity V_T = 1.078962 m/sec or -1.46242 m/sec (rejected)

Inside tunnel concentration = emission rate / (tunnel air flow x underpass cross-sectional area)
= 22.96477 ug/m^3

For congested traffic condition

Vehicle speed Vc = 10 km/h
= 2.777778 m/s
average length of vehicle = (0.03+0.67)*4.6+0.06*6.5+0.11*5.2+0.05*16+0.08*12
= 5.942 m
distance between vehicle = 1 m
head to head length = 6.942 m
Number of vehicles per lane = 6.914434
Number of lanes = 1
Number of vehicles in tunnel N = 6.914434

Solving for V_T by equation (1)
a = -96.44

b = -99.34
c = 15.63

tunnel air flow velocity V_T = 0.138647 m/sec or -1.16875 m/sec (rejected)

Inside tunnel concentration = emission rate / (tunnel air flow x underpass cross-sectional area)
= 178.7135 ug/m^3

Background Concentration

Four assessment points (ASR P5-P8) at the boundary of the Long Section of the underpass are chosen (see Figure A3). Using CALINE4 model, the NO2 concentrations at the 4 assessment points at different levels are calculated.
Sample output file is shown in Appendix 4.7.
The highest concentration among the four assessment points is assumed to be the background NO2 concentration inside the Short Section of the underpass.

Without proposed noise barriers:

ASRs	NO2 Concentrations (ug/m3) at Various Levels below Lei Yue Mun Road		
	0m	4.5m	9m
P5	373	365	353
P6	380	416	397
P7	382	423	408
P8	452	514	516

The highest background concentration is 516 ug/m3

With proposed noise barriers:

ASRs	NO2 Concentrations (ug/m3) at Various Levels below Lei Yue Mun Road		
	0m	4.5m	9m
P5	373	365	353
P6	380	416	397
P7	382	423	408
P8	452	514	516

The highest background concentration is 516 ug/m3

Overall Maximum NO2 concentration inside the Underpass under Normal Condition

= 23 + 516 ug/m3
= 539 ug/m3

Overall Maximum NO2 concentration inside the Underpass under Worst Condition

= 179 + 516 ug/m3
= 695 ug/m3