Predicted NO_2 Concentration

	Predicted Maximum Hourly NO_2 Concentration, $\mu g/m^3$					Predicted Maximum Daily Average NO_2 Concentration, $\mu g/m^3$					Predicted Annual Average NO_2 Concentration, $\mu g/m^3$				
ASR	1.5m	5m	10m	15m	20m	1.5m	5m	10m	15m	20m	1.5m	5m	10m	15m	20m
ASR2*	206	206	206	206	207	99	98	98	97	95	45	44	43	41	38
ASR3	256	255	252	242	233	106	105	100	95	90	44	43	40	37	35
ASR5	258	257	256	255	254	115	115	114	110	104	60	60	59	53	46
ASR6	223	216	223	217	216	126	117	121	116	109	52	41	48	44	42
ASR7	225	225	224	223	219	109	108	106	102	98	52	51	49	46	43
ASR8	216	215	215	214	213	109	109	109	109	108	28	28	28	28	27
ASR9A	203	201	189	187	187	124	121	112	105	105	52	49	44	40	40
ASR9B	199	199	194	192	192	115	114	113	110	110	53	51	48	43	43
ASR9C	196	196	196	195	195	109	109	109	108	108	53	51	45	39	39
ASR10	245	241	235	225	228	133	131	130	126	120	46	36	41	38	35
ASR11A	203	203	203	203	203	114	114	114	114	113	36	36	35	34	33
ASR11B	205	205	205	204	204	119	119	118	117	116	44	43	40	37	34
ASR11C	201	201	201	201	201	116	116	116	115	114	43	42	39	36	33
ASR12A	188	188	188	188	188	100	99	99	99	99	35	35	34	33	33
ASR12B	205	200	190	189	189	129	120	105	101	101	62	46	38	36	36
ASR12C	210	209	206	202	202	130	120	105	100	100	62	45	38	35	35
ASR13	184	184	184	184	184	101	101	100	100	100	38	38	36	35	35
ASR14*	168	168	169	169	170	71	71	71	73	75	26	26	26	26	27
ASR15	196	196	196	196	196	111	111	111	111	110	31	31	31	30	30

Remark: * - Since ASR2 and ASR14 are only 5 storeys and 1 storey respectively, the level of 20m above ground would not be considered.

Predicted RSP Concentration

	Predicted Maximum Hourly RSP Concentration, $\mu g/m^3$					Predicted Maximum Daily Average RSP Concentration, $\mu g/m^3$					Predicted Annual Average RSP Concentration, $\mu g/m^3$				
ASR	1.5m	5m	10m	15m	20m	1.5m	5m	10m	15m	20m	1.5m	5m	10m	15m	20m
ASR2	544	543	541	538	521	103	103	103	103	102	48	48	48	48	47
ASR3	563	562	560	557	551	111	111	110	110	110	48	48	48	48	47
ASR5	538	537	535	532	517	110	110	110	109	108	49	49	49	48	47
ASR6	549	548	546	542	526	125	124	123	123	121	50	50	50	50	49
ASR7	542	542	540	536	521	106	106	106	106	105	48	48	48	48	47
ASR8	116	116	116	116	116	89	89	89	89	89	43	43	43	43	43
ASR9A	116	115	114	114	114	92	91	91	91	91	45	45	45	45	45
ASR9B	115	115	115	114	114	91	91	91	91	91	45	45	45	45	45
ASR9C	114	114	114	114	114	91	91	91	91	91	45	45	45	45	45
ASR10	713	712	712	711	709	131	130	130	130	128	49	49	49	49	49
ASR11A	118	118	118	118	118	92	92	92	91	91	44	44	44	44	44
ASR11B	118	118	118	118	118	92	92	92	92	92	45	45	45	44	44
ASR11C	123	123	123	123	122	92	92	92	92	92	45	45	44	44	44
ASR12A	114	114	114	114	114	90	90	90	90	90	44	44	44	44	44
ASR12B	121	118	114	114	114	93	91	91	91	91	46	45	45	44	44
ASR12C	119	117	114	114	114	94	92	91	91	91	46	45	45	44	44
ASR13	114	114	114	114	114	91	91	91	91	91	44	44	44	44	44
ASR14	355	355	355	355	354	93	91	93	93	93	46	46	46	46	46
ASR15	118	118	118	118	118	91	91	91	91	91	44	44	44	44	44

In-Underpass Air Quality Assessment

Underpass Parameter

Length (L)	=	230	m
Height (H)	=	5.1	m
Width (W)	=	8.3	m
Cross-Sectional Area (A_T) = H x W	=	42.33	m^2
Perimeter (P)	=	26.80	m

Emission Data

Traffic Flow = 785 veh/hr

Traffic Breakdown	PC-p	LGV3	LGV4	PLB	LGV6	HGV7	HGV8	FBDD	MC	taxi	PV4	PV5	NFB6	NFB7	NFB8	FBSD
Vehicle Mix	0.17	0.01	0.10	0.00	0.06	0.13	0.39	0.00	0.01	0.11	0.00	0.00	0.01	0.01	0.01	0.00
NOx Emission Factor (g/mile/veh)	0.15	0.28	0.27	0.00	1.53	2.81	3.65	2.63	1.12	0.36	0.00	0.00	1.53	2.82	3.70	0.00

Total NO_2 Emission Rate = Total NOx 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 NOx and 5% of NO_2/NOx for in-underpass air)

Weighted NOx Emission Factor	=	1.2760	g/km/veh
Total NO_2 Emission Factor	=	0.0080	g/s

Vehicle Data

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

	W (m)	H (m)	L (m)	Vehicle Mix
Motor Cycles	1.7	1.5	4.6	0.17
Petrol PC & LGV	1.7	1.5	4.6	0.01
Taxi	1.7	1.5	4.6	0.10
Non-Franchised Buses (<6.4t)	2.5	3.5	12.0	0.00
Non-Franchised Buses (6.4 - 15t)	2.5	3.5	12.0	0.06
Non-Franchised Buses (>15t)	2.5	3.5	12.0	0.13
Private Light Buses (<3.5t)	2.0	3.0	6.5	0.39
Private Light Buses (>3.5t)	2.0	3.0	6.5	0.00
Diesel PC&LGV (<2.5t)	2.1	1.6	5.2	0.01
Diesel LGV (2.5 - 3.5t)	2.1	1.6	5.2	0.11
Diesel LGV (>3.5t)	2.1	1.6	5.2	0.00
HGV (<15t)	2.5	4.6	16.0	0.00
HGV (>15t)	2.5	4.6	16.0	0.01
Single Deck Franchised Buses	2.5	3.5	12.0	0.01
Double Deck Franchised Buses	2.5	4.6	12.0	0.01
Public Light Buses	2.0	3.0	6.5	0.00

* 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 (A_c)	=	5.42	m^2
Average Length of Vehicle	=	7.11	m

Underpass Airflow

For Uni-Directional Traffic,

Push Force by Vehicles: $Fc = 0.5\rho(V_c - V_T)^2 C_d A_c N$

Resisting Force by Underpass: $F_T = 0.5\rho V_T^2 [K_{in} + K_{out} + (fL/D)] A_T$

External Wind at the Entrance and Exit Portal: $F_w = 0.5\rho C_w(V_w \cos\theta)^2 A_T$

where:

ρ = Air Density	=	1.2	kg/m^3
V_c = Velocity of Vehicle (m/s)			
V_T = Velocity of Airflow in Underpass (m/s)			
C_d = Vehicle Drag Coefficient	=	0.645	
A_c = Vehicle Frontal Area	=	5.42	m^2
N = No. of Vehicle in Underpass			
K_{in} = Inlet Loss Coefficient	=	0.5	
K_{out} = Outlet Loss Coefficient	=	1.0	
f = Underpass Friction Factor	=	0.0155	
L = Length of Underpass	=	230	m
D = Hydraulic Diameter of Underpass = $4A_T/P$	=	6.32	m
P = Perimeter of Underpass	=	26.80	m
A_T = Cross-Sectional Area of Tunnel	=	42.33	m^2
C_w = External Wind Coefficient	=	0.3	
V_w = Velocity of Wind	=	3.48	m/s
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: $F_c - F_T - F_W = 0$ Equation (1)

Solving the Equation, $aV_T^2 + bV_T + c = 0$

where,

$a = C_dA_cN - [K_{in} + K_{out} + (fL/D)]A_T$

$b = -2C_dA_cNV_c$

$c = C_dA_cNV_c^2 - C_wV_w^2A_T$

For Normal Traffic Condition

Traffic Flow (Q)	=	0.2181	veh/s
Vehicle Speed (V_c)	=	30	km/h
	=	8.33	m/s
Number of Vehicles in Underpass (N) = QL/V_c	=	6.02	

Solving for V_T for Equation (1)

a =	-66.33	
b =	-350.86	
c =	1,307.96	

Velocity of Airflow in Underpass (V_T) = -7.81 m/s or (rejected)

= 2.52 m/s

Inside Underpass NO_2 Concentration = Emission Rate / (Tunnel Airflow x Underpass Cross-Sectional Area)

= 74.88 μg/m^3

Background Concentration

6 assessment points with 3 levels (UP1L1 to UP6L3) at the exit and entrance of the underpass are selected.
Using CALINE4 and ISCST3 model, the air pollutants concentration at these 18 assessment points are calculated.
The highest concentration among these 18 assessment points is considered to be the background concentration inside the underpass.

Assessment Point	mAG	Maximum Concentration (μg/m^3)
UP1L1	0.00	280.86
UP1L2	2.55	256.56
UP1L3	5.10	254.23
UP2L1	0.00	276.55
UP2L2	2.55	254.45
UP2L3	5.10	252.54
UP3L1	0.00	261.21
UP3L2	2.55	252.82
UP3L3	5.10	251.21
UP4L1	0.00	308.63
UP4L2	2.55	306.89
UP4L3	5.10	290.49
UP5L1	0.00	348.49
UP5L2	2.55	339.88
UP5L3	5.10	312.93
UP6L1	0.00	212.47
UP6L2	2.55	211.97
UP6L3	5.10	211.44

Therefore, the NO_2 background concentration inside the underpass is 348.49 μg/m^3.

Total Maximum NO_2 Concentration Inside
the Proposed Underpass (Normal Condition) =
= 423.38 μg/m^3