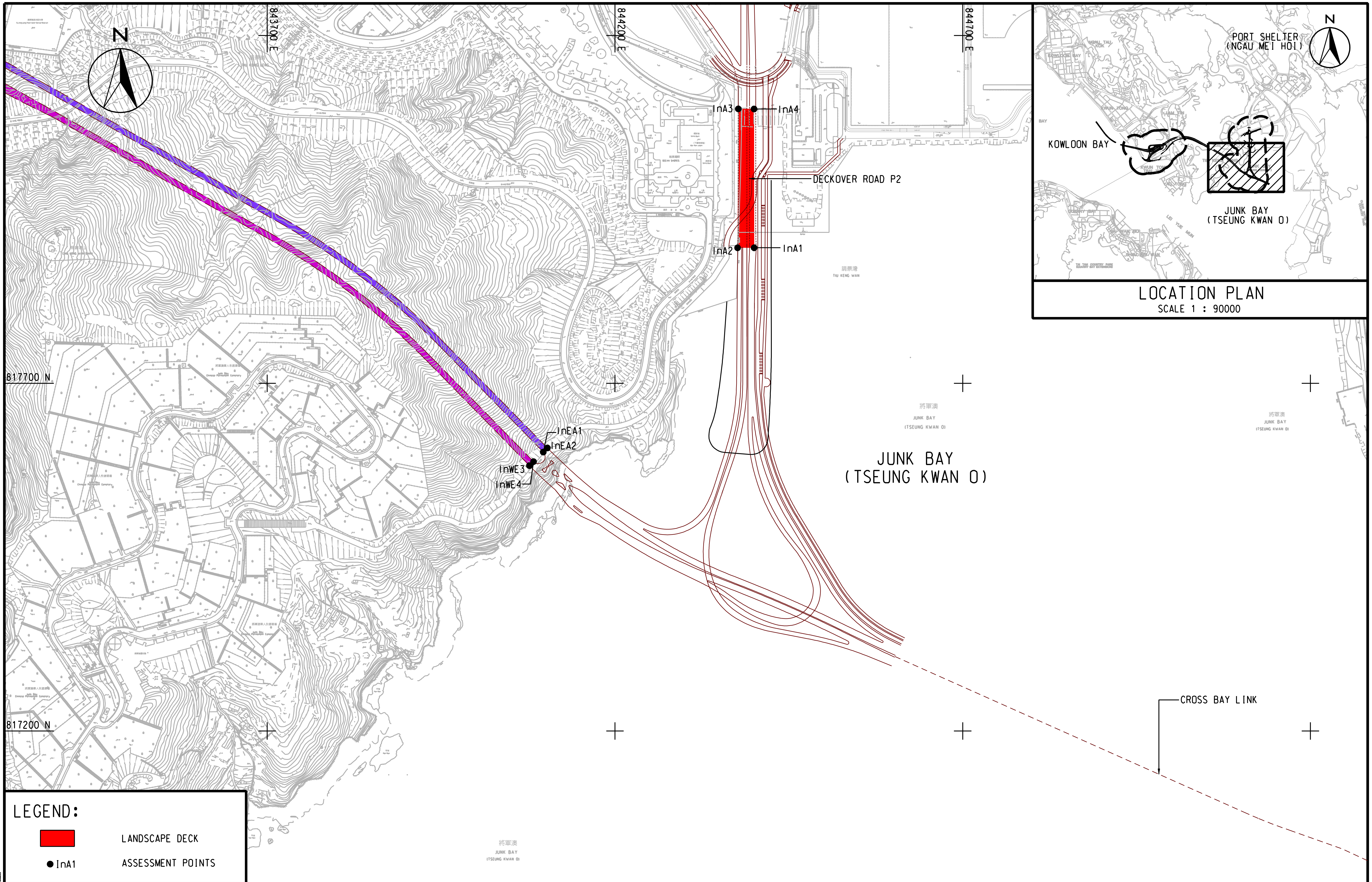

LEGEND:

(red box)	LANDSCAPE DECK
● InA1	ASSESSMENT POINTS

AECOM

AGREEMENT NO. CE 42/2008 (CE)
TSEUNG KWAN O - LAM TIN TUNNEL AND ASSOCIATED WORKS - INVESTIGATION

DESIGNATED ASSESSMENT POINTS FOR IN-TUNNEL AIR QUALITY (TSEUNG KWAN O)

SCALE	A3 1 : 5000	DATE	NOV. 2012
CHECK	-	DRAWN	HLL
JOB No.	60097677	DRAWING No.	APPENDIX 3.9
		REV	-

Plot File by : 3/14/2013 qiuan

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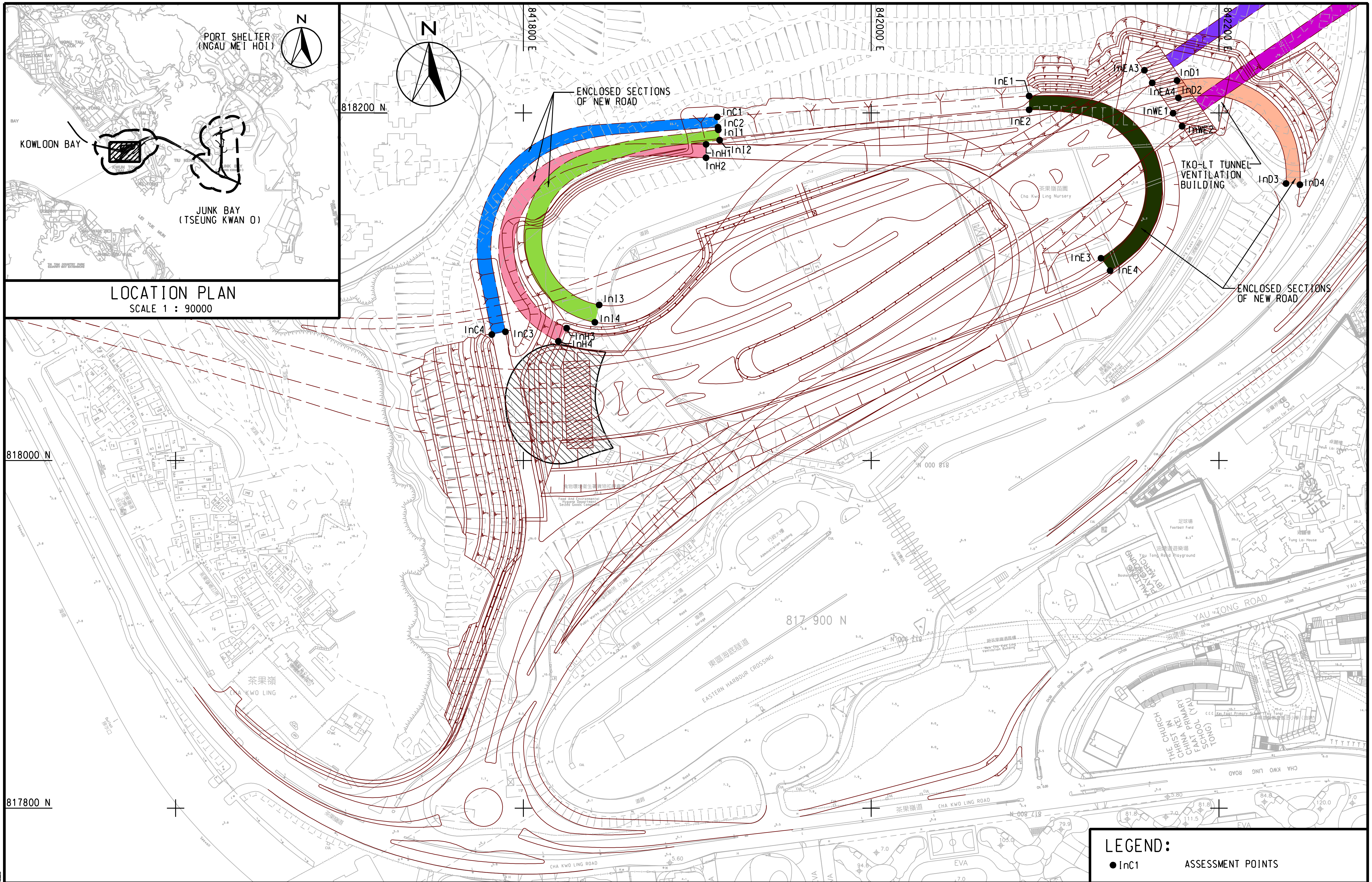

AECOM

AGREEMENT NO. CE 42/2008 (CE)
TSEUNG KWAN O - LAM TIN TUNNEL AND ASSOCIATED WORKS - INVESTIGATION

DESIGNATED ASSESSMENT POINTS FOR IN-TUNNEL AIR QUALITY (LAM TIN)

SCALE	A3 1 : 2000	DATE	OCT. 2012
CHECK	--	DRAWN	HLL
JOB No.	60097677	DRAWING No.	APPENDIX 3.9
		REV	--

Plot File by : 3/14/2013 qiuam

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Appendix 3.9A **Calculation of In-Tunnel Air Quality for Proposed Deckover on Road P2**

Normal Condition **(Deckover TKO-P2)**

Tunnel Parameter

Tunnel length (m), L	=	200
Tunnel height (m), H	=	7
Tunnel width (m), W	=	22
Tunnel size (m2), At	=	H * W
		154
Equivalent diameter (m), dt	=	(4*At/π)^0.5
		14.00282313
Effective length of the tunnel (m), Le	=	L + 2*3*dt
		284.0169388

Emission Data

Traffic Breakdown (%)

Tunnel traffic (Link no.)	Traffic flow (veh/hr)		Motorcycles	Private Cars	Taxi	Non-franchised Bus<=6.4t	Non-franchised Bus 6.4-15t	Non-franchised Bus >15t	Private Light Bus <=3.5t	Private Light Bus >3.5t	Light Goods Vehicles<=2.5t	Lt Goods Vehicles 2.5-3.5t	Light Goods Vehicles>3.5t	Heavy Goods Vehicles<=15t	Heavy Goods Vehicles >15t	Single Deck Franchised Bus	Double Deck Franchised Bus	Public Light Bus
113	1078		4.3%	60.0%	20.9%	0.9%	0.7%	0.7%	0.3%	0.3%	0.1%	4.6%	2.7%	1.1%	3.1%	0.0%	0.1%	0.1%
114	1025		4.2%	59.1%	20.6%	1.0%	0.7%	0.7%	0.4%	0.3%	0.1%	5.0%	3.0%	1.2%	3.4%	0.0%	0.1%	0.2%
Total	2104	no. vehicle	46	647	226	10	7	7	4	3	1	50	29	12	33	0	1	2
			43	606	211	10	7	7	4	3	1	52	31	12	35	0	1	2
NOx Emission Factor (g/mile)		80km/hr	0.45	0.02	0.50	1.27	2.53	4.01	0.10	0.93	1.56	1.08	1.67	2.17	4.07	4.35	5.03	1.44
		50km/hr	0.75	0.05	0.60	1.62	3.25	5.17	0.20	1.95	2.02	1.02	2.02	2.57	4.73	5.28	5.96	2.00

Weighted NOX E.F. (g/km/veh) = 0.3201

NO_2 emission factor per unit length (g/m/s), w = 12.5% * Weight NO_X E.F. * Traffic flow

= 2.34E-05

Vehicle Data

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

	W	H	L
Motorcycles	1.7	1.5	4.6
Petrol PC &LGV	1.7	1.5	4.6
Taxi	1.7	1.5	4.6
Non-franchised Bus <6.4t	2.5	3.5	12
Non-franchised Bus 6.4-15t	2.5	3.5	12
Non-franchised Bus >15t	2.5	3.5	12
Private Light Bus <3.5t	2	3	6.5
Private Light Bus >3.5t	2	3	6.5
PC&LGV <2.5t	2.1	1.6	5.2
LGV 2.5-3.5t	2.1	1.6	5.2
LGV >3.5t	2.1	1.6	5.2
HGV<15t	2.5	4.6	16
HGV>15t	2.5	4.6	16
Single Deck Franchised Buses	2.5	3.5	12
Double Deck Franchised Buses	2.5	4.6	12
Public Light Bus	2	3	6.5

* No dimensions for motor cycles and non-franchised buses are provided.
* For the purpose of this study, the dimensions of motor cycles and taxi are assumed to be the same as private car and the dimension of non-franchised buses are assumed to be the same as single deck franchised buses.

Nominal cross-sectional area (m^2) = [(1.7*1.5*89.45)+(1.7*1.5*1252.36)+(1.7*1.5*437.05)+(2.5*3.5*20.41)+(2.5*3.5*14.63)+(2.5*3.5*14.88)+(2*3*7.35)+(2*3*6.09)+(2.1*1.6*2.65)+(2.1*1.6*101.19)+(2.1*1.6*60.06)
+(2.5*4.6*23.92)+(2.5*4.6*67.82)+(2.5*3.5*0.09)+(2.5*4.6*2.42)+(2*3*3.14)]/2104

= 3.19

Appendix 3.9A **Calculation of In-Tunnel Air Quality for Proposed Deckover on Road P2**

Normal Condition **(Deckover TKO-P2)**

Number of lanes per direction, nl	=	2		
Equivalent cross-sectional area for each direction (m2), Av			=	6.376635271
Equivalent diameter of vehicle (m), dv	=	(4*Av/π)^0.5		
	=	2.849384328		
Traffic density (traffic flow /s), N	=	0.584308647		
Weighted Average vehicle speed (m/s), v	=			
	=	18.16055715		
Head to head distance on a lane (m), l	=	2*nl*v/N		
	=	124.3216731		
Diffusion Parameters				
Reynolds number, Re	=	(v*dv)/σ	where σ = 15.6*10^-6	
	=	3317077.367		
According to Figure 16 (Ohashi and Koso)				
Since l / dt	=	8.878329176		
D / (N * dt^2 * Re^0.13)	=	0.4		
Longitudinal diffusion coefficient (m^2/s) , D	=	0.4 * (N * dt^2 * Re^0.13)		
	=	322.7243532		
Maximum Concentration of NO_2				
Cmax (μg/m^3)	=	w * Le^2 / (8 * D * At)		
(without background)	=	5		

Appendix 3.9A | **Calculation of In-Tunnel Air Quality for Proposed Deckover on Road P2**

Worse Condition | **(Deckover TKO-P2)**

Tunnel Parameter

Tunnel length (m), L	=	200
Tunnel height (m), H	=	7
Tunnel width (m), W	=	22
Tunnel size (m2), At	=	H * W
		154
Equivalent diameter (m), dt	=	(4*At/π)^0.5
		14.00282313
Effective length of the tunnel (m), Le	=	L + 2*3*dt
		284.0169388

Emission Data

Traffic Breakdown (%)

Tunnel traffic (Link no.)	Traffic flow (veh/hr)		Motorcycles	Private Cars	Taxi	Non-franchised Bus<=6.4t	Non-franchised Bus 6.4-15t	Non-franchised Bus >15t	Private Light Bus <=3.5t	Private Light Bus >3.5t	Light Goods Vehicles<=2.5t	Lt Goods Vehicles 2.5-3.5t	Light Goods Vehicles>3.5t	Heavy Goods Vehicles<=15t	Heavy Goods Vehicles >15t	Single Deck Franchised Bus	Double Deck Franchised Bus	Public Light Bus
113	1078		4.3%	60.0%	20.9%	0.9%	0.7%	0.7%	0.3%	0.3%	0.1%	4.6%	2.7%	1.1%	3.1%	0.0%	0.1%	0.1%
114	1025		4.2%	59.1%	20.6%	1.0%	0.7%	0.7%	0.4%	0.3%	0.1%	5.0%	3.0%	1.2%	3.4%	0.0%	0.1%	0.2%
Total	2104	no. vehicle	46	647	226	10	7	7	4	3	1	50	29	12	33	0	1	2
			43	606	211	10	7	7	4	3	1	52	31	12	35	0	1	2
NOx Emission Factor (g/mile)		80km/hr	0.70	0.04	0.87	3.41	6.87	10.93	0.17	1.72	2.22	1.56	4.20	5.36	9.84	11.37	12.78	1.66
		50km/hr	0.94	0.06	0.87	3.41	6.87	10.93	0.25	2.65	2.87	1.58	4.20	5.36	9.84	11.37	12.78	2.29

Weighted NO_X E.F. (g/km/veh)	=	0.6240
NO_2 emission factor per unit length (g/m/s), w	=	12.5% * Weight NO_X E.F. * Traffic flow
	=	4.56E-05

Vehicle Data

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

	W	H	L
Motorcycles	1.7	1.5	4.6
Petrol PC &LGV	1.7	1.5	4.6
Taxi	1.7	1.5	4.6
Non-franchised Bus <6.4t	2.5	3.5	12
Non-franchised Bus 6.4-15t	2.5	3.5	12
Non-franchised Bus >15t	2.5	3.5	12
Private Light Bus <3.5t	2	3	6.5
Private Light Bus >3.5t	2	3	6.5
PC&LGV <2.5t	2.1	1.6	5.2
LGV 2.5-3.5t	2.1	1.6	5.2
LGV >3.5t	2.1	1.6	5.2
HGV<15t	2.5	4.6	16
HGV>15t	2.5	4.6	16
Single Deck Franchised Buses	2.5	3.5	12
Double Deck Franchised Buses	2.5	4.6	12
Public Light Bus	2	3	6.5

* No dimensions for motor cycles and non-franchised buses are provided.
* For the purpose of this study, the dimensions of motor cycles and taxi are assumed to be the same as private car and the dimension of non-franchised buses are assumed to be the same as single deck franchised buses.

Nominal cross-sectional area (m^2) = [(1.7*1.5*89.45)+(1.7*1.5*1252.36)+(1.7*1.5*437.05)+(2.5*3.5*20.41)+(2.5*3.5*14.63)+(2.5*3.5*14.88)+(2*3*7.35)+(2*3*6.09)+(2.1*1.6*2.65)+(2.1*1.6*101.19)+(2.1*1.6*60.06)+(2.5*4.6*23.92)+(2.5*4.6*67.82)+(2.5*3.5*0.09)+(2.5*4.6*2.42)+(2*3*3.14)]/2104

= 3.19

Appendix 3.9A | **Calculation of In-Tunnel Air Quality for Proposed Deckover on Road P2**

Worse Condition | **(Deckover TKO-P2)**

Number of lanes per direction, nl	=	2
Equivalent cross-sectional area for each direction (m^2), Av	=	6.376635271
Equivalent diameter of vehicle (m), dv	=	(4*Av/π)^0.5
	=	2.849384328
Equivalent length of each vehicle (m)	=	(4.6*89.45)+(4.6*1252.36)+(4.6*437.05)+(12*20.41)+(12*14.63)+(12*14.88)+(6.5*7.35)+(6.5*6.09)+(5.2*2.654)+(5.2*101.19)+(5.2*60.06)+(16*23.92)+(16*67.82)+(12*0.09)+(12*2.42)+(6.5*3.14)
	=	5.34
Distance between vehicle (m)	=	1 (worst case)
Head to head distance on a lane (m), l	=	6.34
Traffic density (traffic flow /s), N	=	0.584308647
Average vehicle speed (m/s), v	=	l*N/(2*nl)
	=	0.926615969

Diffusion Parameters

Reynolds number, Re	=	(v*dv)/σ where σ = 15.6*10^-6
	=	169249.0397
According to Figure 16 (Ohashi and Koso)		
Since l / dt	=	0.45300381
D / (N * dt^2 * Re^0.13)	=	0.13
Longitudinal diffusion coefficient (m^2/s) , D	=	0.13 * (N * dt^2 * Re^0.13)
	=	71.24022453

Maximum Concentration of NO2

Cmax (μg/m^3)	=	w * Le^2 / (8 * D * At)
(without background)	=	42

Appendix 3.9A **Calculation of In-Tunnel Air Quality for Proposed Deckover on Road P2**

Overall Concentrations (Deckover TKO-P2)

Four assessment points (ASRs InA1-InA4) at the boundary of the enclosure are chosen.
Using CALINE4 and ISCST3 model, the air pollutants concentrations at the 4 assessment points at different levels are calculated.
The highest concentration among the eight assessment points is assumed to be the background concentration inside the proposed enclosure section.

Elevation	**NO_2 Concentrations (ug/m^3) at Various Levels**	
	(mAG)	NO_2
InA1	0.0	212
InA1	3.8	210
InA1	7.5	209
InA2	0.0	209
InA2	3.8	209
InA2	7.5	209
InA3	0.0	209
InA3	3.2	209
InA3	6.3	209
InA4	0.0	210
InA4	3.2	209
InA4	6.3	209

Therefore, the NO_2 background concentration inside the enclosure is 212 ug/m^3

Total Maximum NO_2 concentration inside deckover on Road P2 (Normal Speed) **= 5 + 212**
= 217 ug/m^3

Total Maximum NO_2 concentration inside deckover on Road P2 (Worse Case) **= 42 + 212**
= 254 ug/m^3

Appendix 3.9B **Calculation of In-Tunnel Air Quality for Portal C (Lam Tin)**

One-way Enclosure - Normal Condition (Portal C)

Tunnel Parameter

Length L	= 200	m	
Height H	= 8	m	
Width W	= 7	m	
Cross-sectional area A_T = H x W =			56 m^2
Perimeter P	=	30	m

Emission Data

Traffic Breakdown (%)

Tunnel Traffic (Link no.)	Traffic flow (veh/hr)	Motorcycles	Private Cars	Taxi	Non-franchised Bus<=6.4t	Non-franchised Bus 6.4-15t	Non-franchised Bus >15t	Private Light Bus <=3.5t	Private Light Bus >3.5t	Light Goods Vehicles<=2.5t	Lt Goods Vehicles 2.5-3.5t	Light Goods Vehicles>3.5t	Heavy Goods Vehicles<=15t	Heavy Goods Vehicles >15t	Single Deck Franchised Bus	Double Deck Franchised Bus	Public Light Bus
190	355	3.6%	50.6%	17.7%	1.1%	0.8%	0.8%	0.4%	0.3%	0.3%	9.8%	5.8%	2.3%	6.6%	0.0%	0.0%	0.0%
NOx Emission Factor (g/mile)		0.75	0.05	0.60	1.62	3.25	5.17	0.20	1.95	2.02	1.02	2.02	2.57	4.73	5.28	5.96	2.00

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)

Weighted NOX E.F. (g/km/veh)	=	0.523	g/km/veh
Total NO_2 emission factor (g/s)	=	1.29E-03	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
Motorcycles	1.7	1.5	4.6
Petrol PC &LGV	1.7	1.5	4.6
Taxi	1.7	1.5	4.6
Non-franchised Bus <6.4t	2.5	3.5	12
Non-franchised Bus 6.4-15t	2.5	3.5	12
Non-franchised Bus >15t	2.5	3.5	12
Private Light Bus <3.5t	2	3	6.5
Private Light Bus >3.5t	2	3	6.5
PC&LGV <2.5t	2.1	1.6	5.2
LGV 2.5-3.5t	2.1	1.6	5.2
LGV >3.5t	2.1	1.6	5.2
HGV<15t	2.5	4.6	16
HGV>15t	2.5	4.6	16
Single Deck Franchised Buses	2.5	3.5	12
Double Deck Franchised Buses	2.5	4.6	12
Public Light Bus	2	3	6.5

* No dimensions for motorcycles and non-franchised bus are provided.
* For the purpose of this study, the dimensions of motorcycles and taxi are assumed to be the same as private car and the dimension of non-franchised bus are assumed to be the same as single deck franchised bus.

Nominal cross-sectional area A_C = (1.7*1.5*0.036)+(1.7*1.5*0.506)+(1.7*1.5*0.177)+(2.5*3.5*0.011)+(2.5*3.5*0.008)+(2.5*3.5*0.008)+(2*3*0.004)+(2*3*0.003)+(2.1*1.6*0.003)+(2.1*1.6*0.098)+(2.1*1.6*0.058)
+(2.5*4.6*0.023)+(2.5*4.6*0.066)+(2.5*3.5*0)+(2.5*4.6*0)+(2*3*0)
= 3.6643 m^2

Appendix 3.9B Calculation of In-Tunnel Air Quality for Portal C (Lam Tin)

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/m^3	
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	=	3.6643006	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	=	200	m	
D	=	Hydraulic diameter of tunnel =	$4A_T/P$ =	7.46666667	m, P is the Perimeter of tunnel	
A_T	=	Cross-sectional area of tunnel	=	56	m^2	
C_W	=	External wind coefficient	=	0.3		
$V_{W(ref)}$	=	Velocity of wind at SE Station	=	3.19	m/s	(Average of 2011 Southeast Kowloon Weather 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

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

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

$$c = C_d A_c N V_c^{\,2} - C_w V_w^{\,2} A_T$$

<u>For normal traffic condition</u>

traffic flow Q	=	0.098545418	veh/s
Vehicle speed V_C	=	50	km/h
	=	13.88888889	m/s
Number of vehicles in tunnel N	=	QL/V_C	
	=	1.419054024	

Solving for V_T by equation (1)

a = -103.90
b = -93.16
c = 476.01

tunnel air flow velocity V_T = 1.738573494 m/sec or -2.6352752 m/sec (rejected)

Inside tunnel concentration = emission rate / (tunnel air flow x tunnel cross-sectional area)

NO_2 = 13 ug/m^3

Appendix 3.9B **Calculation of In-Tunnel Air Quality for Portal C (Lam Tin)**

One-way Enclosure - Worst Condition (Portal C)

Tunnel Parameter

Length L	= 200	m	
Height H	= 8	m	
Width W	= 7	m	
Cross-sectional area A_T = H x W =		56	m^2
Perimeter P	=	30	m

Emission Data

Traffic Breakdown (%)

Tunnel Traffic (Link no.)	Traffic flow (veh/hr)	Motorcycles	Private Cars	Taxi	Non-franchised Bus<=6.4t	Non-franchised Bus 6.4-15t	Non-franchised Bus >15t	Private Light Bus <=3.5t	Private Light Bus >3.5t	Light Goods Vehicles<=2.5t	Lt Goods Vehicles 2.5-3.5t	Light Goods Vehicles>3.5t	Heavy Goods Vehicles<=15t	Heavy Goods Vehicles >15t	Single Deck Franchised Bus	Double Deck Franchised Bus	Public Light Bus
190	355	3.6%	50.6%	17.7%	1.1%	0.8%	0.8%	0.4%	0.3%	0.3%	9.8%	5.8%	2.3%	6.6%	0.0%	0.0%	0.0%
NOx Emission Factor (g/mile)		0.94	0.06	0.87	3.41	6.87	10.93	0.25	2.65	2.87	1.58	4.20	5.36	9.84	11.37	12.78	2.29

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)

Weighted NOX E.F. (g/km/veh)	=	0.983	g/km/veh
Total NO_2 emission factor (g/s)	=	2.42E-03	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
Motorcycles	1.7	1.5	4.6
Petrol PC &LGV	1.7	1.5	4.6
Taxi	1.7	1.5	4.6
Non-franchised Bus <6.4t	2.5	3.5	12
Non-franchised Bus 6.4-15t	2.5	3.5	12
Non-franchised Bus >15t	2.5	3.5	12
Private Light Bus <3.5t	2	3	6.5
Private Light Bus >3.5t	2	3	6.5
PC&LGV <2.5t	2.1	1.6	5.2
LGV 2.5-3.5t	2.1	1.6	5.2
LGV >3.5t	2.1	1.6	5.2
HGV<15t	2.5	4.6	16
HGV>15t	2.5	4.6	16
Single Deck Franchised Buses	2.5	3.5	12
Double Deck Franchised Buses	2.5	4.6	12
Public Light Bus	2	3	6.5

* No dimensions for motorcycles and non-franchised bus are provided.
* For the purpose of this study, the dimensions of motorcycles and taxi are assumed to be the same as private car
and the dimension of non-franchised bus are assumed to be the same as single deck franchised bus.

Nominal cross-sectional area A_C = (1.7*1.5*0.042)+(1.7*1.5*0.496)+(1.7*1.5*0.175)+(2.5*3.5*0.002)+(2.5*3.5*0.031)+(2.5*3.5*0.001)+(2*3*0.003)+(2*3*0.005)+(2.1*1.6*0)+(2.1*1.6*0.108)+(2.1*1.6*0.035)
+(2.5*4.6*0.093)+(2.5*4.6*0.008)+(2.5*3.5*0)+(2.5*4.6*0)+(2*3*0)
= 3.6643 m^2

Appendix 3.9B **Calculation of In-Tunnel Air Quality for Portal C (Lam Tin)**

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/m^3
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	=	3.6643006	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	=	200	m
D	=	Hydraulic diameter of tunnel =	$4A_T/P$ =	7.46666667	m, P is the Perimeter of tunnel
A_T	=	Cross-sectional area of tunnel	=	56	m^2
C_W	=	External wind coefficient	=	0.3	
$V_{W(ref)}$	=	Velocity of wind at SE Station	=	3.19	m/s (Average of 2011 Southeast Kowloon Weather 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 : $$F_C - F_T - F_W = 0 \qquad (1)$$

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

where

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

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

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

<u>For congested traffic condition</u>

Vehicle speed Vc	=	10	km/h
	=	2.777777778	m/s
average length of vehicle	=	(4.6*0.04)+(4.6*0.51)+(4.6*0.18)+(12*0.01)+(12*0.01)+(12*0.01)+(6.5*0)+(6.5*0)+(5.2*0)+(5.2*0.1)+(5.2*0.06)+(16*0.02)+(16*0.07)+(12*0)+(12*0)+(6.5*0)	
	=	5.919486811	m
distance between vehicle	=	1	m
head to head length	=	6.919486811	m
Number of vehicles per lane	=	28.90387762	
Number of lanes	=	1	
Number of vehicles in tunnel N	=	28.90387762	

Solving for V_T by equation (1)

a = -38.94
b = -379.52
c = 356.15

tunnel air flow velocity V_T = 0.862167436 m/sec or -10.609329 m/sec (rejected)

Inside tunnel concentration = emission rate / (tunnel air flow x tunnel cross-sectional area)

NO_2 = 50 ug/m^3

Appendix 3.9B **Calculation of In-Tunnel Air Quality for Portal C (Lam Tin)**

Overall Concentrations **(Portal C)**

Four assessment points (ASRs InC1-InC4) at the boundary of the enclosure are chosen.
Using CALINE4 and ISCST3 model, the air pollutants concentrations at the 4 assessment points at different levels are calculated.
The highest concentration among the four assessment points is assumed to be the background concentration inside the proposed enclosure section.

Elevation	**NO_2 Concentrations (ug/m^3) at Various Levels**	
	(mAG)	NO_2
InC1	0.0	226
InC1	4.0	226
InC1	8.0	225
InC2	0.0	226
InC2	4.0	226
InC2	8.0	225
InC3	0.0	226
InC3	4.0	226
InC3	8.0	225
InC4	0.0	226
InC4	4.0	226
InC4	8.0	225

Therefore, the NO_2 background concentration inside the enclosure is 226 ug/m^3

Total Maximum NO_2 concentration inside tunnel at Portal C (Normal Speed) **= 13 + 226**
= 239 ug/m^3

Total Maximum NO_2 concentration inside tunnel at Portal C (Worst Case) **= 50 + 226**
= 276 ug/m^3

Appendix 3.9C **Calculation of In-Tunnel Air Quality for Portal D (Lam Tin)**

One-way Enclosure - Normal Condition (Portal D)

Tunnel Parameter

Length L	=	100	m
Height H	=	8	m
Width W	=	9	m
Cross-sectional area A_T = H x W =		72	m^2
Perimeter P	=	34	m

Emission Data

Traffic Breakdown (%)

Tunnel Traffic (Link no.)	Traffic flow (veh/hr)	Motorcycles	Private Cars	Taxi	Non-franchised Bus<=6.4t	Non-franchised Bus 6.4-15t	Non-franchised Bus >15t	Private Light Bus <=3.5t	Private Light Bus >3.5t	Light Goods Vehicles<=2.5t	Lt Goods Vehicles 2.5-3.5t	Light Goods Vehicles>3.5t	Heavy Goods Vehicles<=15t	Heavy Goods Vehicles >15t	Single Deck Franchised Bus	Double Deck Franchised Bus	Public Light Bus
191	1725	4.4%	61.4%	21.4%	1.3%	1.0%	1.0%	0.5%	0.4%	0.1%	3.4%	2.0%	0.8%	2.3%	0.0%	0.0%	0.0%
NOx Emission Factor (g/mile)		0.75	0.05	0.60	1.62	3.25	5.17	0.20	1.95	2.02	1.02	2.02	2.57	4.73	5.28	5.96	2.00

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)

Weighted NOX E.F. (g/km/veh)	=	0.317	g/km/veh
Total NO_2 emission factor (g/s)	=	1.90E-03	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
Motorcycles	1.7	1.5	4.6
Petrol PC &LGV	1.7	1.5	4.6
Taxi	1.7	1.5	4.6
Non-franchised Bus <6.4t	2.5	3.5	12
Non-franchised Bus 6.4-15t	2.5	3.5	12
Non-franchised Bus >15t	2.5	3.5	12
Private Light Bus <3.5t	2	3	6.5
Private Light Bus >3.5t	2	3	6.5
PC&LGV <2.5t	2.1	1.6	5.2
LGV 2.5-3.5t	2.1	1.6	5.2
LGV >3.5t	2.1	1.6	5.2
HGV<15t	2.5	4.6	16
HGV>15t	2.5	4.6	16
Single Deck Franchised Buses	2.5	3.5	12
Double Deck Franchised Buses	2.5	4.6	12
Public Light Bus	2	3	6.5

* No dimensions for motorcycles and non-franchised bus are provided.
* For the purpose of this study, the dimensions of motorcycles and taxi are assumed to be the same as private car
and the dimension of non-franchised bus are assumed to be the same as single deck franchised bus.

Nominal cross-sectional area A_C = (1.7*1.5*0.044)+(1.7*1.5*0.614)+(1.7*1.5*0.214)+(2.5*3.5*0.013)+(2.5*3.5*0.01)+(2.5*3.5*0.01)+(2*3*0.005)+(2*3*0.004)+(2.1*1.6*0.001)+(2.1*1.6*0.034)+(2.1*1.6*0.02)
+(2.5*4.6*0.008)+(2.5*4.6*0.023)+(2.5*3.5*0)+(2.5*4.6*0)+(2*3*0)
= 3.1071 m^2

Appendix 3.9C **Calculation of In-Tunnel Air Quality for Portal D (Lam Tin)**

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/m^3	
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	=	3.10710049	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	=	100	m	
D	=	Hydraulic diameter of tunnel =	$4A_T/P$ =	8.47058824	m, P is the Perimeter of tunnel	
A_T	=	Cross-sectional area of tunnel	=	72	m^2	
C_W	=	External wind coefficient	=	0.3		
$V_{W(ref)}$	=	Velocity of wind at SE Station	=	3.19	m/s	(Average of 2011 Southeast Kowloon Weather 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

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

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

$$c = C_d A_c N V_c^{\,2} - C_w V_w^{\,2} A_T$$

<u>For normal traffic condition</u>

traffic flow Q	=	0.479249508	veh/s
Vehicle speed V_C	=	50	km/h
	=	13.88888889	m/s
Number of vehicles in tunnel N	=	QL/V_C	
	=	3.450596456	
Solving for V_T by equation (1)			
a	=	-114.26	
b	=	-192.09	
c	=	1114.16	

tunnel air flow velocity V_T = 2.393249773 m/sec or -4.074427 m/sec (rejected)

Inside tunnel concentration = emission rate / (tunnel air flow x tunnel cross-sectional area)

NO_2 = 11 ug/m^3

Appendix 3.9C **Calculation of In-Tunnel Air Quality for Portal D (Lam Tin)**

One-way Enclosure - Worst Condition (Portal D)

Tunnel Parameter

Length L	= 100		m
Height H	= 8		m
Width W	= 9		m
Cross-sectional area A_T = H x W =		72	m^2
Perimeter P	=	34	m

Emission Data

Traffic Breakdown (%)

Tunnel Traffic (Link no.)	Traffic flow (veh/hr)	Motorcycles	Private Cars	Taxi	Non-franchised Bus<=6.4t	Non-franchised Bus 6.4-15t	Non-franchised Bus >15t	Private Light Bus <=3.5t	Private Light Bus >3.5t	Light Goods Vehicles<=2.5t	Lt Goods Vehicles 2.5-3.5t	Light Goods Vehicles>3.5t	Heavy Goods Vehicles<=15t	Heavy Goods Vehicles >15t	Single Deck Franchised Bus	Double Deck Franchised Bus	Public Light Bus
191	1725	4.4%	61.4%	21.4%	1.3%	1.0%	1.0%	0.5%	0.4%	0.1%	3.4%	2.0%	0.8%	2.3%	0.0%	0.0%	0.0%
NOx Emission Factor (g/mile)		0.94	0.06	0.87	3.41	6.87	10.93	0.25	2.65	2.87	1.58	4.20	5.36	9.84	11.37	12.78	2.29

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)

Weighted NOX E.F. (g/km/veh)	=	0.564	g/km/veh
Total NO_2 emission factor (g/s)	=	3.38E-03	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
Motorcycles	1.7	1.5	4.6
Petrol PC &LGV	1.7	1.5	4.6
Taxi	1.7	1.5	4.6
Non-franchised Bus <6.4t	2.5	3.5	12
Non-franchised Bus 6.4-15t	2.5	3.5	12
Non-franchised Bus >15t	2.5	3.5	12
Private Light Bus <3.5t	2	3	6.5
Private Light Bus >3.5t	2	3	6.5
PC&LGV <2.5t	2.1	1.6	5.2
LGV 2.5-3.5t	2.1	1.6	5.2
LGV >3.5t	2.1	1.6	5.2
HGV<15t	2.5	4.6	16
HGV>15t	2.5	4.6	16
Single Deck Franchised Buses	2.5	3.5	12
Double Deck Franchised Buses	2.5	4.6	12
Public Light Bus	2	3	6.5

* No dimensions for motorcycles and non-franchised bus are provided.
* For the purpose of this study, the dimensions of motorcycles and taxi are assumed to be the same as private car and the dimension of non-franchised bus are assumed to be the same as single deck franchised bus.

Nominal cross-sectional area A_C = (1.7*1.5*0.042)+(1.7*1.5*0.496)+(1.7*1.5*0.175)+(2.5*3.5*0.002)+(2.5*3.5*0.031)+(2.5*3.5*0.001)+(2*3*0.003)+(2*3*0.005)+(2.1*1.6*0)+(2.1*1.6*0.108)+(2.1*1.6*0.035)
+(2.5*4.6*0.093)+(2.5*4.6*0.008)+(2.5*3.5*0)+(2.5*4.6*0)+(2*3*0)
= 3.1071 m^2

Appendix 3.9C **Calculation of In-Tunnel Air Quality for Portal D (Lam Tin)**

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/m^3
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	=	3.10710049	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	=	100	m
D	=	Hydraulic diameter of tunnel =	$4A_T/P$ =	8.47058824	m, P is the Perimeter of tunnel
A_T	=	Cross-sectional area of tunnel	=	72	m^2
C_W	=	External wind coefficient	=	0.3	
$V_{W(ref)}$	=	Velocity of wind at SE Station	=	3.19	m/s (Average of 2011 Southeast Kowloon Weather 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 : $$F_C - F_T - F_W = 0 \qquad (1)$$

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 congested traffic condition

Vehicle speed Vc	=	10	km/h
	=	2.777777778	m/s
average length of vehicle	=	(4.6*0.04)+(4.6*0.61)+(4.6*0.21)+(12*0.01)+(12*0.01)+(12*0.01)+(6.5*0)+(6.5*0)+(5.2*0)+(5.2*0.03)+(5.2*0.02)+(16*0.01)+(16*0.02)+(12*0)+(12*0)+(6.5*0)	
	=	5.247437833	m
distance between vehicle	=	1	m
head to head length	=	6.247437833	m
Number of vehicles per lane	=	16.00656184	
Number of lanes	=	1	
Number of vehicles in tunnel N	=	16.00656184	

Solving for V_T by equation (1)

a = -89.10
b = -178.21
c = 27.71

tunnel air flow velocity V_T = 0.145003724 m/sec or -2.145232 m/sec (rejected)

Inside tunnel concentration = emission rate / (tunnel air flow x tunnel cross-sectional area)

NO_2 = 323 ug/m^3

Appendix 3.9C **Calculation of In-Tunnel Air Quality for Portal D (Lam Tin)**

Overall Concentrations **(Portal D)**

Four assessment points (ASRs InD1-InD4) at the boundary of the enclosure are chosen.
Using CALINE4 and ISCST3 model, the air pollutants concentrations at the 4 assessment points at different levels are calculated.
The highest concentration among the four assessment points is assumed to be the background concentration inside the proposed enclosure section.

Elevation	NO_2 Concentrations (ug/m^3) at Various Levels	
	(mAG)	NO_2
InD1	0.0	249
InD1	4.0	252
InD1	8.0	259
InD2	0.0	247
InD2	4.0	246
InD2	8.0	245
InD3	0.0	250
InD3	4.0	249
InD3	8.0	248
InD4	0.0	249
InD4	4.0	249
InD4	8.0	248

Therefore, the NO_2 background concentration inside the enclosure is 259 ug/m^3

Total Maximum NO_2 concentration inside tunnel at Portal D (Normal Speed) **= 11 + 259**
= 270 ug/m^3

Total Maximum NO_2 concentration inside tunnel at Portal D (Worst Case) **= 323 + 259**
= 582 ug/m^3

Appendix 3.9D **Calculation of In-Tunnel Air Quality for Portal E (Lam Tin)**

One-way Enclosure - Normal Condition (Portal E)

Tunnel Parameter

Length L	= 160	m	
Height H	= 8	m	
Width W	= 7	m	
Cross-sectional area A_T = H x W =		56	m^2
Perimeter P	=	30	m

Emission Data

Traffic Breakdown (%)

Tunnel Traffic (Link no.)	Traffic flow (veh/hr)	Motorcycles	Private Cars	Taxi	Non-franchised Bus<=6.4t	Non-franchised Bus 6.4-15t	Non-franchised Bus >15t	Private Light Bus <=3.5t	Private Light Bus >3.5t	Light Goods Vehicles<=2.5t	Lt Goods Vehicles 2.5-3.5t	Light Goods Vehicles>3.5t	Heavy Goods Vehicles<=15t	Heavy Goods Vehicles >15t	Single Deck Franchised Bus	Double Deck Franchised Bus	Public Light Bus
192	1082	4.0%	55.5%	19.4%	1.2%	0.9%	0.9%	0.4%	0.4%	0.2%	6.9%	4.1%	1.6%	4.6%	0.0%	0.0%	0.0%
NOx Emission Factor (g/mile)		0.75	0.05	0.60	1.62	3.25	5.17	0.20	1.95	2.02	1.02	2.02	2.57	4.73	5.28	5.96	2.00

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)

Weighted NOX E.F. (g/km/veh)	=	0.428	g/km/veh
Total NO_2 emission factor (g/s)	=	2.57E-03	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
Motorcycles	1.7	1.5	4.6
Petrol PC &LGV	1.7	1.5	4.6
Taxi	1.7	1.5	4.6
Non-franchised Bus <6.4t	2.5	3.5	12
Non-franchised Bus 6.4-15t	2.5	3.5	12
Non-franchised Bus >15t	2.5	3.5	12
Private Light Bus <3.5t	2	3	6.5
Private Light Bus >3.5t	2	3	6.5
PC&LGV <2.5t	2.1	1.6	5.2
LGV 2.5-3.5t	2.1	1.6	5.2
LGV >3.5t	2.1	1.6	5.2
HGV<15t	2.5	4.6	16
HGV>15t	2.5	4.6	16
Single Deck Franchised Buses	2.5	3.5	12
Double Deck Franchised Buses	2.5	4.6	12
Public Light Bus	2	3	6.5

* No dimensions for motorcycles and non-franchised bus are provided.
* For the purpose of this study, the dimensions of motorcycles and taxi are assumed to be the same as private car
and the dimension of non-franchised bus are assumed to be the same as single deck franchised bus.

Nominal cross-sectional area A_C = (1.7*1.5*0.04)+(1.7*1.5*0.555)+(1.7*1.5*0.194)+(2.5*3.5*0.012)+(2.5*3.5*0.009)+(2.5*3.5*0.009)+(2*3*0.004)+(2*3*0.004)+(2.1*1.6*0.002)+(2.1*1.6*0.069)+(2.1*1.6*0.041)
+(2.5*4.6*0.016)+(2.5*4.6*0.046)+(2.5*3.5*0)+(2.5*4.6*0)+(2*3*0)
= 3.4083 m^2

Appendix 3.9D **Calculation of In-Tunnel Air Quality for Portal E (Lam Tin)**

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/m^3
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	=	3.40825581	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	=	160	m
D	=	Hydraulic diameter of tunnel =	$4A_T/P$ =	7.46666667	m, P is the Perimeter of tunnel
A_T	=	Cross-sectional area of tunnel	=	56	m^2
C_W	=	External wind coefficient	=	0.3	
$V_{W(ref)}$	=	Velocity of wind at SE Station	=	3.19	m/s (Average of 2011 Southeast Kowloon Weather 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 :

$$F_C - F_T - F_W = 0 \qquad (1)$$

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	=	0.300465461	veh/s
Vehicle speed V_C	=	50	km/h
	=	13.88888889	m/s
Number of vehicles in tunnel N	=	QL/V_C	
	=	3.461362116	
Solving for V_T by equation (1)			
a	=	-94.99	
b	=	-211.37	
c	=	1296.87	

tunnel air flow velocity V_T = 2.746235907 m/sec or -4.9713633 m/sec (rejected)

Inside tunnel concentration = emission rate / (tunnel air flow x tunnel cross-sectional area)

NO_2 = 17 ug/m^3

Appendix 3.9D **Calculation of In-Tunnel Air Quality for Portal E (Lam Tin)**

One-way Enclosure - Worst Condition (Portal E)

Tunnel Parameter

Length L	= 160	m	
Height H	= 8	m	
Width W	= 7	m	
Cross-sectional area A_T = H x W =		56	m^2
Perimeter P	=	30	m

Emission Data

Traffic Breakdown (%)

Tunnel Traffic (Link no.)	Traffic flow (veh/hr)	Motorcycles	Private Cars	Taxi	Non-franchised Bus<=6.4t	Non-franchised Bus 6.4-15t	Non-franchised Bus >15t	Private Light Bus <=3.5t	Private Light Bus >3.5t	Light Goods Vehicles<=2.5t	Lt Goods Vehicles 2.5-3.5t	Light Goods Vehicles>3.5t	Heavy Goods Vehicles<=15t	Heavy Goods Vehicles >15t	Single Deck Franchised Bus	Double Deck Franchised Bus	Public Light Bus
192	1082	4.0%	55.5%	19.4%	1.2%	0.9%	0.9%	0.4%	0.4%	0.2%	6.9%	4.1%	1.6%	4.6%	0.0%	0.0%	0.0%
NOx Emission Factor (g/mile)		0.94	0.06	0.87	3.41	6.87	10.93	0.25	2.65	2.87	1.58	4.20	5.36	9.84	11.37	12.78	2.29

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)

Weighted NOX E.F. (g/km/veh)	=	0.790	g/km/veh
Total NO_2 emission factor (g/s)	=	4.75E-03	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
Motorcycles	1.7	1.5	4.6
Petrol PC &LGV	1.7	1.5	4.6
Taxi	1.7	1.5	4.6
Non-franchised Bus <6.4t	2.5	3.5	12
Non-franchised Bus 6.4-15t	2.5	3.5	12
Non-franchised Bus >15t	2.5	3.5	12
Private Light Bus <3.5t	2	3	6.5
Private Light Bus >3.5t	2	3	6.5
PC&LGV <2.5t	2.1	1.6	5.2
LGV 2.5-3.5t	2.1	1.6	5.2
LGV >3.5t	2.1	1.6	5.2
HGV<15t	2.5	4.6	16
HGV>15t	2.5	4.6	16
Single Deck Franchised Buses	2.5	3.5	12
Double Deck Franchised Buses	2.5	4.6	12
Public Light Bus	2	3	6.5

* No dimensions for motorcycles and non-franchised bus are provided.
* For the purpose of this study, the dimensions of motorcycles and taxi are assumed to be the same as private car and the dimension of non-franchised bus are assumed to be the same as single deck franchised bus.

Nominal cross-sectional area A_C = (1.7*1.5*0.042)+(1.7*1.5*0.496)+(1.7*1.5*0.175)+(2.5*3.5*0.002)+(2.5*3.5*0.031)+(2.5*3.5*0.001)+(2*3*0.003)+(2*3*0.005)+(2.1*1.6*0)+(2.1*1.6*0.108)+(2.1*1.6*0.035)
+(2.5*4.6*0.093)+(2.5*4.6*0.008)+(2.5*3.5*0)+(2.5*4.6*0)+(2*3*0)
= 3.4083 m^2

Appendix 3.9D **Calculation of In-Tunnel Air Quality for Portal E (Lam Tin)**

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/m^3
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	=	3.40825581	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	=	160	m
D	=	Hydraulic diameter of tunnel =	$4A_T/P$ =	7.46666667	m, P is the Perimeter of tunnel
A_T	=	Cross-sectional area of tunnel	=	56	m^2
C_W	=	External wind coefficient	=	0.3	
$V_{W(ref)}$	=	Velocity of wind at SE Station	=	3.19	m/s (Average of 2011 Southeast Kowloon Weather 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 : $$F_C - F_T - F_W = 0 \qquad (1)$$

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

where

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

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

$$c = C_d\,A_c N V_c^{\,2} - C_w V_w^{\,2} A_T$$

<u>For congested traffic condition</u>

Vehicle speed Vc	=	10	km/h
	=	2.777777778	m/s
average length of vehicle	=	(4.6*0.04)+(4.6*0.56)+(4.6*0.19)+(12*0.01)+(12*0.01)+(12*0.01)+(6.5*0)+(6.5*0)+(5.2*0)+(5.2*0.07)+(5.2*0.04)+(16*0.02)+(16*0.05)+(12*0)+(12*0)+(6.5*0)	
	=	5.610666627	m
distance between vehicle	=	1	m
head to head length	=	6.610666627	m
Number of vehicles per lane	=	24.20330793	
Number of lanes	=	1	
Number of vehicles in tunnel N	=	24.20330793	

Solving for V_T by equation (1)

a	=	-49.39
b	=	-295.59
c	=	239.59

tunnel air flow velocity V_T = 0.723147978 m/sec or -6.7076277 m/sec (rejected)

Inside tunnel concentration = emission rate / (tunnel air flow x tunnel cross-sectional area)

NO_2 = 117 ug/m^3

Appendix 3.9D Calculation of In-Tunnel Air Quality for Portal E (Lam Tin)

Overall Concentrations (Portal E)

Four assessment points (ASRs InE1-InE4) at the boundary of the enclosure are chosen.
Using CALINE4 and ISCST3 model, the air pollutants concentrations at the 4 assessment points at different levels are calculated.
The highest concentration among the four assessment points is assumed to be the background concentration inside the proposed enclosure section.

Elevation	NO_2 Concentrations (ug/m^3) at Various Levels	
	(mAG)	NO_2
InE1	0.0	242
InE1	4.0	242
InE1	8.0	241
InE2	0.0	244
InE2	4.0	243
InE2	8.0	241
InE3	0.0	248
InE3	4.0	247
InE3	8.0	246
InE4	0.0	247
InE4	4.0	247
InE4	8.0	246

Therefore, the NO_2 background concentration inside the enclosure is 248 ug/m^3

Total Maximum NO_2 concentration inside tunnel at Portal E (Normal Speed) = **17 + 248**
= **265 ug/m^3**

Total Maximum NO_2 concentration inside tunnel at Portal E (Worst Case) = **117 + 248**
= **366 ug/m^3**

Appendix 3.9E Calculation of In-Tunnel Air Quality for Portal H (Lam Tin)

One-way Enclosure - Normal Condition (Portal H)

Tunnel Parameter

Length L	= 200	m	
Height H	= 8	m	
Width W	= 9	m	
Cross-sectional area A_T = H x W =			72 m^2
Perimeter P	=	34 m	

Emission Data

Traffic Breakdown (%)

Tunnel Traffic (Link no.)	Traffic flow (veh/hr)	Motorcycles	Private Cars	Taxi	Non-franchised Bus<=6.4t	Non-franchised Bus 6.4-15t	Non-franchised Bus >15t	Private Light Bus <=3.5t	Private Light Bus >3.5t	Light Goods Vehicles<=2.5t	Lt Goods Vehicles 2.5-3.5t	Light Goods Vehicles>3.5t	Heavy Goods Vehicles<=15t	Heavy Goods Vehicles >15t	Single Deck Franchised Bus	Double Deck Franchised Bus	Public Light Bus
225	1624	5.3%	59.3%	15.8%	1.4%	1.0%	1.0%	0.6%	0.5%	0.2%	6.8%	4.0%	1.1%	3.0%	0.0%	0.0%	0.0%
NOx Emission Factor (g/mile)		0.64	0.04	0.59	1.65	3.31	5.26	0.17	1.62	1.78	1.01	2.04	2.58	4.74	5.20	5.87	1.95

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)

Weighted NOX E.F. (g/km/veh)	=	0.369 g/km/veh
Total NO_2 emission factor (g/s)	=	4.16E-03 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
Motorcycles	1.7	1.5	4.6
Petrol PC &LGV	1.7	1.5	4.6
Taxi	1.7	1.5	4.6
Non-franchised Bus <6.4t	2.5	3.5	12
Non-franchised Bus 6.4-15t	2.5	3.5	12
Non-franchised Bus >15t	2.5	3.5	12
Private Light Bus <3.5t	2	3	6.5
Private Light Bus >3.5t	2	3	6.5
PC&LGV <2.5t	2.1	1.6	5.2
LGV 2.5-3.5t	2.1	1.6	5.2
LGV >3.5t	2.1	1.6	5.2
HGV<15t	2.5	4.6	16
HGV>15t	2.5	4.6	16
Single Deck Franchised Buses	2.5	3.5	12
Double Deck Franchised Buses	2.5	4.6	12
Public Light Bus	2	3	6.5

* No dimensions for motorcycles and non-franchised bus are provided.
* For the purpose of this study, the dimensions of motorcycles and taxi are assumed to be the same as private car
and the dimension of non-franchised bus are assumed to be the same as single deck franchised bus.

Nominal cross-sectional area A_C = (1.7*1.5*0.053)+(1.7*1.5*0.593)+(1.7*1.5*0.158)+(2.5*3.5*0.014)+(2.5*3.5*0.01)+(2.5*3.5*0.01)+(2*3*0.006)+(2*3*0.005)+(2.1*1.6*0.002)+(2.1*1.6*0.068)+(2.1*1.6*0.04)
+(2.5*4.6*0.011)+(2.5*4.6*0.03)+(2.5*3.5*0)+(2.5*4.6*0)+(2*3*0)
= 3.2490 m^2

Appendix 3.9E **Calculation of In-Tunnel Air Quality for Portal H (Lam Tin)**

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/m^3	
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	=	3.24895583	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	=	200	m	
D	=	Hydraulic diameter of tunnel =	$4A_T/P$ =	8.47058824	m, P is the Perimeter of tunnel	
A_T	=	Cross-sectional area of tunnel	=	72	m^2	
C_W	=	External wind coefficient	=	0.3		
$V_{W(ref)}$	=	Velocity of wind at SE Station	=	3.19	m/s	(Average of 2011 Southeast Kowloon Weather 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 :

$$F_C - F_T - F_W = 0 \qquad (1)$$

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	=	0.451026541	veh/s
Vehicle speed V_C	=	50	km/h
	=	13.88888889	m/s
Number of vehicles in tunnel N	=	QL/V_C	
	=	6.494782197	

Solving for V_T by equation (1)

a = -120.74
b = -378.06
c = 2405.64

tunnel air flow velocity V_T = 3.164643228 m/sec or -6.2958775 m/sec (rejected)

Inside tunnel concentration = emission rate / (tunnel air flow x tunnel cross-sectional area)

NO_2 = 18 ug/m^3

Appendix 3.9E **Calculation of In-Tunnel Air Quality for Portal H (Lam Tin)**

One-way Enclosure - Worst Condition (Portal H)

Tunnel Parameter

Length L	= 200		m
Height H	= 8		m
Width W	= 9		m
Cross-sectional area A_T = H x W =		72	m^2
Perimeter P	=	34	m

Emission Data

Traffic Breakdown (%)

Tunnel Traffic (Link no.)	Traffic flow (veh/hr)	Motorcycles	Private Cars	Taxi	Non-franchised Bus<=6.4t	Non-franchised Bus 6.4-15t	Non-franchised Bus >15t	Private Light Bus <=3.5t	Private Light Bus >3.5t	Light Goods Vehicles<=2.5t	Lt Goods Vehicles 2.5-3.5t	Light Goods Vehicles>3.5t	Heavy Goods Vehicles<=15t	Heavy Goods Vehicles >15t	Single Deck Franchised Bus	Double Deck Franchised Bus	Public Light Bus
225	1624	5.3%	59.3%	15.8%	1.4%	1.0%	1.0%	0.6%	0.5%	0.2%	6.8%	4.0%	1.1%	3.0%	0.0%	0.0%	0.0%
NOx Emission Factor (g/mile)		0.82	0.05	0.86	3.39	6.82	10.85	0.22	2.29	2.62	1.56	4.17	5.32	9.77	11.29	12.69	2.24

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)

Weighted NOX E.F. (g/km/veh)	=	0.669	g/km/veh
Total NO_2 emission factor (g/s)	=	7.54E-03	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
Motorcycles	1.7	1.5	4.6
Petrol PC &LGV	1.7	1.5	4.6
Taxi	1.7	1.5	4.6
Non-franchised Bus <6.4t	2.5	3.5	12
Non-franchised Bus 6.4-15t	2.5	3.5	12
Non-franchised Bus >15t	2.5	3.5	12
Private Light Bus <3.5t	2	3	6.5
Private Light Bus >3.5t	2	3	6.5
PC&LGV <2.5t	2.1	1.6	5.2
LGV 2.5-3.5t	2.1	1.6	5.2
LGV >3.5t	2.1	1.6	5.2
HGV<15t	2.5	4.6	16
HGV>15t	2.5	4.6	16
Single Deck Franchised Buses	2.5	3.5	12
Double Deck Franchised Buses	2.5	4.6	12
Public Light Bus	2	3	6.5

* No dimensions for motorcycles and non-franchised bus are provided.
* For the purpose of this study, the dimensions of motorcycles and taxi are assumed to be the same as private car
and the dimension of non-franchised bus are assumed to be the same as single deck franchised bus.

Nominal cross-sectional area A_C = (1.7*1.5*0.042)+(1.7*1.5*0.496)+(1.7*1.5*0.175)+(2.5*3.5*0.002)+(2.5*3.5*0.031)+(2.5*3.5*0.001)+(2*3*0.003)+(2*3*0.005)+(2.1*1.6*0)+(2.1*1.6*0.108)+(2.1*1.6*0.035)
+(2.5*4.6*0.093)+(2.5*4.6*0.008)+(2.5*3.5*0)+(2.5*4.6*0)+(2*3*0)
= 3.2490 m^2

Appendix 3.9E **Calculation of In-Tunnel Air Quality for Portal H (Lam Tin)**

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/m^3
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	=	3.24895583	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	=	200	m
D	=	Hydraulic diameter of tunnel =	$4A_T/P$ =	8.47058824	m, P is the Perimeter of tunnel
A_T	=	Cross-sectional area of tunnel	=	72	m^2
C_W	=	External wind coefficient	=	0.3	
$V_{W(ref)}$	=	Velocity of wind at SE Station	=	3.19	m/s (Average of 2011 Southeast Kowloon Weather 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 : $$F_C - F_T - F_W = 0 \qquad (1)$$

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

where

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

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

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

<u>For congested traffic condition</u>

Vehicle speed Vc	=	10	km/h
	=	2.777777778	m/s
average length of vehicle	=	(4.6*0.05)+(4.6*0.59)+(4.6*0.16)+(12*0.01)+(12*0.01)+(12*0.01)+(6.5*0.01)+(6.5*0)+(5.2*0)+(5.2*0.07)+(5.2*0.04)+(16*0.01)+(16*0.03)+(12*0)+(12*0)+(6.5*0)	
	=	5.399116974	m
distance between vehicle	=	1	m
head to head length	=	6.399116974	m
Number of vehicles per lane	=	31.25431225	
Number of lanes	=	1	
Number of vehicles in tunnel N	=	31.25431225	

Solving for V_T by equation (1)

a = -68.85
b = -363.87
c = 285.57

tunnel air flow velocity V_T = 0.693738192 m/sec or -5.978319 m/sec (rejected)

Inside tunnel concentration = emission rate / (tunnel air flow x tunnel cross-sectional area)

NO_2 = 151 ug/m^3

Appendix 3.9E Calculation of In-Tunnel Air Quality for Portal H (Lam Tin)

Overall Concentrations (Portal H)

Four assessment points (ASRs InH1-InH4) at the boundary of the enclosure are chosen.
Using CALINE4 and ISCST3 model, the air pollutants concentrations at the 4 assessment points at different levels are calculated.
The highest concentration among the four assessment points is assumed to be the background concentration inside the proposed enclosure section.

Elevation	NO_2 Concentrations (ug/m^3) at Various Levels	
	(mAG)	NO_2
InH1	0.0	225
InH1	4.0	225
InH1	8.0	225
InH2	0.0	225
InH2	4.0	225
InH2	8.0	225
InH3	0.0	225
InH3	4.0	225
InH3	8.0	225
InH4	0.0	226
InH4	4.0	225
InH4	8.0	225

Therefore, the NO_2 background concentration inside the enclosure is 226 ug/m^3

Total Maximum NO_2 concentration inside tunnel at Portal H (Normal Speed) **= 18 + 226**
= 244 ug/m^3

Total Maximum NO_2 concentration inside tunnel at Portal H (Worst Case) **= 151 + 226**
= 377 ug/m^3

Appendix 3.9F **Calculation of In-Tunnel Air Quality for Portal I (Lam Tin)**

One-way Enclosure - Normal Condition (Portal I)

Tunnel Parameter

Length L	= 200	m	
Height H	= 8	m	
Width W	= 7	m	
Cross-sectional area A_T = H x W =			56 m^2
Perimeter P	=	30 m	

Emission Data

Traffic Breakdown (%)

Tunnel Traffic (Link no.)	Traffic flow (veh/hr)	Motorcycles	Private Cars	Taxi	Non-franchised Bus<=6.4t	Non-franchised Bus 6.4-15t	Non-franchised Bus >15t	Private Light Bus <=3.5t	Private Light Bus >3.5t	Light Goods Vehicles<=2.5t	Lt Goods Vehicles 2.5-3.5t	Light Goods Vehicles>3.5t	Heavy Goods Vehicles<=15t	Heavy Goods Vehicles >15t	Single Deck Franchised Bus	Double Deck Franchised Bus	Public Light Bus
226	728	4.1%	58.1%	20.3%	1.3%	0.9%	0.9%	0.5%	0.4%	0.1%	5.4%	3.2%	1.3%	3.6%	0.0%	0.0%	0.0%
NOx Emission Factor (g/mile)		0.75	0.05	0.60	1.62	3.25	5.17	0.20	1.95	2.02	1.02	2.02	2.57	4.73	5.28	5.96	2.00

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)

Weighted NOX E.F. (g/km/veh) = 0.380 g/km/veh
Total NO_2 emission factor (g/s) = 1.92E-03 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
Motorcycles	1.7	1.5	4.6
Petrol PC &LGV	1.7	1.5	4.6
Taxi	1.7	1.5	4.6
Non-franchised Bus <6.4t	2.5	3.5	12
Non-franchised Bus 6.4-15t	2.5	3.5	12
Non-franchised Bus >15t	2.5	3.5	12
Private Light Bus <3.5t	2	3	6.5
Private Light Bus >3.5t	2	3	6.5
PC&LGV <2.5t	2.1	1.6	5.2
LGV 2.5-3.5t	2.1	1.6	5.2
LGV >3.5t	2.1	1.6	5.2
HGV<15t	2.5	4.6	16
HGV>15t	2.5	4.6	16
Single Deck Franchised Buses	2.5	3.5	12
Double Deck Franchised Buses	2.5	4.6	12
Public Light Bus	2	3	6.5

* No dimensions for motorcycles and non-franchised bus are provided.
* For the purpose of this study, the dimensions of motorcycles and taxi are assumed to be the same as private car and the dimension of non-franchised bus are assumed to be the same as single deck franchised bus.

Nominal cross-sectional area A_C = (1.7*1.5*0.041)+(1.7*1.5*0.581)+(1.7*1.5*0.203)+(2.5*3.5*0.013)+(2.5*3.5*0.009)+(2.5*3.5*0.009)+(2*3*0.005)+(2*3*0.004)+(2.1*1.6*0.001)+(2.1*1.6*0.054)+(2.1*1.6*0.032)
+(2.5*4.6*0.013)+(2.5*4.6*0.036)+(2.5*3.5*0)+(2.5*4.6*0)+(2*3*0)
= 3.2771 m^2

Appendix 3.9F **Calculation of In-Tunnel Air Quality for Portal I (Lam Tin)**

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/m^3	
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	=	3.27708228	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	=	200	m	
D	=	Hydraulic diameter of tunnel =	$4A_T/P$ =	7.46666667	m, P is the Perimeter of tunnel	
A_T	=	Cross-sectional area of tunnel	=	56	m^2	
C_W	=	External wind coefficient	=	0.3		
$V_{W(ref)}$	=	Velocity of wind at SE Station	=	3.19	m/s	(Average of 2011 Southeast Kowloon Weather 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 :
$$F_C - F_T - F_W = 0 \qquad (1)$$

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

where
$$a = C_d A_c N - (K_{in} + K_{out} + \frac{fL}{D}) A_T$$
$$b = -\ 2\ C_d\ A_c\ N\ V_c$$
$$c = C_d A_c N V_c^{\ 2} - C_w V_w^{\ 2} A_T$$

<u>For normal traffic condition</u>

traffic flow Q = 0.202154327 veh/s

Vehicle speed V_C = 50 km/h

= 13.88888889 m/s

Number of vehicles in tunnel N = QL/V_C

= 2.911022306

Solving for V_T by equation (1)

a = -101.10

b = -170.92

c = 1015.98

tunnel air flow velocity V_T = 2.435549403 m/sec or -4.1261934 m/sec (rejected)

Inside tunnel concentration = emission rate / (tunnel air flow x tunnel cross-sectional area)

NO_2 = 14 ug/m^3

Appendix 3.9F **Calculation of In-Tunnel Air Quality for Portal I (Lam Tin)**

One-way Enclosure - Worst Condition (Portal I)

Tunnel Parameter

Length L	= 200	m	
Height H	= 8	m	
Width W	= 7	m	
Cross-sectional area A_T = H x W =		56	m^2
Perimeter P	=	30	m

Emission Data

Traffic Breakdown (%)

Tunnel Traffic (Link no.)	Traffic flow (veh/hr)	Motorcycles	Private Cars	Taxi	Non-franchised Bus<=6.4t	Non-franchised Bus 6.4-15t	Non-franchised Bus >15t	Private Light Bus <=3.5t	Private Light Bus >3.5t	Light Goods Vehicles<=2.5t	Lt Goods Vehicles 2.5-3.5t	Light Goods Vehicles>3.5t	Heavy Goods Vehicles<=15t	Heavy Goods Vehicles >15t	Single Deck Franchised Bus	Double Deck Franchised Bus	Public Light Bus
226	728	4.1%	58.1%	20.3%	1.3%	0.9%	0.9%	0.5%	0.4%	0.1%	5.4%	3.2%	1.3%	3.6%	0.0%	0.0%	0.0%
NOx Emission Factor (g/mile)		0.94	0.06	0.87	3.41	6.87	10.93	0.25	2.65	2.87	1.58	4.20	5.36	9.84	11.37	12.78	2.29

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)

Weighted NOX E.F. (g/km/veh)	=	0.692	g/km/veh
Total NO_2 emission factor (g/s)	=	3.50E-03	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
Motorcycles	1.7	1.5	4.6
Petrol PC &LGV	1.7	1.5	4.6
Taxi	1.7	1.5	4.6
Non-franchised Bus <6.4t	2.5	3.5	12
Non-franchised Bus 6.4-15t	2.5	3.5	12
Non-franchised Bus >15t	2.5	3.5	12
Private Light Bus <3.5t	2	3	6.5
Private Light Bus >3.5t	2	3	6.5
PC&LGV <2.5t	2.1	1.6	5.2
LGV 2.5-3.5t	2.1	1.6	5.2
LGV >3.5t	2.1	1.6	5.2
HGV<15t	2.5	4.6	16
HGV>15t	2.5	4.6	16
Single Deck Franchised Buses	2.5	3.5	12
Double Deck Franchised Buses	2.5	4.6	12
Public Light Bus	2	3	6.5

* No dimensions for motorcycles and non-franchised bus are provided.
* For the purpose of this study, the dimensions of motorcycles and taxi are assumed to be the same as private car
and the dimension of non-franchised bus are assumed to be the same as single deck franchised bus.

Nominal cross-sectional area A_C = (1.7*1.5*0.042)+(1.7*1.5*0.496)+(1.7*1.5*0.175)+(2.5*3.5*0.002)+(2.5*3.5*0.031)+(2.5*3.5*0.001)+(2*3*0.003)+(2*3*0.005)+(2.1*1.6*0)+(2.1*1.6*0.108)+(2.1*1.6*0.035)
+(2.5*4.6*0.093)+(2.5*4.6*0.008)+(2.5*3.5*0)+(2.5*4.6*0)+(2*3*0)
= 3.2771 m^2

Appendix 3.9F **Calculation of In-Tunnel Air Quality for Portal I (Lam Tin)**

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/m^3
	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	=	3.27708228	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	=	200	m
	D	=	Hydraulic diameter of tunnel =	$4A_T/P$ =	7.46666667	m, P is the Perimeter of tunnel
	A_T	=	Cross-sectional area of tunnel	=	56	m^2
	C_W	=	External wind coefficient	=	0.3	
	$V_{W(ref)}$	=	Velocity of wind at SE Station	=	3.19	m/s (Average of 2011 Southeast Kowloon Weather 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

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

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

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

<u>For congested traffic condition</u>

Vehicle speed Vc	=	10	km/h
	=	2.777777778	m/s
average length of vehicle	=	(4.6*0.04)+(4.6*0.58)+(4.6*0.2)+(12*0.01)+(12*0.01)+(12*0.01)+(6.5*0)+(6.5*0)+(5.2*0)+(5.2*0.05)+(5.2*0.03)+(16*0.01)+(16*0.04)+(12*0)+(12*0)+(6.5*0)	
	=	5.4524559	m
distance between vehicle	=	1	m
head to head length	=	6.4524559	m
Number of vehicles per lane	=	30.99594993	
Number of lanes	=	1	
Number of vehicles in tunnel N	=	30.99594993	

Solving for V_T by equation (1)

a = -41.73

b = -363.98

c = 334.57

tunnel air flow velocity V_T = 0.838571527 m/sec or -9.5601838 m/sec (rejected)

Inside tunnel concentration = emission rate / (tunnel air flow x tunnel cross-sectional area)

NO_2 = 74 ug/m^3

Appendix 3.9F **Calculation of In-Tunnel Air Quality for Portal I (Lam Tin)**

Overall Concentrations **(Portal I)**

Four assessment points (ASRs InI1-InI4) at the boundary of the enclosure are chosen.
Using CALINE4 and ISCST3 model, the air pollutants concentrations at the 4 assessment points at different levels are calculated.
The highest concentration among the four assessment points is assumed to be the background concentration inside the proposed enclosure section.

Elevation	**NO_2 Concentrations (ug/m^3) at Various Levels**	
	(mAG)	NO_2
InI1	0.0	226
InI1	4.0	225
InI1	8.0	225
InI2	0.0	230
InI2	4.0	225
InI2	8.0	225
InI3	0.0	238
InI3	4.0	233
InI3	8.0	233
InI4	0.0	241
InI4	4.0	239
InI4	8.0	235

Therefore, the NO_2 background concentration inside the enclosure is 241 ug/m^3

Total Maximum NO_2 concentration inside tunnel at Portal I (Normal Speed) **= 14 + 241**
= 255 ug/m^3

Total Maximum NO_2 concentration inside tunnel at Portal I (Worst Case) **= 74 + 241**
= 315 ug/m^3