Lam Geotechnics Limited

Ground Investigation & Instrumentation Professionals

華益土力有限公司

Ref : G1525/CS/L1075/HyD
Date : 28 June 2019

3rd Floor
Ho Man Tin Government Offices,
88 Chung Hau Street,
Ho Man Tin,
Kowloon

By Post and Fax (2714-5289)

Attn: Senior Engineer, Mr. Tony Cheung

Dear Mr. Cheung,

Contract No. HK/2015/01
Wanchai Development Phase II and Central-Wanchai Bypass
Sampling, Field Measurement and Testing Works (Stage 3)
Investigation Report on Breakdown of Tunnel Ventilation System at East Ventilation Building

Referring to the captioned submission received via email on 28 June 2019 at 17:43, we have reviewed the submitted details and have no further comment at this stage. We hereby certify the Investigation Report for submission to EPD as per Condition 1.8 of EP-482/2013/A.

Please be reminded that the certification will be limited to the existing approved EIA report and/or EM&A requirements, with qualifications laid down for the relevant part(s) of the investigation report be to be counter-signed or confirmed in written by the relevant professionals involving in the CWB tunnel ventilation system and the EIA professional for the CWB project, to confirm the corresponding relevant context beyond the existing approved EIA report and/or EM&A requirements, including the following at a minimum,

a. Supervision and acceptance of rectification measures of ventilation installation by CRE of the CWB tunnel commissioning contract;
b. Engineering review by ventilation design engineer on the operation and functioning of both TVS and APS to achieve Zero Portal Emission after rectification;
c. Environmental impact assessment further to the approved EIA report in terms of air quality impact assessment and modelling results by the party in the capacity of conduct/review the EIA for the CWB project; and
d. Any further technical/professional aspects other than the above to be included as part of the investigation report as per the latest review and comments as given by EPD.

Whilst we will continue to keep reviewing the effectiveness of the interim notification system between MOm, ET, IEC, RSS, HyD and TD established to handle reporting/investigation of faults since early April 2019, please be reminded to ensure all the further step-up measures in respect to EP-482/2013/A as per Section F(vi) of the captioned be properly implemented, in particular to set up the long-term notification arrangement with MOm, TD and relevant parties to enhance the communication and reporting mechanism for satisfying the requirements under EP-482/2013/A, the associated EM&A Manuals (AEIAR-041/2001 and AEIAR-125/2008), the Air Quality Management Plan (AQMP) approved under Condition 2.9 of the EP-482/2013/A.

Yours faithfully,
For and On Behalf of Lam Geotechnics Limited

Raymond Dai
Environmental Team Leader

Encl.

c.c	*CEDD*	*- Mr. Lee Hon*	*By Fax: 2301-1277*
	AECOM WDII	*- Ms. Gloria Tang*	*By Fax: 2587-1877*
	AECOM CWB	*- Mr. David Kwan*	*By Fax: 3665-0106*
	AECOM CWB	*- Mr. Eric Wong*	*By Fax: 3912-3010*
	Ramboll	*- Mr. David Yeung*	*By Fax: 3465-2899*

11/F, Centre Point, 181-185 Gloucester Road, Wanchai, Hong Kong
Tel: (852) 2882-3939 Fax: (852) 2882-3331
Website: www.lamgeo.com Email: info@lamgeo.com

RAMBOLL

Ref.: AACWBIECEM00_0_11431L.19

28 June 2019

Highways Department
Major Works Project Management Office
Major Works Office (2)
3rd Floor, Ho Man Tin Government Offices
88 Chung Hau Street
Ho Man Tin, Kowloon
Hong Kong

By Post and Fax (2714 5289)

Attention: Mr. Tony Cheung

Dear Mr. Cheung,

Re: **EP-482/2013/A – Central – Wan Chai Bypass (CWB) including its Road Tunnel and Slip Roads**

Investigation Report on Breakdown of Tunnel Ventilation System at East Ventilation Building

We refer to the captioned Investigation Report on Breakdown of Tunnel Ventilation System at East Ventilation Building received through RSS's e-mail on 28 June 2019 at 17:43 for our review and comment and ET's certification letter (Ref.: G1525/CS/L1075/HyD) received on 28 June 2019 at 18:12.

We concur with ET's clarification that our verification is limited to the existing EIA recommendations and/or EM&A requirements as stipulated in the approved EIA reports. The relevant parts of the investigation report that fall beyond the information and recommendations contained in the approved EIA reports and/or EM&A manuals should be verified by other parties, including but not limited to the following issues:-

a. Supervision and acceptance of rectification measures of the ventilation equipment installations of the CWB tunnel commissioning contract; and

b. Detailed ventilation engineering design on the operation and functioning of TVS and APS to achieve the zero portal emission design and their removal efficiencies respectively.

Having reviewed the investigation report with the above-mentioned items taken into consideration, we write to verify the captioned report in accordance with Condition 1.8 in the captioned Environmental Permit.

Q:\Projects\AACWBIECEM00\Corr\AACWBIECEM00_0_11431L.19.docx

Ramboll Hong Kong Limited 英環香港有限公司
21/F, BEA Harbour View Centre, 56 Gloucester Road, Wan Chai, Hong Kong Tel: 852.3465 2888 Fax: 852.3465 2899
www.ramboll.com

Thank you very much for your attention and please do not hesitate to contact the undersigned should you have any queries.

Yours sincerely,

David Yeung
Independent Environmental Checker

c.c.	CEDD	Attn: Mr. Lee Hon	by fax: 2301 1277
	AECOM CWB	Attn: Mr. David Kwan	by fax: 3665 0106
	AECOM CWB	Attn: Mr. Eric Wong	by fax: 3912 3010
	AECOM WDII	Attn: Ms. Gloria Tang	by fax: 2587 1877
	Lam	Attn: Mr. Raymond Dai	by fax: 2882 3331

AECOM

Environmental Impact Assessment Ordinance (Chapter 499)

(Section 10 & 13)

Central – Wan Chai Bypass and Island Eastern Corridor Link

Investigation Report on Breakdown of Tunnel Ventilation System at East Ventilation Building

Prepared by:	Patrick Wong / Eric Wong	Date:	28 JUNE 2019
Position:	SRE (E&M) / SRE (S&E) AECOM		
Endorsed by:	David Kwan	Date:	28 June 2019
Position:	Chief Resident Engineer AECOM		

Content

A. Introduction

B. Chronology of Events Leading to Breakdown of the Tunnel Ventilation System at East Ventilation Building

C. Investigation and Review on the Possible Causes of Fan Blade Bolt Failures
   i. Fans Bolts
   ii. Workmanship in Assembly of Fan Blades
   iii. Review on the Tunnel Ventilation System
   iv. Conclusion

D. Proposals on Monitoring and Assessment of Air Quality Impacts
   i. Detailed air quality assessment under the worst-case meteorological scenarios during the TVF down-time
   ii. Ambient air quality monitoring plan to check the air quality impact on appropriate ASRs near the tunnel portal
   iii. Action plan in case of exceedance of air quality at the nearby ASRs
   iv. Action plan/mitigation measures to ensure the in-tunnel air quality fulfilling the limit as specified in EDP's Practice Note on Control of Air Pollution in Vehicle Tunnels before resumption of TVF/APS operation at EVB

E. Action Plan/Mitigation Measures
   i. Reporting of the Incident

ii. Tunnel Air Quality
iii. Complete Temporary Retrofitting of TVF as soon as Practicable

F. Action Taken and The Way Forward
i. Completion of Rectification of TVF Problem and Resumption of Normal Operation of APS and TVS
ii. Investigation on the Ventilation Fan System
iii. Issue of Investigation Report
iv. Step-up measures taken/to be taken to prevent recurrence of failure of TVS
v. Contingency Plan and Remedial Actions in case TVS encounters malfunction/breakdown
vi. Further Step-up Measures in Respect to EP-482/2013/A

A. Introduction

As part of the APS (Air Purification System) Commissioning Test Plan approved under Condition 2.7 of the Environmental Permit (EP-482/2013/A), Stage 2 which covers the efficiency test of the Air Purification System (APS) of Central Wan Chai Bypass (CWB) follows after the satisfactory completion of Stage 1 which comprised Factory Acceptance Test (FAT) and Site Acceptance Test (SAT) on individual key elements of the APS. During the efficiency test of the APS of the CWB, fan casing vibration alarms of the tunnel ventilation fans (TVF) (EVB-TVF-008B) of the APS installed at the East Ventilation Building (EVB) were activated on 28 February 2019 and it was found through promptly arranged inspection that some of the connecting bolts of that particular fan were broken. After thorough inspection by the Resident Site Staff (RSS)/Contractor, it was eventually found that 7 out of 15 fans at the EVB had some broken bolts and minor notched damage of fan blades, including Fan Nos. EVB-TVF-006a & b, EVB-TVF-007a & b, EVB-TVF-008a & b and EVB-TVF-009b (please see schematic diagram of Tunnel Ventilation System (TVS) and APS in **Appendix 1**). While pending investigation of the premature failure of the bolts, for safety reason, the operation of APS-related fans was suspended, thus leading to temporary shutdown of the APS at the EVB.

Condition 2.9 of the Environmental Permit (EP-482/2013/A) sets out the requirements for the monitoring of the performance of the APS after the commencement of the operation of the CWB. An Air Quality Monitoring Plan (AQMP) as required in Condition 2.9 of EP-482/2013/A was approved by the Director of Environmental Protection on 17 January 2019 (See EPD website link : https://www.epd.gov.hk/eia/register/english/permit /vep5112016/documents/aqmp/pdf/aqmp.pdf). In the AQMP, there is a provision of Contingency Plan (Clause 3.2) which caters for emergency situations, such as an accidental breakdown of individual component causing malfunction of the TVFs and APS. The current situation has been handled in accordance with the procedures of the contingency plan. Please refer to the flowchart (in **Appendix 2**) which summarizes such procedures.

According to Clause 4.2 of EPD's approved APS Commissioning Test Plan required under Condition 2.7 of EP-482/2013/A (See EPD website link:
https://www.epd.gov.hk/eia/register/english/permit/vep5112016/documents

/rapsctp/pdf/rapsctp.pdf), the Efficiency Tests for the APS will be carried out after the CWB tunnel is opened for 30 days. The purpose of conducting the APS Efficiency Test is to demonstrate that the efficiency of the APS can achieve the design criteria and target performance.

HyD submitted to the DEP a full investigation report pursuant to Condition 2.9 of the Environmental Permit (EP-482/2013/A) regarding this emergency incident on 8 April 2019. This report provides the chronology of events leading to breakdown of the tunnel ventilation system at East Ventilation Building, investigation and review on the possible causes of fan blade bolt failures, proposals on monitoring and assessment of air quality impacts, action plan/mitigation measures and the way forward as detailed in the following sections.

B. Chronology of Events Leading to Breakdown of the Tunnel Ventilation System at East Ventilation Building

Parties Involved

Highways Department (HyD)	The Permit Holder of EP-482/2013/A and the Employer of HyD Contract No. HY/2011/08
AECOM (Resident Site Staff (RSS), The Engineer)	The Consultant of HyD for the CWB project
Chun Wo Tunnel Management Ltd (MOm)	The Management, Operation and Maintenance contractor– Operator of the CWB tunnel
LAM Geotechnics Ltd.	Environmental Team (ET) under Environmental Permit No. EP-482/2013/A
Ramboll Hong Kong Ltd.	Independent Environmental Checker (IEC) under Environmental Permit No. EP-482/2013/A
Leighton Joint Venture (LJV)	The Contractor for Contract No. HY/2011/08 which includes the APS and TVS
Zitron	The manufacturer and supplier for the TVFs and a Sub-contractor of LJV
Filtrontec	The manufacturer for the APS and a Sub-contractor of LJV
Transport Department/Tunnels and Tsing Ma Section (TD/TTMS)	Management of CWB Tunnel
Electrical and Mechanical Services Department/Government Management Team (EMSD(GMT))	E & M Advisor to TD/TTMS

Chronology

Date	Site Activities	Communications and Meeting Events
November 2018	After completion of the Factory Acceptance Test (FAT), fans were delivered on site and the Functional test and Site Acceptance Test (SAT) were completed	
19 February 2019 (Tue)	First Commencement of APS Efficiency Test by LJV and Filtrontec	
20 – 26 February 2019	Fine tuning of APS by LJV and Filtrontec	
27 February 2019 (Wed) 11:00AM	Efficiency Test of APS was re-started by LJV and Filtrontec	
28 February 2019 (Thu)	Fan No. EVB-TVF-008B was found persistently faulty with "Fan Vibration Alarm" signal between 11:21am and 3:36pm. LJV stopped all ventilation fans related to APS i.e. Fan nos. EVB-TVF-004A&B to EVB-TVF-009A&B inclusive in EVB at 3:40pm for investigation in view of safety concern and informed RSS that they would investigate why the alarm was triggered. The operation of the APS in EVB was stopped.	LJV notified AECOM RSS via email at 18:42pm that the Efficiency Test of APS was stopped and said that they need to investigate the reason.
1 March 2019 (Fri)		RSS called LJV and urged LJV to look into the cause of fan vibration alarm from EVB-TVF-008B. LJV responded that they would check the condition of vibration sensor and the fan foundation as the first step.
4 March 2019 (Mon)	RSS accompanied LJV and observed that LJV and Zitron's local representative found the fan blades connection bolts of Fan Nos. EVB-TVF-008A (1 no. out of 64) and EVB-TVF-008B (14 nos. out of 64) were broken in the morning and the afternoon respectively	RSS emailed to LJV to record some fan blades were dismantled and requested LJV's report on their findings.

5 March 2019 (Tue)		RSS urged LJV in writing (copy letter to HyD) to submit the investigation report on the cause of the fan vibration alarm and the breakage of the fan blade connection bolts of Fan Nos. EVB-TVF-008A and 008B. Also RSS urged LJV to submit the proposed remedial measures as soon as possible and take immediate action to rectify the deficiency. LJV reported by email that they have arranged Zitron's engineer to check the TVFs. Zitron's engineer arrived in HK on 5 March 2019 afternoon.
6 March 2019 (Wed)	Zitron's engineer from Spain investigated the fan on site.	
7 March 2019 (Thu)	RSS witnessed LJV replaced all (64 nos.) fan blade connection bolts in Fan No. EVB-TVF-008B by black bolts of the same strength. LJV/Zitron also replaced all (64nos) fan blade connection bolts in Fan No. EVB-TVF-008A subsequently in the evening.	LJV submitted Zitron's proposal of using black bolts of same material grade of 10.9 as a temporary measures. In the afternoon, the Engineer wrote by email and urged LJV to promptly carry out a complete overhaul of the fans in view of the log result showing abnormalities at other fans prominently EVB-TVF-006A and the potential profound consequence.
8 March 2019 (Fri)	Witnessed by RSS, LJV/Zitron conducted trial run of Fan Nos. EVB-TVF-008A and EVB-TVF-008B (using black bolts) for 1-min and 5-min respectively and the test results were found to be in order. On the same day, LJV proceeded to check other fans and 6 nos. bolts in 4 out of 16 fan blades in Fan No. EVB-TVF-007A were found broken.	
9 March 2019 (Sat)		RSS issued letter to LJV to record that the emergency stops of fans were pressed and activated by LJV staff at around 3:39pm on 28 February 2019,

		and the stop status were continued up to 9 March 2019. RSS requested LJV to explain the reason for stopping the fans for the investigation of the cause of the problem at Fan No. EVB-TVF-008B fan and submit schedule and remedial action to resume the operation of fans immediately. LJV relayed Zitron's advice that further investigation would be needed to identify the cause of the bolt failure. A skilled technician from Spain would come to site to investigate.
11 March 2019 (Mon)	In the morning, LJV checked Fan No. EVB-TVF-009B which is of the same fan group of Fan Nos. EVB-TVF-007 to 009 and observed that there were 4 nos. of M14 bolts out of 8 bolts in two of the fan blades (Blade nos. 9 &10) were broken. LJV continued to found more bolts broken in Fan No. EVB-TVF-009B. A total of 17 nos. of M14 bolts were broken. All 64 nos. of bolts (including the 17 nos. broken bolts) were replaced by black bolts during night time.	LJV provided via email the latest investigation findings on the TVFs. Their findings revealed not only the fan blade bolts of Fan Nos. EVB-TVF-007 to 009 were broken but also the fan blade bolts of Fan No. EVB-TVF-006A were broken.
12 March 2019 (Tue)	RSS witnessed and LJV reported that they further found some cracked mounting bases of Fan Nos. EVB-TVF-007A (1 no.) and EVB-TVF-009B (2nos).	RSS emailed to LJV that since not only M14 bolts in the fan group of Fan Nos. EVB-TVF-007 to 009 fans were found broken but also two bolts M16 bolts used in fan group of Fan Nos. EVB-TVF-004 to 006 were broken, all the fan blade connection bolts in Zitron fans should be checked. A schedule of checking for monitoring was requested to be submitted by LJV. LJV responded that they were focusing on Fan Nos. EVB-TVF-004 to 009. RSS forwarded LJV latest investigation findings to

		HyD for information. HyD immediately responded and in view of numbers of fans with broken bolts and damaged fan blades, demanded RSS to instruct LJV to thoroughly check all the TVFs to ascertain the situation.
13 March 2019 (Wed)	RSS witnessed that LJV and Zitron senior technician replaced the damage fan blade on Fan No. EVB-TVF-007A from Fan No. EVB-TVF-009B. They also checked the pressure and vibration values of Fan Nos. EVB-TVF-008A&B. No exceedance of fan vibration alarm was found.	
14 March 2019 (Thu)	RSS witnessed that LJV and Zitron's senior technician carried out their tests in checking the EVB TVF pressures, starting currents and voltages under different fan operations in parallel and in selected sequence	RSS informed ET and IEC during the site safety and environmental meeting for Contract HY/2011/08 that the APS Efficiency Test began on 19 February 2019 but was temporarily suspended at the moment.
15 March 2019 (Fri)	LJV and Zitron's skilled technician visually inspected WVB fans and did not find any broken bolts.	A briefing session to HyD and RSS was conducted by LJV on the preliminary findings. In the meeting, LJV presented a summary of affected fans in EVBLJV reported that since there were no more spare parts for replacement of fan blades or bolts, they would order new bolts and fan blades from Zitron to replace all broken bolts and blades. LJV also reported that they have engaged Dr. Alex Chan to investigate the ventilation system.
19 March 2019 (Tue)		A meeting was held with HyD senior management, TD, GMT (EMSD) on the possible causes of the incident. RSS and LJV

		attended the meeting.
20 March 2019 (Wed)	LJV performed and RSS witnessed fan blade bolt torque checking to Fan Nos. WVB-TVF-002 and 003. RSS joined LJV and Dr. Alex Chan when they carried out dimensional measurements of the intake and discharge sides air plenums of Fan Nos. EVB-TVF-004 to 009	
22 March 2019 (Fri)		Meeting amongst HyD/AECOM/ EMSD in HyD office to brief HyD senior management on the preliminary findings and there were divergent views about the possible causes of the incidents. HyD was dissatisfied that the cause of the broken bolts had not been identified. HyD decided to appoint an independent expert Dr. Eric Lim from Safety, Accident & Failure Experts Ltd. (S.A.F.E.) to conduct independent investigation on the incident. HyD approached Dr. Lim on the same day.
25 March 2019 (Mon)		HyD had a meeting with Dr. Eric Lim at which he offered his preliminary view on the suspected cause of broken bolts. Dr Lim suspected that the reason of the failure of the mounting bolts was likely due to the problem in the assembly of the blades with the bolts at the fans. Further inspection and detailed investigation would be carried out.
26 March 2019 (Tue)		HyD informed EPD verbally of the incident.
27 March 2019 (Wed)		HyD pressed LJV to deliver the replacement of fan blades and bolts from Spain as soon as possible.
28 March 2019 (Thu)	HyD's independent expert Dr. Eric Lim visually inspected Fan Nos. MVB-TVF-012 and 013 at MVB, and Fan No. EVB-TVF-006 at EVB.	Interdepartmental meeting between HyD and EPD was held. HyD presented the details of the fans breakdown and remedial

	RSS handed over to Dr. Lim all bolts recovered from Fan Nos. EVB-TVF-006 to 009	actions taken / to be taken.
28 March 2019 (Thu)		As instructed by HyD, AECOM issued a letter to LJV urging to complete all necessary work to restore full functionality of the CWB Tunnel Ventilation System within a month of the letter date.
1 April 2019 (Mon)		RSS informed ET in writing and copied to IEC, and advised that due to EVB fan failure, the EVB APS could not operate and the requirement of zero portal emission at Eastern Portal of the CWB Tunnel could not be fulfilled since 28 February 2019.
2 April 2019 (Tue)	RSS witnessed LJV delivered 3 nos. of new fan blades and installed to Fan No. EVB-TVF-009B	ET and IEC received the letter from RSS dated 1 April 2019 by fax on 2 April 2019 at 11:27am and 11:45am respectively. ET recorded the incident as change of circumstances of Zero Portal Emission of Eastern Portal in ET Leader Logbook. IEC received ET's letter at 8:50pm by hand notifying the change of circumstances of zero portal emission of Eastern Portal. A meeting amongst HyD, ET, IEC, LJV and RSS was held at 7pm to discuss the way forward. LJV advised that the 1st batch of the replacement of bolt and blade was being delivered by flight and delivered to site on 2 April 2019. LJV also advised that all the replacements were expected to be arrived on site in mid-April 2019. It was expected that the replacement works could be completed by end of April 2019. HyD received a letter from EPD at 9:59pm regarding the incident and requested an investigation

		report. AECOM issued letter to instruct LJV to engage Hong Kong Productivity Council (HKPC) to examine the bolts taken from Fan Nos. EVB-TVF-004 to 009.
3 April 2019 (Wed)	RSS witnessed LJV and Zitron technician installed 5 pressure switches to the fan body of Fan Nos. EVB-TVF-004, 005, 007, 008 and 009 for investigation on any possible stalling circumstance.	IEC issued letter to EPD at 11:56am notifying that the Zero Portal Emission of Eastern Portal of the CWB Tunnel could not be properly achieved due to the failure of EVB TVFs.
4 April 2019 (Thu)	RSS witnessed LJV installed 6 nos. of pressure transmitters to the discharge side of Fan Nos. EVB-TVF-004 to 009 for investigation of the ventilation system. RSS witnessed and LJV performed fan pressure measurement using different fan operation sequences running up to any 5 out of 6 TVFs among Fan Nos. EVB-TVF-004 to 009.	Dr. Zhi NING of HKUST and his team were engaged to carry out air quality monitoring of NOx (NO & NO_2) to determine the air quality impact on appropriate ASRs near the tunnel portal and inside the east section of the tunnel
5 April 2019 (Fri)	LJV continued to check fan pressure measurement for Fan Nos. EVB-TVF-004 to 009 using different fan operation sequences running up to any 5 out of 6 TVFs.	AECOM and Dr. NING's team from HKUST set up 4 Mini Air Stations MAS-AF300 for the monitoring of NO_2 at 3 locations inside the east bound tunnel, the eastern portal and EVS of CWB and started NO_x monitoring at 2:20am and set up 1 Mini Air Station MAS-AF300 for the monitoring of NO_2 at the ASR Causeway Bay Community Centre and started NO_x monitoring at 9:30am
6 April 2019 (Sat)	LJV delivered the second batch of replacements comprising 47 nos of new fan blades with connection bolts to site in readiness for replacement starting from 8 April 2019. The third batch comprising 78 nos. of fan blades with connection bolts is scheduled to be delivered to site on 11 April 2019.	NO_x monitoring at the abovementioned 5 locations was continued.
7 April 2019 (Sun)		NO_x monitoring at the abovementioned 5 locations was continued.

C. Investigation and Review on the Possible Causes of Fan Blade Bolt Failures

i. Fans Bolts

(a) In order to assess the possibility of inferior bolt material as a contributing factor leading to the failure, the independent expert engaged by HyD had conducted laboratory examination on the fan bolts in question. The broken bolts were also sent to Zitron's factory for examination. The report from Zitron and laboratory results from the independent expert showed that the strength of all the bolts under tensile tests exceeded the requirements stipulated in the specification

(b) The bolts in place were up to the international standards and of sufficient strength. As-designed, the blades were held in place with four bolts which yielded a safety factor in excess of 3 as per the analysis given by the manufacturer. The bolts were found able to hold the blade in position even when only two bolts were left in place, and these bolts had remained intact even after the other two bolts had fractured.

ii. Workmanship in Assembly of Fan Blades

(a) The independent expert examined all fan blade-mounting bolts and revealed that the mode of failure of the fan blade-mounting bolts was metal fatigue. During installation of the fan blades, some undue bending stresses induced to the bolts, which were induced due to improper tightening sequence onto the fan hub, i.e., workmanship while the bolts were tightened. There was evidence that some bolts had been re-tightened before the fans were put into operation. The failed bolts under examination were found to be tightened with uneven torques, and this had further exaggerated the extent of bending stress induced on individual bolts.

(b) When the bolts under the bending stress as stated in the above paragraph (a) encountered some high magnitude cyclic stresses induced, which one might commonly encounter during the commissioning of the fans, as the fan(s) were being fine-tuned at that stage, fatigue crack was then initiated. These stresses were unlikely to have any significant effect in the absence of the bending stress as mentioned in the above paragraph (a).

(c) Once initiated, the fatigue cracks continued to propagate under very low amplitude cyclic load at the blade passage frequency of the running fans. The amplitude of the cyclic load that lead to fatigue crack propagation was very low, and the bolts with lower initial torque would be more susceptible to fatigue crack formation and propagation.

iii. Review on the Tunnel Ventilation System

(a) The independent expert and the Contractor carried out system tests on the fans in different operating sequences and combinations. It was revealed some pressure fluctuation and vibration of the fans during running. In view of magnitude and amplitude, the level of fluctuation and vibration would not normally lead to fatigue crack initiation but could accelerate the propagation of the fatigue cracks once fatigue cracks initiated due to the mentioned factors in the above Section ii.

(b) The independent expert concluded that the root cause of this premature failure was not due to pressure and vibration fluctuation of the fans during running.

iv. Conclusion

It was concluded that the reason of fan bolt failure is due to workmanship on tightening of the fan blade-mounting bolts. When such bolts under the bending stress due to improper tightening sequence encountered some high magnitude cyclic stresses induced, which one might commonly encounter during

the commissioning of the fans, as the fan(s) were being fine-tuned at that stage, fatigue crack was then initiated, thus leading to bolt broken.

D. Proposals on Monitoring and Assessment of Air Quality Impacts

i. Detailed air quality assessment under the worst-case meteorological scenarios during the TVF down-time

Air quality of the Air Sensitive Receivers (ASRs) near the EVB and Eastern Portal under the worst-case meteorological scenarios during APS downtime at EVB have been modeled and assessed.

(a) Evaluation Criteria

(1) The criteria for evaluating air quality impacts and the guidelines for air quality impact assessment are set out in Annex 4 and Annex 12 of the Technical Memorandum on Environmental Impact Assessment Process (EIAO-TM) under the Environmental Impact Assessment Ordinance (EIAO).

(2) The Air Pollution Control Ordinance (APCO) (Cap. 311) provides the statutory framework for controlling air pollutants from a variety of sources. The Hong Kong Air Quality Objectives (AQOs) stipulate the maximum allowable concentrations over specific periods for a number of criteria air pollutants. The relevant AQOs are listed in the table below:

Hong Kong Air Quality Objectives

Pollutants	Averaging Time	Concentration Limit (μg/m³) (1)	No. of Exceedances to be Allowed per Calendar Year
Sulphur Dioxide (SO_2)	10-min	500	3
	24-hour	125	3
Respirable Suspended Particulates (PM_{10} / RSP) (2)	24-hour	100	9
	1-year	50	Not applicable
Fine Suspended Particulates ($PM_{2.5}$ / FSP) (3)	24-hour	75	9
	1-year	35	Not applicable
Nitrogen Dioxide (NO_2)	1-hour	200	18
	1-year	40	Not applicable
Ozone (O_3)	8-hour	160	9
Carbon Monoxide (CO)	1-hour	30000	0
	8-hour	10000	0
Lead (Pb)	1-year	0.5	Not applicable

Notes:
(1) All measurements of the concentration of gaseous air pollutants, i.e. sulphur dioxide, nitrogen dioxide, ozone and carbon monoxide, are to be adjusted to a reference temperature of 293°K and a reference pressure of 101.325kPa.
(2) Respirable suspended particulates mean suspended particles in air with a nominal aerodynamic diameter of 10μm or less.
(3) Fine suspended particulates means suspended particles in air with a nominal aerodynamic diameter of 2.5μm or less.

(b) Review of the Current Situation from the Approved Environment Impact Assessment (EIA)

(1) The air quality assessment conducted in the approved EIA is based on the predicted traffic background in 2031. The morning peak hour traffic forecast for the concerned CWB tunnel in Year 2031 as adopted in the approved EIA is extracted and compared with the current actual hourly traffic flow from East Tunnel Portal to North Point in Year 2019.

(2) The comparison shows the current actual peak hourly traffic flow of 1423 vehicles is much smaller than the predicted morning peak hour traffic flow of 4187 vehicles in 2031 as adopted in the approved EIA.

(3) In addition to the traffic flows, the peak hourly emission rates calculated in this air quality impact assessment has been compared with that adopted in the approved EIA. The current peak hourly NOx and RSP emission rates from EVB prior to treatment of APS adopted are 0.288 g/s and 0.007 g/s, respectively, which are much lower than 2 g/s and 0.02258 g/s (where electrostatic precipitator system with dust removal efficiency of 80% taken into account) adopted in the approved EIA. To demonstrate the air quality in the current situation, an air quality impact assessment is conducted with the details presented below.

(c) Air Sensitive Receivers

(1) ASRs which are located within a distance of 500m from the Eastern Portal are selected from the representative ASRs covered in **Section 3.4** of the approved EIA Report.

(2) The selected representative ASRs are listed in following table and the corresponding locations are shown in **Figure 3.2** of the approved EIA Report and reproduced **below**.

Selected Representative ASRs

ASRs	Location	Existing / Planned Land Use	No. of floors	Horizontal Distance to East Portal (m)
A58	Mayson Garden	Residential	24	494
A59	Gordon House	Residential	15	456
A60	Belle House	Residential	24	393
A61	Citicorp Centre	Commercial	36	360
A62	Hoi Tao Building	Residential	30	287
A63	Victoria Centre	Residential	30	224
A64	Seaview Estate	Industrial/ Commercial	13	173
A65	Harbour Heights	Residential	44	133
A66	Whitfield Road Rest Garden	Recreation	0	392
A91	Harbour Grand Hong Kong	CDA(1)	45	67
A92	Harbour Glory	CDA	45	104
A93	City Garden (Block 11) (the height of 1st Sensitive Receiver is located at 5m above	Residential	27	175

ASRs	Location	Existing / Planned	No. of floors	Horizontal Distance
	ground)			
A94	City Garden (Block 6) (the height of 1st Sensitive Receiver is located at 5m above ground)	Residential	27	308
A95	Hong Kong Baptist Church Henrietta Secondary School	Educational	N/A	372
A96	Provident Centre (Block 1)	Residential	25	481

(d) Predicted Concentrations

(1) In order to evaluate the impact from the fans breakdown incident, a Normal Scenario and an Abnormal Scenario as listed below have been assessed at the representative ASRs identified in.

- Normal Scenario – The vehicular emission generated inside the east section of the east-bound CWB tunnel would all be emitted from the EVB with APS; and
- Abnormal Scenario – The vehicular emission generated inside the east section of the east-bound CWB tunnel would all be emitted from the East Portal without APS.

(2) Based on the assessment methodology presented in **Appendix 3.1 of Appendix 3**, the predicted cumulative 1-hr average NO_2 and daily average RSP concentrations under Normal and Abnormal Scenarios are tabulated in **Appendix 3.2 of Appendix 3**. The predicted 19th highest hourly NO_2 concentrations under Abnormal Scenario and Normal Scenario among the representative ASRs are 161 $\mu g/m^3$ and 158 $\mu g/m^3$ respectively, while the 10th highest daily RSP concentrations under Abnormal Scenario and Normal Scenario among the representative ASRs are both 81 $\mu g/m^3$. The predicted concentrations of NO_2 and RSP

at all selected representative ASRs would comply with the respective AQOs.

(3) Despite the small increase in the maximum of the predicted 19th highest hourly NO_2 concentration at the concerned ASRs due to the EVB APS fans breakdown, the predicted cumulative NO_2 and RSP concentrations at the concerned ASRs are still well below the respective AQO requirements (i.e. 200 $\mu g/m^3$ for hourly NO_2 and 100 $\mu g/m^3$ for daily RSP). Therefore, no adverse air quality impact would be anticipated by the current incident.

ii. Ambient air quality monitoring plan to check the air quality impact on appropriate ASRs near the tunnel portal

(a) On 4 April 2019, Dr. Zhi NING of HKUST and his team was engaged to carry out air quality monitoring of NOx (NO & NO_2) to determine the air quality impact on appropriate ASRs near the tunnel portal and inside the East section of the tunnel starting from 5 April 2019. The air quality monitoring of PM_{10} was added in the monitoring parameter at Causeway Bay Community Centre starting from 11 April 2019.

The monitoring works consists of the following tasks:

(b) Task 1 – Provision, calibration of monitoring equipment

(1) With the potential constraints in the available space and power supply in the sampling locations, the study team uses high performance Mini Air Station MAS-AF300 which has been validated with reference air monitoring method. The MAS can be mounted on walls or portably deployed for flexible arrangement of the air quality measurements.

(2) Calibration of the air stations will be conducted against HKEPD AQMS for quality control and quality assurance. The mini air monitoring stations and portable air monitoring stations have unit dimension of less than 60 cm × 40 cm × 25 cm (height × width ×

depth) excluding inlet and footing. The following air pollutants are included, i.e. NO, NO_2, PM_{10} with highest time resolution at 1-minute.

(3) The Mini Air Station used for the AQMP is calibrated and validated against traceable standards. There are three tiers of quality assurance and quality control for the gas pollutant measurements:

(i) NO and NO_2 measurements:

- Prior to the deployment of 5 units of MAS at Site1-5, each has been conducted a thorough performance check with calibration against the traceable standards for NO and NO2, separately, with zero air and 1ppm span gas assessment. The records are shown in Appendix 6. The results showed <5% error.

- Cross collocation with AQMS data. All MAS units deployed at Site1-5 on NOx measurement had been conducted with the validation test at HKEPD Tsuen Wan AQMS with collocation assessment. See Appendix 6. The tests showed hourly regression coefficients > 0.90 for NO and NO2 gases, independent of the ambient variation in temperature and humidity.

- During on-site deployment, there are periodic autos or manual zeroing checks for the MAS units to minimize the baseline drift. For deployment longer than 3 months according to the sensor supplier's instruction, a span check or collocation with transfer standards will be conducted to ensure the sensitivity consistency.

(ii) PM calibration record:

- Prior to the deployment of the MAS to Site 4 for PM10 measurement, the unit was calibrated and parameterized at HKEPD Mong Kok AQMS site to ensure the sensitivity consistency. The record is shown in Appendix 6.

- There are also periodic zero checks for the MAS PM monitoring embedded in the module to minimize the baseline drift. All reported data have been drifting corrected.

(iii) With the regard of future QA/QC plan:

- To ensure data accuracy for a long-term operation, Mini Air Station will be zeroed on a weekly basis to correct for the baseline, if any.

- For longer term operation above 3 months, the QAQC will include field collocation with transfer standards or span checks.

Calibration results are attached in **Appendix 4** for reference.

(4) To facilitate the fast monitoring status checking and data verification, the air stations provide wireless data transmission capabilities via 4G network with cloud-based data platform for data storage and visualization and SD card for raw data storage.

(c) Task 2 – Measurements and maintenance of air monitoring equipment

The monitors were installed inside and outside the CWB Eastbound Tunnel (Site 1 to Site 3) and East Ventilation Shaft (site 5), monitoring NOx pollutants, with another monitoring location at Causeway Bay Community Centre (Site 4), recording NO, NO_2 and together with PM_{10} concentration and respectively (see **Appendix 4**).

(d) Task 3 – Data analysis and interpretation

The multiple point air quality monitoring data inside and outside of the tunnel will be analyzed in terms of diurnal variations, spatial distributions in order to assess the air quality impact on appropriate ASRs near the tunnel portal.

Tentative Schedule for the Monitoring Works

	Action Items	Target Completion Date
1	Provision, calibration of air monitoring equipment	4 April 2019 (Actual)
2	Measurements and maintenance of air	5 April 2019 (Actual) until 2 weeks after the resumption of

	monitoring equipment	the TVFs and APS in EVB.
3	Data analysis and interpretation	Interim reports will be issued at regular intervals, and a final report will be issued after the completion of the measurement.

A set of preliminary monitoring results taken on 5 to 7 April 2019, together with data analysis and interpretation are enclosed in **Appendix 4**.

(e) In summary,

(1) 5-minute NO_2 concentrations inside the CWB Tunnel (Sites 1, 2 and 3) are below the 5-min concentration limit as required in the Practice Note on Control of Air Pollution in Vehicle Tunnels.

(2) NO_2 concentration measured at Site 4 (Causeway Bay Community Centre, nearby ASR) is within the HKAQO 1-hour NO_2 concentration limit since the start of air quality monitoring. The measured 1-hour NO_2 concentration was in the range 30-180 $\mu g/m^3$ which is lower than the limit of 200 $\mu g/m^3$.

(3) EVS (Site 5) had NO_2 levels comparable to general ambient Air Quality Monitoring Stations in Central Western and Eastern.

iii. Action plan in case of exceedance of air quality at the nearby ASRs

(a) In the event of exceedance of HKAQO 1-hour average concentration of NO_2 at Site 4 (Causeway Bay Community Centre, nearby ASR) and at the same time exceeding the measured level at Causeway Bay road side air quality monitoring station, it is suggested to resume operation of Fan Nos. TVFs EVB-TVF-004 to 009 (already fitted with temporary black bolt) through the APS for discharge to the EVS subject to two conditions of (1) measured NO_2 level at ASR (Site 4) exceeds the AQO(200 $\mu g/m^3$) and (2) NO_2 level measured at the Causeway Bay Roadside

monitoring station does not exceed the AQO. Under this situation, the air quality in the vicinity of Causeway Bay might be affected by the tunnel exhaust from tunnel portal. The condition of the fans will be closely monitored to ensure their safe operation before the permanent repair/replacement works are completed. Such arrangement on the one hand would tackle the issue of exceedance of air quality at the nearby ASRs and on the other hand would allow LJV to replace the fan blades and temporary black bolts* to achieve permanent installation status.

*Temporary black bolt is the same as the original bolt class 10.9 but without surface protection.

(b) Due to time lag in obtaining measured levels at Causeway Bay road side air quality monitoring station, it may take time to trigger this action plan.

iv. Action plan/mitigation measures to ensure the in-tunnel air quality fulfilling the limit as specified in EDP's Practice Note on Control of Air Pollution in Vehicle Tunnels before resumption of TVF/APS operation at EVB

(a) The current in-tunnel air quality is well within limits in EPD's Practice Note on the Control of Air Pollution in Vehicle Tunnels. If the in-tunnel air quality deteriorate to 80% of the limit in the EPD's Practice Note, in-tunnel ventilation system will be turned on automatically until the in-tunnel air quality is improved to be lower than 40% of the limit in EPD's Practice Note on the Control of Air Pollution in Vehicle Tunnels.

(b) The in-tunnel air monitoring is conducted continuously to give a 5-min average value. The ventilation fans (MVB-TVF-009 for CH1480 – CH2885) and (MVB-TVF-004 for CH2885 – CH3770)

will be activated automatically when the in-tunnel air quality reach the action level (80% of the limits) to improve the air quality in East bound. In case of persistence of exceedance of action levels or limit levels, the ventilation level will go up automatically (MVB-TVF-005 for CH2885 – CH3770) until the air quality is below the pre-set value.

(c) Currently under the AQMP, there is no specified mechanism for actions against such occurrence of in-tunnel air quality exceedance.

E. Action Plan/Mitigation Measures

i. Reporting of the Incident

In the AQMP, there is a provision of Contingency Plan (Clause 3.2) which caters for emergency situations, such as an accidental breakdown of individual component causing malfunction of the TVFs and APS. The incident had been handled in accordance with the flowchart of "Component Breakdown" in the contingency plan (**Appendix 2**). TD, HyD, ET, IEC and AECOM had been notified (refer to Section B chronology for details) and upon the notification by ET of the incident on 2 April 2019, IEC notified the DEP under Condition 2.2 of EP-482/2013/A on 3 April 2019. HyD, AECOM, LJV, Zitron and Filtrontec were investigating the cause of the incident.

ii. Tunnel Air Quality

With respect to tunnel air quality during EVB fans breakdown from 1 March to 28 May 2019, it is observed from air quality records that the in-tunnel air quality was still within the EPD guidelines.

From 1 March to 28 May 2019, the in-tunnel air quality as below:

	Maximum limit as stated in the Practice Note#	Eastbound	Westbound
CO	<100ppm	0.12ppm to 43.43ppm	0.27ppm to 22.80ppm
NO_2	<1ppm	0.0010ppm to 0.43ppm	0.0010ppm to 0.20ppm

Practice Note on Control of Air Pollution in Vehicle Tunnels issued by Air Services Group of Environmental Protection Department in Nov 1995.

iii. Complete temporary retrofitting of TVF as soon as practicable

After carrying temporary retrofitting of the concerned fans and relevant on-site tests on the fans, LJV/Zitron confirmed on 3 April 2019 that the concerned fans were "suitable for running". AECOM had reviewed LJV/Zitron's proposal and agreed to adopt this interim arrangement. As such, the full operation of the EVB TVS and APS could be resumed on a temporary basis as necessary. The performance of the fans will be closely monitored to ensure their integrity and hence safety before the permanent repair/replacement works were completed.

F. Action Taken and The Way Forward

i. Completion of Rectification of TVF Problem and Resumption of normal operation of APS and TVS

LJV/Zitron commenced on 8 April 2019 necessary permanent replacement of the concerned fans parts for full resumption of operation of the EVB TVS and APS. Furthermore, LJV had ordered replacement bolts for all the remaining fans. Replacement parts had been delivered to site in batches since 2 April 2019 Replacement of the concerned blades including tests was completed by end April 2019. Normal operation of the TVS and APS was resumed on 2 May 2019.

ii. Investigation on the Ventilation Fan System

Under the instruction of HyD and AECOM, LJV had already conducted the investigation & measure on the vibration, pressure, stalling (if any), flow, loading/current, fan and damper operating sequence under automatic operation on start/stop, level up and level down for ventilation levels 0, 1, 2, 3, 4 & 5. The investigation confirmed that no undesirable conditions exist.

iii. Issue of Investigation Report

The independent expert had carried out thorough examination to ascertain the cause of fan bolt failure and findings were provided under Section C.

iv. Step-up measures taken/to be taken to prevent recurrence of failure of TVS

(a) Fan stalling detection device are installed to prevent the TVFs from stalling;
(b) Damper status signal is modified to ensure the air path is unobstructed; and

(c) To ensure the fan blade bolts are installed properly in future, the fan blade bolt installation procedure including torque sequence and the required tightening torque shall be included in the O&M manual.

v. Contingency Plan and Remedial Actions in case TVS encounters malfunction/breakdown

1 set of bolts for the concerned TVFs fan blade will be procured and kept in stock in case the TVFs encounter the same mal-function/break down so that the TVFs can be repaired and put back in service in short period of time.

vi. Further step-up measures in respect to EP-482/2013/A

(a) In view of the late notification of the incident to EPD, HyD will liaise with MOm to enhance the communication and reporting mechanism as stated in EP-482/2013/A, the associated EM&A Manuals (AEIAR-041/2001 and AEIAR-125/2008), the updated EM&A Manual submitted under C2.5 of EP-364/2009, Air Quality Management Plan (AQMP) submitted under Condition 2.9 of the EP-482/2013/A and other relevant documents which include:

(1) Mechanism for communication and reporting of operation data, including but not limited to air quality exceedance as stipulated under Condition 2.6(d), in-tunnel monitoring results in accordance with EPD's Practice Note on Control of Air Pollution in Vehicle Tunnels and other air quality monitoring results for evaluation of the compliance in operation and maintenance of the ventilation system of the Eastern Portal of the CWB Tunnel to satisfy zero portal emission requirement as set out under Condition 2.6(e) of EP-482/2013/A shall be established.

(2) Detailed setting out for tunnel management to provide continuous tunnel monitoring results to relevant parties as per Section 2.11.7 to Section 2.11.9 of the updated EM&A manual submitted under C.2.5 of the EP-364/2009 shall be established. The tunnel operator shall seek agreement from EPD or other regulatory authority on the action required in case of severe in-tunnel air pollution.

(3) Detailed setting out for the operator of the CWB tunnel to conduct air quality monitoring as per Section 2.12.1 of the updated EM&A Manual (Dec 2010) (AEIAR-125/2008) shall be established. HyD will arrange further discussion with EPD to come up with an agreeable action plan on in tunnel air quality monitoring.

(b) The criteria on non-compliance of zero portal emission will be established and discussed with EPD in accordance with the section 2.4.18 of the EIA report AEIAR-125/2008).

(c) The AQMP and its contingency plan will be reviewed and discussed with EPD for updating.

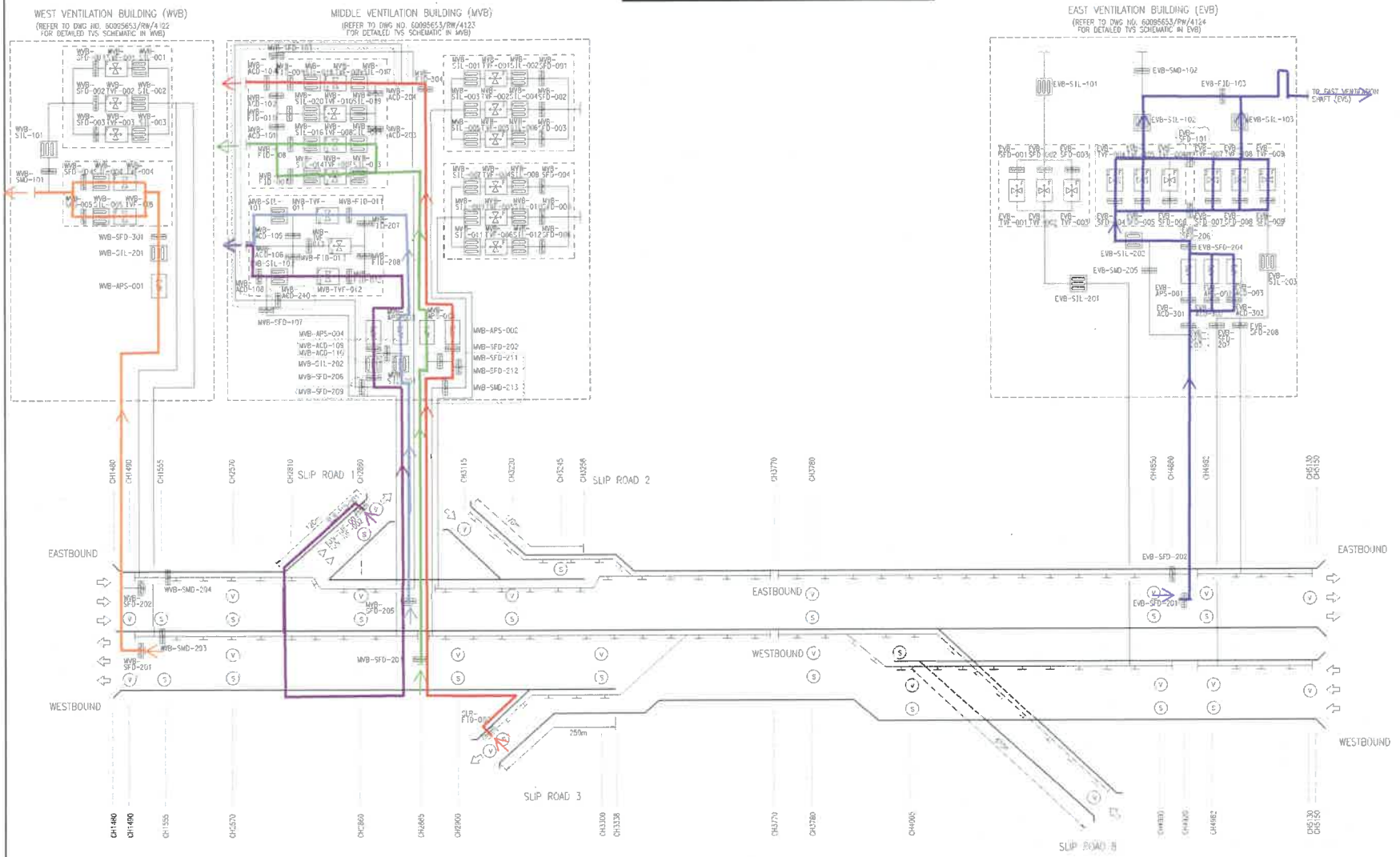
(d) Any other related matters identified later on during the discussion with HyD, EPD and relevant departments.

Appendices

Appendix 1

Schematic Diagram of Tunnel Ventilation System (TVS) and APS

Uni-Directional



NOTES:

EXTRACTED FROM WORKING DRAWING No. 60095653/RW/4121

-	ISSUED FOR CONSTRUCTION	KYH	CKC	KHL
No.	Date	Description	By	Checked	Approved

AECOM

CENTRAL - WAN CHAI BYPASS -
CONTRACT NO. HY/2011/08
TUNNEL BUILDINGS, SYSTEMS AND FITTINGS, AND WORKS ASSOCIATED WITH TUNNEL COMMISSIONING

TITLE:
TUNNEL VENTILATION SYSTEM
OVERALL TVS SCHEMATIC

SKETCH NO. 60095653/RW/SK1094 | SCALE N.T.S.

T:\HY_2011_08\SK\SK1094_4121.dgn 21/02/2018 10:34:50

Appendix 2

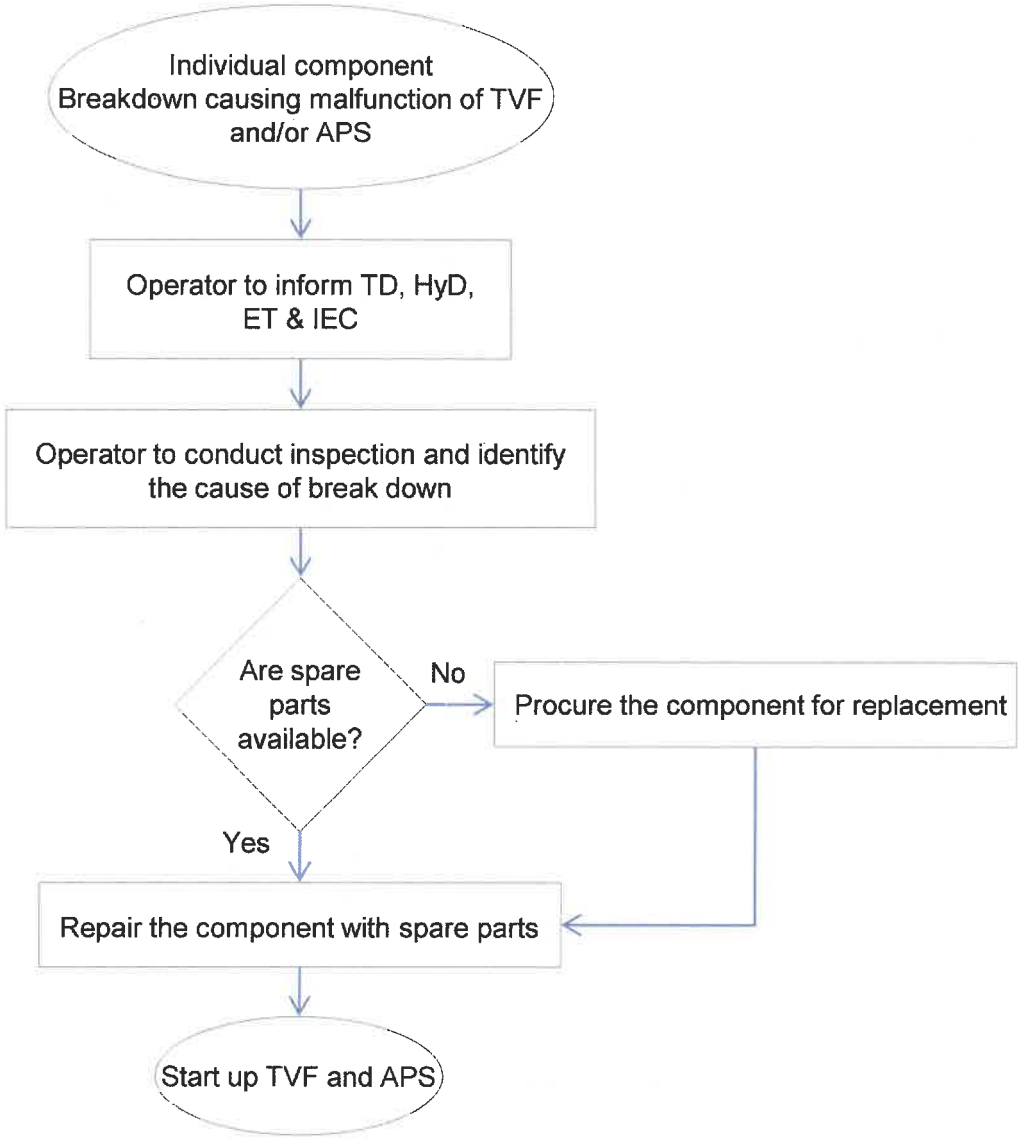
Procedure Flowchart of AQMP Contingency Plan

When there is an accidental breakdown of individual component causing malfunction of TVFs and/or APS, the Operator will follow the procedures below to start up TVFs and APS as soon as practicable.

1. Operator to inform TD, HyD, ET and IEC;
2. Operator to conduct inspection and identify the root cause of the breakdown;
3. Operator to check if there is any spare part available for repair;
4. If there are spare parts available, Operator to repair the broke down component with spare parts;
5. If there is no spare part available, Operator to procure the broke down component for replacement;
6. Operator to start up the APS according to the APS Operational Procedures after finishing repair/replace the broke down component.

The emergency flowchart for individual component breakdown is attached below.

Component Breakdown



Appendix 3

Model Assessment

Appendix 3.1 – Assessment Methodology

1 ASSESSMENT METHODOLOGY

Assessment Scenarios

1.1.1 In order to evaluate the impact from the fans breakdown incident, a Normal Scenario and an Abnormal Scenario as listed below have been assessed at the representative ASRs identified in.

- Normal Scenario – The vehicular emission generated inside the east section of the east-bound CWB tunnel would all be emitted from the EVB with APS; and
- Abnormal Scenario – The vehicular emission generated inside the east section of the east-bound CWB tunnel would all be emitted from the East Portal without APS.

EMFAC-HK Model

1.1.2 EMFAC-HK model (Version 4.1) provided by EPD is adopted to determine the vehicle emission factors of NOx (i.e. initial NO + initial NO_2) and RSP for the road traffic emissions simulated in the AERMOD model.

1.1.3 The actual hourly traffic flow from East Tunnel Portal to North Point and the vehicular type and fuel type breakdown are recorded and used in the model assessment, and are presented in **Annex 1**. The Daily Trips are zero inside the tunnel. Diurnal Variation of Daily Vehicle-Kilometer-Travelled (VKT) is calculated based on the traffic flow and the distance of the total tunnel length served by EVB. As no traffic congestion is observed inside the CWB tunnel, Speed Fraction is assumed to be 100% travelling at 80kph as the design speed limit. Modelling year of 2019 and Burden Mode have been adopted in the EMFAC-HK model. The calculated 24-hour NOx, initial NO, initial NO_2 and RSP emission factors of 16 vehicle classes are adopted in this air quality impact assessment, and are presented in **Annex 2**.

AERMOD Model

1.1.4 The emissions from EVB and Eastern Portal have been modelled by AERMOD model.

1.1.5 The emissions (initial NO, initial NO_2 and RSP) are calculated based on the 24-hour vehicle emission factors predicted by EMFAC-HK model and vehicle flows are presented in **Annex 3**. The locations of ventilation building and portal emission sources are also presented in **Annex 3**. For the design parameters of EVB, reference is made to the approved EIA Report (Register No. AEIAR-125/2008).

1.1.6 Portal emissions are modelled in accordance with the Permanent International Association of Road Congress Report (PIARC, 1991). Pollutants are assumed to eject from the tunnel portal as a portal jet such that 2/3 of the total emissions are dispersed within the first 50m of the portal and 1/3 of the total emissions within the second 50m.

1.1.7 Grid-specific composite meteorological data extracted from the EPD's PATH-2016 model is adopted in AERMOD model, including relevant temperature, wind speed, wind direction, etc. The mixing height is capped between 121 metres and 1667 metres according to the observation in Year 2010 by HKO. Surface roughness is separated into 12 zones with heights corresponding to the land use characteristics. The emission sources are considered as urban in the AERMOD model.

CALINE4 Model

1.1.8 Road traffic emissions from open roads have been assessed with CALINE4 model for cumulative assessment. The predicted peak hour traffic flows and vehicle mixes for the road networks are made reference to the Appendix 3.2 of the approved EIA Report

1.1.9 The dispersion modelling is conducted based on the meteorological data extracted from relevant grid cells of the Pollutants in the Atmosphere and the Transport over Hong Kong 2016 Version (PATH-2016) model.

Ozone Limiting Method

1.1.10 Ozone Limiting Method (OLM) is adopted for conversion of NOx and NO to NO_2 based on the predicted O_3 level from PATH-2016. The NO_2/NOx conversion is calculated as follows:

$$[NO_2]_{pred} = [NO_2]_{initial} + MIN \{[NO]_{initial} + [NOx]_{initial}, \text{ or } (46/48) \times [O_3]_{bkgd}\}$$

where

$[NO_2]_{pred}$	is the predicted NO_2 concentration
$[NO_2]_{initial}$	is the predicted initial NO_2 concentration from portals or ventilation building
$[NO]_{initial}$	is the predicted initial NO concentration from portals or ventilation building
$[NOx]_{initial}$	is the predicted initial NOx concentration from open roads
MIN	means the minimum of the two values within the brackets
$[O_3]_{bkgd}$	is the representative O_3 background concentration
(46/48)	is the molecular weight of NO_2 divided by the molecular weight of O_3

PATH-2016 Model

1.1.11 PATH-2016 model released by EPD in January 2016 is used to quantify the background air quality in the cumulative assessment. The emission sources including those in Pearl River Delta Economic Zone, roads, marine, airport, power plants and industries within Hong Kong are all considered in the PATH-2016 model.

Cumulative Concentration Calculation

1.1.12 The PATH-2016 model output is added to the sum of the CALINE4 and AERMOD model results sequentially on an hour-to-hour basis to derive the cumulative impacts at the representative ASRs.

1.1.13 With reference to the EPD's *Guidelines on Choice of Models and Model Parameters*, PATH-2016's output of RSP concentrations are adjusted as follows:

- 10th highest daily RSP concentration: add 26.5 $\mu g/m^3$

Annex 1 – Actual Traffic Flow Data for AERMOD Model

Central-Wan Chai Bypass Tunnel (Eastbound)
Road Type: Post Speed 80 kph
Year: 2019

		PC	PC	Taxi	LGV3	LGV3	LGV4	LGV4	LGV6	HGV7	HGV8	PLB	PLB	PV4	PV4	PV5	PV5	PV5	NFB6	NFB7	NFB8	FBSD	FBDD	MC
Hour	To North Point from East Tunne Portal	Petrol	Diesel	LPG	Petrol	Diesel	Petrol	Diesel	Diesel	Diesel	Diesel	Diesel	LPG	Petrol	Diesel	Petrol	Diesel	LPG	Diesel	Diesel	Diesel	Diesel	Diesel	Petrol
00:00-01:00	227	142	2	56	0	0	0	10	4	1	3	0	0	0	0	0	1	0	1	0	1	0	1	5
01:00-02:00	132	82	1	33	0	0	0	6	2	1	2	0	0	0	0	0	0	0	0	0	0	0	1	3
02:00-03:00	87	54	1	21	0	0	0	4	2	0	1	0	0	0	0	0	0	0	0	0	0	0	1	2
03:00-04:00	62	39	1	15	0	0	0	3	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
04:00-05:00	62	39	1	15	0	0	0	3	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
05:00-06:00	86	55	1	22	0	0	0	4	2	0	1	0	0	0	0	0	0	0	0	0	0	0	1	2
06:00-07:00	233	146	2	58	0	0	0	10	4	1	3	0	0	0	0	0	1	0	1	0	1	0	1	5
07:00-08:00	699	352	5	184	0	1	2	57	23	4	11	0	0	1	0	0	5	2	5	4	7	1	13	21
08:00-09:00	1493	753	10	394	0	1	4	122	50	9	25	0	0	2	1	0	10	5	11	8	14	2	29	44
09:00-10:00	1531	664	9	456	0	2	5	152	62	20	53	0	0	1	1	0	8	4	9	6	11	2	34	33
10:00-11:00	1228	467	6	346	0	2	6	192	78	18	47	0	0	1	0	0	5	2	5	4	6	1	14	26
11:00-12:00	1148	518	7	299	0	1	5	143	58	16	43	0	0	1	0	0	4	2	4	3	5	1	11	27
12:00-13:00	915	399	5	232	0	1	4	121	49	16	41	0	0	1	0	0	5	2	6	4	7	0	2	21
13:00-14:00	866	397	5	225	0	1	3	104	42	10	27	0	0	1	0	0	6	3	7	5	8	0	5	16
14:00-15:00	954	452	6	238	0	1	4	116	47	12	31	0	0	1	0	0	4	2	4	3	6	0	4	22
15:00-16:00	1171	568	8	266	0	1	5	145	59	15	38	0	0	1	1	0	8	4	9	6	11	0	2	24
16:00-17:00	1144	561	8	263	0	1	5	140	57	8	21	0	0	1	1	0	9	4	10	7	12	0	1	33
17:00-18:00	1196	672	9	241	0	1	3	94	38	7	19	0	0	2	1	0	11	5	12	8	14	0	0	59
18:00-19:00	1137	691	9	232	0	1	2	68	28	5	14	0	0	1	0	0	4	2	4	3	5	0	6	61
19:00-20:00	1099	687	9	271	0	0	2	47	19	5	12	0	0	0	0	0	3	1	3	2	4	0	6	26
20:00-21:00	695	434	6	172	0	0	1	30	12	3	8	0	0	0	0	0	2	1	2	1	2	0	4	16
21:00-22:00	497	311	4	123	0	0	1	21	9	2	6	0	0	0	0	0	1	1	1	1	2	0	3	12
22:00-23:00	531	332	5	131	0	0	1	23	9	2	6	0	0	0	0	0	1	1	1	1	2	0	3	13
23:00-24:00	366	229	3	90	0	0	1	16	6	2	4	0	0	0	0	0	1	0	1	1	1	0	2	9
Total	17561	9044	123	4384	2	16	55	1627	663	159	416	0	0	14	7	0	89	40	97	67	120	8	145	484

Annex 2 – Summary of 24-hour Vehicular Emission Factors of 16 Vehicle Classes for AERMOD Model

Central-Wan Chai Bypass - 80kph

Emission Factor (gm/mile/vehicle) - NO_x

Hour	16 - Motorcycles (MC)	01 - Private Cars (PC)	02 - Taxi	11 - Non-franchised Bus<=6.4t	12 - Non-franchised Bus 6.4-15t	13 - Non-franchised Bus >15t	09 - Private Light Bus <=3.5t	10 - Private Light Bus >3.5t	03 - Light Goods Vehicles<=2.5t	04 - Lt Goods Vehicles 2.5-3.5t	05 - Light Goods Vehicles>3.5t	06 - Heavy Goods Vehicles<=15t	07 - Heavy Goods Vehicles >15t	14 - Franchised Bus (SD)	15 - Franchised Bus (DD)	08 - Public Light Buses
0:00 - 1:00	0.02169	0.00324	0.01298	0.63528	1.20440	0.49861	0.05224	0.26809	0.14492	0.11842	0.51676	0.80749	0.40240	0.42021	0.66706	0.00000
1:00 - 2:00	0.02174	0.00324	0.01301	0.63570	1.20521	0.49895	0.05225	0.26821	0.14525	0.11850	0.51711	0.80813	0.40257	0.42049	0.66751	0.00000
2:00 - 3:00	0.02180	0.00325	0.01304	0.63634	1.20642	0.49944	0.05251	0.26835	0.14559	0.11859	0.51762	0.80906	0.40307	0.42091	0.66817	0.00000
3:00 - 4:00	0.02188	0.00326	0.01308	0.63731	1.20825	0.50020	0.05357	0.26920	0.14527	0.11877	0.51841	0.81043	0.40369	0.42155	0.66919	0.00000
4:00 - 5:00	0.02195	0.00327	0.01312	0.63823	1.21001	0.50093	0.05368	0.26967	0.14549	0.11892	0.51917	0.81174	0.40428	0.42217	0.67016	0.00000
5:00 - 6:00	0.02204	0.00328	0.01317	0.63929	1.21201	0.50176	0.05285	0.27013	0.14611	0.11909	0.52002	0.81322	0.40494	0.42286	0.67127	0.00000
6:00 - 7:00	0.02208	0.00329	0.01320	0.63991	1.21319	0.50225	0.05259	0.27042	0.14582	0.11918	0.52053	0.81408	0.40534	0.42328	0.67193	0.00000
7:00 - 8:00	0.02207	0.00329	0.01320	0.63997	1.21330	0.50230	0.05283	0.27048	0.14603	0.11919	0.52058	0.81409	0.40537	0.42331	0.67199	0.00000
8:00 - 9:00	0.02208	0.00329	0.01322	0.64083	1.21493	0.50297	0.05286	0.27082	0.14627	0.11933	0.52128	0.81511	0.40592	0.42388	0.67289	0.00000
9:00 - 10:00	0.02198	0.00328	0.01318	0.64018	1.21370	0.50246	0.05275	0.27041	0.14607	0.11922	0.52075	0.81403	0.40551	0.42345	0.67221	0.00000
10:00 - 11:00	0.02181	0.00327	0.01312	0.63879	1.21106	0.50137	0.05256	0.26963	0.14575	0.11899	0.51962	0.81189	0.40463	0.42253	0.67075	0.00000
11:00 - 12:00	0.02172	0.00326	0.01308	0.63800	1.20957	0.50075	0.05241	0.26916	0.14559	0.11886	0.51897	0.81066	0.40413	0.42201	0.66992	0.00000
12:00 - 13:00	0.02164	0.00325	0.01304	0.63722	1.20809	0.50014	0.05232	0.26876	0.14540	0.11874	0.51834	0.80951	0.40363	0.42150	0.66910	0.00000
13:00 - 14:00	0.02159	0.00325	0.01302	0.63663	1.20697	0.49967	0.05227	0.26845	0.14527	0.11864	0.51786	0.80868	0.40326	0.42111	0.66848	0.00000
14:00 - 15:00	0.02153	0.00324	0.01299	0.63577	1.20534	0.49900	0.05220	0.26803	0.14506	0.11850	0.51716	0.80751	0.40271	0.42054	0.66758	0.00000
15:00 - 16:00	0.02151	0.00323	0.01297	0.63519	1.20425	0.49855	0.05212	0.26777	0.14492	0.11841	0.51669	0.80676	0.40235	0.42016	0.66697	0.00000
16:00 - 17:00	0.02152	0.00323	0.01297	0.63509	1.20406	0.49847	0.05213	0.26775	0.14489	0.11839	0.51661	0.80670	0.40229	0.42009	0.66687	0.00000
17:00 - 18:00	0.02155	0.00323	0.01296	0.63507	1.20402	0.49845	0.05216	0.26781	0.14487	0.11839	0.51659	0.80679	0.40227	0.00000	0.00000	0.00000
18:00 - 19:00	0.02156	0.00323	0.01295	0.63480	1.20350	0.49824	0.05217	0.26772	0.14484	0.11835	0.51637	0.80652	0.40210	0.41990	0.66656	0.00000
19:00 - 20:00	0.02154	0.00322	0.01292	0.63414	1.20226	0.49772	0.05211	0.26743	0.14469	0.11824	0.51564	0.80568	0.40169	0.41946	0.66587	0.00000
20:00 - 21:00	0.02153	0.00322	0.01291	0.63384	1.20169	0.49749	0.05203	0.26730	0.14460	0.11819	0.51559	0.80532	0.40149	0.41926	0.66555	0.00000
21:00 - 22:00	0.02155	0.00322	0.01292	0.63393	1.20186	0.49756	0.05221	0.26736	0.14465	0.11821	0.51567	0.80549	0.40155	0.41932	0.66565	0.00000
22:00 - 23:00	0.02158	0.00322	0.01293	0.63411	1.20219	0.49770	0.05212	0.26743	0.14462	0.11824	0.51581	0.80577	0.40166	0.41944	0.66583	0.00000
23:00 - 0:00	0.02161	0.00323	0.01294	0.63447	1.20288	0.49798	0.05224	0.26762	0.14467	0.11839	0.51611	0.80631	0.40189	0.41968	0.66621	0.00000
daily	0.02169	0.00325	0.01305	0.63702	1.20771	0.49996	0.05238	0.26878	0.14537	0.11872	0.51827	0.80979	0.40365	0.42234	0.67045	0.00000

Emission Factor (gm/mile/vehicle) - NO

Hour	16 - Motorcycles (MC)	01 - Private Cars (PC)	02 - Taxi	11 - Non-franchised Bus<=6.4t	12 - Non-franchised Bus 6.4-15t	13 - Non-franchised Bus >15t	09 - Private Light Bus <=3.5t	10 - Private Light Bus >3.5t	03 - Light Goods Vehicles<=2.5t	04 - Lt Goods Vehicles 2.5-3.5t	05 - Light Goods Vehicles>3.5	06 - Heavy Goods Vehicles<=15t	07 - Heavy Goods Vehicles >15t	14 - Franchised Bus (SD)	15 - Franchised Bus (DD)	08 - Public Light Buses
0:00 - 1:00	0.41407	0.05917	0.70565	1.72428	3.48639	5.74514	0.34425	0.87215	1.60461	1.31288	1.60944	2.19058	3.64012	4.46192	4.61354	0.00000
1:00 - 2:00	0.41496	0.05928	0.70707	1.72544	3.48873	5.74901	0.34429	0.87254	1.60828	1.31368	1.61052	2.19232	3.64257	4.46492	4.61665	0.00000
2:00 - 3:00	0.41607	0.05941	0.70856	1.72717	3.49222	5.75475	0.34597	0.87300	1.61203	1.31473	1.61213	2.19482	3.64621	4.46939	4.62126	0.00000
3:00 - 4:00	0.41760	0.05960	0.71089	1.72979	3.49753	5.76351	0.35297	0.87575	1.60844	1.31673	1.61459	2.19854	3.65176	4.47618	4.62829	0.00000
4:00 - 5:00	0.41906	0.05979	0.71331	1.73231	3.50262	5.77190	0.35369	0.87728	1.61090	1.31841	1.61694	2.20210	3.65707	4.48270	4.63503	0.00000
5:00 - 6:00	0.42066	0.05999	0.71581	1.73517	3.50840	5.78142	0.34823	0.87880	1.61774	1.32023	1.61960	2.20611	3.66310	4.49010	4.64268	0.00000
6:00 - 7:00	0.42153	0.06013	0.71751	1.73686	3.51183	5.78706	0.34652	0.87974	1.61459	1.32131	1.62118	2.20846	3.66668	4.49448	4.64721	0.00000
7:00 - 8:00	0.42122	0.06014	0.71755	1.73702	3.51215	5.78760	0.34809	0.87992	1.61683	1.32138	1.62133	2.20848	3.66702	4.49489	4.64763	0.00000
8:00 - 9:00	0.42144	0.06023	0.71865	1.73935	3.51685	5.79535	0.34832	0.88104	1.61951	1.32290	1.62350	2.21123	3.67193	4.50091	4.65386	0.00000
9:00 - 10:00	0.41947	0.06004	0.71624	1.73760	3.51331	5.78951	0.34760	0.87969	1.61728	1.32172	1.62187	2.20830	3.66823	4.49638	4.64917	0.00000
10:00 - 11:00	0.41640	0.05978	0.71297	1.73382	3.50566	5.77691	0.34633	0.87715	1.61371	1.31919	1.61834	2.20252	3.66024	4.48659	4.63905	0.00000
11:00 - 12:00	0.41454	0.05962	0.71105	1.73167	3.50133	5.76977	0.34533	0.87565	1.61204	1.31775	1.61634	2.19918	3.65572	4.48105	4.63332	0.00000
12:00 - 13:00	0.41301	0.05945	0.70882	1.72956	3.49706	5.76273	0.34476	0.87432	1.60992	1.31634	1.61437	2.19604	3.65126	4.47558	4.62766	0.00000
13:00 - 14:00	0.41213	0.05936	0.70785	1.72796	3.49382	5.75740	0.34441	0.87332	1.60845	1.31529	1.61287	2.19380	3.64788	4.47144	4.62338	0.00000
14:00 - 15:00	0.41103	0.05920	0.70585	1.72562	3.48909	5.74960	0.34394	0.87196	1.60611	1.31373	1.61069	2.19062	3.64294	4.46539	4.61712	0.00000
15:00 - 16:00	0.41050	0.05913	0.70499	1.72406	3.48594	5.74440	0.34344	0.87111	1.60456	1.31271	1.60923	2.18859	3.63965	4.46135	4.61295	0.00000
16:00 - 17:00	0.41077	0.05911	0.70474	1.72379	3.48539	5.74351	0.34352	0.87105	1.60419	1.31253	1.60898	2.18842	3.63908	4.46065	4.61223	0.00000
17:00 - 18:00	0.41141	0.05908	0.70444	1.72373	3.48527	5.74330	0.34373	0.87123	1.60402	1.31250	1.60892	2.18866	3.63895	0.00000	0.00000	0.00000
18:00 - 19:00	0.41162	0.05903	0.70380	1.72300	3.48379	5.74086	0.34374	0.87094	1.60364	1.31203	1.60824	2.18794	3.63740	4.45859	4.61010	0.00000
19:00 - 20:00	0.41110	0.05890	0.70227	1.72121	3.48018	5.73491	0.34340	0.86999	1.60207	1.31084	1.60657	2.18566	3.63364	4.45398	4.60533	0.00000
20:00 - 21:00	0.41098	0.05886	0.70176	1.72040	3.47853	5.73219	0.34287	0.86957	1.60100	1.31030	1.60581	2.18468	3.63191	4.45186	4.60314	0.00000
21:00 - 22:00	0.41135	0.05888	0.70199	1.72064	3.47902	5.73301	0.34403	0.86978	1.60156	1.31049	1.60604	2.18513	3.63243	4.45250	4.60380	0.00000
22:00 - 23:00	0.41182	0.05893	0.70263	1.72112	3.47999	5.73459	0.34343	0.87002	1.60128	1.31081	1.60649	2.18590	3.63343	4.45373	4.60507	0.00000
23:00 - 0:00	0.41253	0.05896	0.70329	1.72210	3.48197	5.73787	0.34420	0.87061	1.60177	1.31146	1.60740	2.18736	3.63551	4.45627	4.60770	0.00000
daily	0.41402	0.05938	0.70907	1.72902	3.49597	5.76093	0.34517	0.87441	1.60958	1.31621	1.61414	2.19660	3.65142	4.48459	4.63699	0.00000

Emission Factor (gm/mile/vehicle) - RSP

Hour	16 - Motorcycles (MC)	01 - Private Cars (PC)	02 - Taxi	11 - Non-franchised Bus<=6.4t	12 - Non-franchised Bus 6.4-15t	13 - Non-franchised Bus >15t	09 - Private Light Bus <=3.5t	10 - Private Light Bus >3.5t	03 - Light Goods Vehicles<=2.5t	04 - Lt Goods Vehicles 2.5-3.5t	05 - Light Goods Vehicles>3.5	06 - Heavy Goods Vehicles<=15t	07 - Heavy Goods Vehicles >15t	14 - Franchised Bus (SD)	15 - Franchised Bus (DD)	08 - Public Light Buses
0:00 - 1:00	0.00852	0.00288	0.00000	0.08259	0.07138	0.30034	0.01677	0.04526	0.01980	0.02180	0.07785	0.05943	0.16775	0.22154	0.20599	0.00000
1:00 - 2:00	0.00852	0.00288	0.00000	0.08259	0.07138	0.30034	0.01676	0.04521	0.01981	0.02180	0.07785	0.05943	0.16775	0.22154	0.20599	0.00000
2:00 - 3:00	0.00852	0.00288	0.00000	0.08259	0.07138	0.30034	0.01680	0.04516	0.01982	0.02180	0.07785	0.05943	0.16775	0.22154	0.20599	0.00000
3:00 - 4:00	0.00852	0.00288	0.00000	0.08259	0.07138	0.30034	0.01703	0.04525	0.01980	0.02181	0.07785	0.05943	0.16775	0.22154	0.20599	0.00000
4:00 - 5:00	0.00852	0.00288	0.00000	0.08259	0.07138	0.30034	0.01703	0.04525	0.01980	0.02181	0.07785	0.05943	0.16775	0.22154	0.20599	0.00000
5:00 - 6:00	0.00852	0.00288	0.00000	0.08259	0.07138	0.30034	0.01680	0.04525	0.01981	0.02180	0.07785	0.05943	0.16775	0.22154	0.20599	0.00000
6:00 - 7:00	0.00852	0.00288	0.00000	0.08259	0.07138	0.30034	0.01672	0.04524	0.01979	0.02180	0.07785	0.05943	0.16775	0.22154	0.20599	0.00000
7:00 - 8:00	0.00852	0.00288	0.00000	0.08259	0.07138	0.30034	0.01678	0.04526	0.01980	0.02180	0.07785	0.05943	0.16775	0.22154	0.20599	0.00000
8:00 - 9:00	0.00852	0.00288	0.00000	0.08259	0.07138	0.30034	0.01678	0.04526	0.01980	0.02180	0.07785	0.05943	0.16775	0.22154	0.20599	0.00000
9:00 - 10:00	0.00852	0.00288	0.00000	0.08259	0.07138	0.30034	0.01678	0.04526	0.01980	0.02180	0.07785	0.05943	0.16775	0.22154	0.20599	0.00000
10:00 - 11:00	0.00852	0.00288	0.00000	0.08259	0.07138	0.30034	0.01678	0.04526	0.01980	0.02180	0.07785	0.05943	0.16775	0.22154	0.20599	0.00000
11:00 - 12:00	0.00852	0.00288	0.00000	0.08259	0.07138	0.30034	0.01678	0.04526	0.01980	0.02180	0.07785	0.05943	0.16775	0.22154	0.20599	0.00000
12:00 - 13:00	0.00852	0.00288	0.00000	0.08259	0.07138	0.30034	0.01678	0.04526	0.01980	0.02180	0.07785	0.05943	0.16775	0.22154	0.20599	0.00000
13:00 - 14:00	0.00852	0.00288	0.00000	0.08259	0.07138	0.30034	0.01678	0.04526	0.01980	0.02180	0.07785	0.05943	0.16775	0.22154	0.20599	0.00000
14:00 - 15:00	0.00852	0.00288	0.00000	0.08259	0.07138	0.30034	0.01679	0.04526	0.01980	0.02180	0.07785	0.05943	0.16775	0.22154	0.20599	0.00000
15:00 - 16:00	0.00852	0.00288	0.00000	0.08259	0.07138	0.30034	0.01678	0.04526	0.01980	0.02180	0.07785	0.05943	0.16775	0.22154	0.20599	0.00000
16:00 - 17:00	0.00852	0.00288	0.00000	0.08259	0.07138	0.30034	0.01678	0.04526	0.01980	0.02180	0.07785	0.05943	0.16775	0.22154	0.20599	0.00000
17:00 - 18:00	0.00852	0.00288	0.00000	0.08259	0.07138	0.30034	0.01678	0.04526	0.01980	0.02180	0.07785	0.05943	0.16775	0.00000	0.00000	0.00000
18:00 - 19:00	0.00852	0.00288	0.00000	0.08259	0.07138	0.30034	0.01678	0.04526	0.01981	0.02180	0.07785	0.05943	0.16775	0.22154	0.20599	0.00000
19:00 - 20:00	0.00852	0.00288	0.00000	0.08259	0.07138	0.30034	0.01678	0.04526	0.01981	0.02180	0.07785	0.05943	0.16775	0.22154	0.20599	0.00000
20:00 - 21:00	0.00852	0.00288	0.00000	0.08259	0.07138	0.30034	0.01677	0.04526	0.01981	0.02180	0.07785	0.05943	0.16775	0.22154	0.20599	0.00000
21:00 - 22:00	0.00852	0.00288	0.00000	0.08259	0.07138	0.30034	0.01681	0.04526	0.01981	0.02180	0.07785	0.05943	0.16775	0.22154	0.20599	0.00000
22:00 - 23:00	0.00852	0.00288	0.00000	0.08259	0.07138	0.30034	0.01678	0.04524	0.01980	0.02180	0.07785	0.05943	0.16775	0.22154	0.20599	0.00000
23:00 - 0:00	0.00852	0.00288	0.00000	0.08259	0.07138	0.30034	0.01679	0.04524	0.01980	0.02180	0.07785	0.05943	0.16775	0.22154	0.20599	0.00000
daily	0.00852	0.00288	0.00000	0.08259	0.07138	0.30034	0.01678	0.04526	0.01980	0.02180	0.07785	0.05943	0.16775	0.22154	0.20599	0.00000

Annex 3 – Summary of Emission Inventory for Portal and Ventilation Building Sources

Calculation of Portal Emission and Emissions of Ventilation Buildings

Portal Name	Description	Length (m)	Portal ID	Hour	Q	Total Emission Factor			Total Emission Rate			Abormal Scenario Daily Emission Rate / Diurnal Porfile (From 1st 50m for Each Portal Source)			Abormal Scenario Daily Emission Rate / Diurnal Porfile (From 2nd 50m for Each Portal Source)			Normal Scenario Daily Emission Rate / Diurnal Porfile (From Each Ventilation Building. Source)		
					(veh/hr)	NO_2 E.F. (g/mile-veh)	NO E.F. (g/mile-veh)	RSP E.F. (g/mile-veh)	NO_2 (g/s)	NO (g/s)	RSP (g/s)	NO_2 (g/s) / %	NO (g/s) / %	RSP (g/s) / %	NO_2 (g/s) / %	NO (g/s) / %	RSP (g/s) / %	NO_2 [1] (g/s) / %	NO (g/s) / %	RSP [1] (g/s) / %
P	Central-Wan Chai Bypass (Eastbound)	1233	P1-P8	1	227	0.0388	0.4212	0.0093	1.875E-03	2.035E-02	4.506E-04	0.7%	0.9%	0.7%	0.7%	0.9%	0.7%	0.7%	0.9%	0.7%
				2	132	0.0388	0.4218	0.0093	1.091E-03	1.185E-02	2.620E-04	0.4%	0.5%	0.4%	0.4%	0.5%	0.4%	0.4%	0.5%	0.4%
				3	87	0.0389	0.4224	0.0093	7.200E-04	7.823E-03	1.727E-04	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%
				4	62	0.0389	0.4235	0.0093	5.141E-04	5.590E-03	1.231E-04	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
				5	62	0.0390	0.4245	0.0093	5.149E-04	5.603E-03	1.231E-04	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
				6	88	0.0391	0.4256	0.0093	7.323E-04	7.973E-03	1.747E-04	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%
				7	233	0.0391	0.4263	0.0093	1.941E-03	2.115E-02	4.625E-04	0.7%	0.9%	0.8%	0.7%	0.9%	0.8%	0.7%	0.9%	0.8%
				8	699	0.0770	0.6621	0.0178	1.146E-02	9.853E-02	2.643E-03	4.2%	4.2%	4.4%	4.2%	4.2%	4.4%	4.2%	4.2%	4.4%
				9	1493	0.0771	0.6630	0.0178	2.451E-02	2.107E-01	5.644E-03	9.0%	9.0%	9.3%	9.0%	9.0%	9.3%	9.0%	9.0%	9.3%
				10	1531	0.0937	0.7889	0.0216	3.055E-02	2.571E-01	7.029E-03	11.2%	11.0%	11.6%	11.2%	11.0%	11.6%	11.2%	11.0%	11.6%
				11	1228	0.1039	0.8347	0.0221	2.717E-02	2.182E-01	5.766E-03	10.0%	9.4%	9.5%	10.0%	9.4%	9.5%	10.0%	9.4%	9.5%
				12	1148	0.0892	0.7347	0.0195	2.180E-02	1.796E-01	4.763E-03	8.0%	7.7%	7.8%	8.0%	7.7%	7.8%	8.0%	7.7%	7.8%
				13	915	0.0978	0.7712	0.0211	1.905E-02	1.502E-01	4.110E-03	7.0%	6.4%	6.8%	7.0%	6.4%	6.8%	7.0%	6.4%	6.8%
				14	866	0.0900	0.7236	0.0194	1.659E-02	1.334E-01	3.584E-03	6.1%	5.7%	5.9%	6.1%	5.7%	5.9%	6.1%	5.7%	5.9%
				15	954	0.0838	0.6880	0.0181	1.702E-02	1.397E-01	3.672E-03	6.3%	6.0%	6.0%	6.3%	6.0%	6.0%	6.3%	6.0%	6.0%
				16	1171	0.0893	0.6985	0.0192	2.226E-02	1.741E-01	4.797E-03	8.2%	7.5%	7.9%	8.2%	7.5%	7.9%	8.2%	7.5%	7.9%
				17	1144	0.0810	0.6461	0.0169	1.972E-02	1.573E-01	4.120E-03	7.2%	6.7%	6.8%	7.2%	6.7%	6.8%	7.2%	6.7%	6.8%
				18	1196	0.0669	0.5479	0.0149	1.704E-02	1.395E-01	3.794E-03	6.3%	6.0%	6.2%	6.3%	6.0%	6.2%	6.3%	6.0%	6.2%
				19	1137	0.0474	0.4510	0.0111	1.148E-02	1.092E-01	2.695E-03	4.2%	4.7%	4.4%	4.2%	4.7%	4.4%	4.2%	4.7%	4.4%
				20	1099	0.0387	0.4198	0.0093	9.056E-03	9.821E-02	2.182E-03	3.3%	4.2%	3.6%	3.3%	4.2%	3.6%	3.3%	4.2%	3.6%
				21	695	0.0387	0.4195	0.0093	5.724E-03	6.207E-02	1.380E-03	2.1%	2.7%	2.3%	2.1%	2.7%	2.3%	2.1%	2.7%	2.3%
				22	497	0.0387	0.4196	0.0093	4.094E-03	4.440E-02	9.866E-04	1.5%	1.9%	1.6%	1.5%	1.9%	1.6%	1.5%	1.9%	1.6%
				23	531	0.0387	0.4199	0.0093	4.376E-03	4.746E-02	1.054E-03	1.6%	2.0%	1.7%	1.6%	2.0%	1.7%	1.6%	2.0%	1.7%
				24	366	0.0387	0.4202	0.0093	3.018E-03	3.274E-02	7.265E-04	1.1%	1.4%	1.2%	1.1%	1.4%	1.2%	1.1%	1.4%	1.2%
				Daily	-	-	-	-	2.723E-01	2.333E+00	6.071E-02	4.539E-02	3.888E-01	1.012E-02	2.269E-02	1.944E-01	5.060E-03	1.362E-02	5.832E-01	3.036E-03

Note:

[1] Under Normal Scenario, the vehicular emission generated inside the east section (i.e. 1/3 length of the whole tunnel) of the east-bound CWB tunnel would all be emitted from the East Ventilation Building (EVB), which is provided with an air purification system (APS), including an electrostatic precipitator system (EPS), with removal efficiency of at least 80% of dust to reduce the level of respirable suspended particulates (RSP), and a Nitrogen Dioxide (NO2) removal system with removal efficiency of at least 80% for NO2.

Calculation of Portal Emission and Emissions of Ventilation Buildings

Abnormal Scenario

Road ID	Source ID	X	Y	Daily Emission Factor (QS) (g/s) [1] NO_2	NO	RSP	HS	SY	SZ	total NO_2	total NO	total RSP
Central-Wan Chai Bypass (Eastbound)	P1	837688.8	816726.9	4.539E-02	3.888E-01	1.012E-02	2.55	5.81	2.37			
	P2	837697.2	816735.8	4.539E-02	3.888E-01	1.012E-02	2.55	5.81	2.37			
	P3	837706.1	816745.0	4.539E-02	3.888E-01	1.012E-02	2.55	5.81	2.37			
	P4	837714.5	816753.7	4.539E-02	3.888E-01	1.012E-02	2.55	5.81	2.37			
	P5	837723.2	816763.0	2.269E-02	1.944E-01	5.060E-03	2.55	5.81	2.37			
	P6	837732.0	816772.0	2.269E-02	1.944E-01	5.060E-03	2.55	5.81	2.37			
	P7	837741.0	816780.9	2.269E-02	1.944E-01	5.060E-03	2.55	5.81	2.37			
	P8	837750.1	816789.4	2.269E-02	1.944E-01	5.060E-03	2.55	5.81	2.37	2.723E-01	2.333E+00	6.071E-02

Normal Scenario

Ventilation Buildings	Source ID	X	Y	Daily Emission Factor (QS) (g/s) [1] [2] NO_2	NO	RSP	Height (m)	HS	TS	VS	DS
Central-Wan Chai Bypass (Eastbound) (100% from VB)	EVB1	837371.8	816585.6	1.362E-02	5.832E-01	3.036E-03	16.3	16.25	305.00	5.66	5.47
Central-Wan Chai Bypass (Eastbound) (100% from VB)	EVB2	837368.4	816561.8	1.362E-02	5.832E-01	3.036E-03	16.3	16.25	305.00	5.66	5.47
Central-Wan Chai Bypass (Eastbound) (100% from VB)	EVB3	837368.4	816556.5	1.362E-02	5.832E-01	3.036E-03	16.3	16.25	305.00	5.66	5.47
Central-Wan Chai Bypass (Eastbound) (100% from VB)	EVB4	837371.5	816552.5	1.362E-02	5.832E-01	3.036E-03	16.3	16.25	305.00	5.66	5.47

Note:

[1] The emission factors for portal and VB are calculated from the results of EMFAC-HK model and traffic data adopted in this study.

[2] Under Normal Scenario, the vehicular emission generated inside the east section (i.e. 1/3 length of the whole tunnel) of the east-bound CWB tunnel would all be emitted from the East Ventilation Building (EVB), which is provided with an air purification system (APS), including an electrostatic precipitator system (EPS), with removal efficiency of at least 80% of dust to reduce the level of respirable suspended particulates (RSP), and a Nitrogen Dioxide (NO_2) removal system with removal efficiency of at least 80% for NO_2.

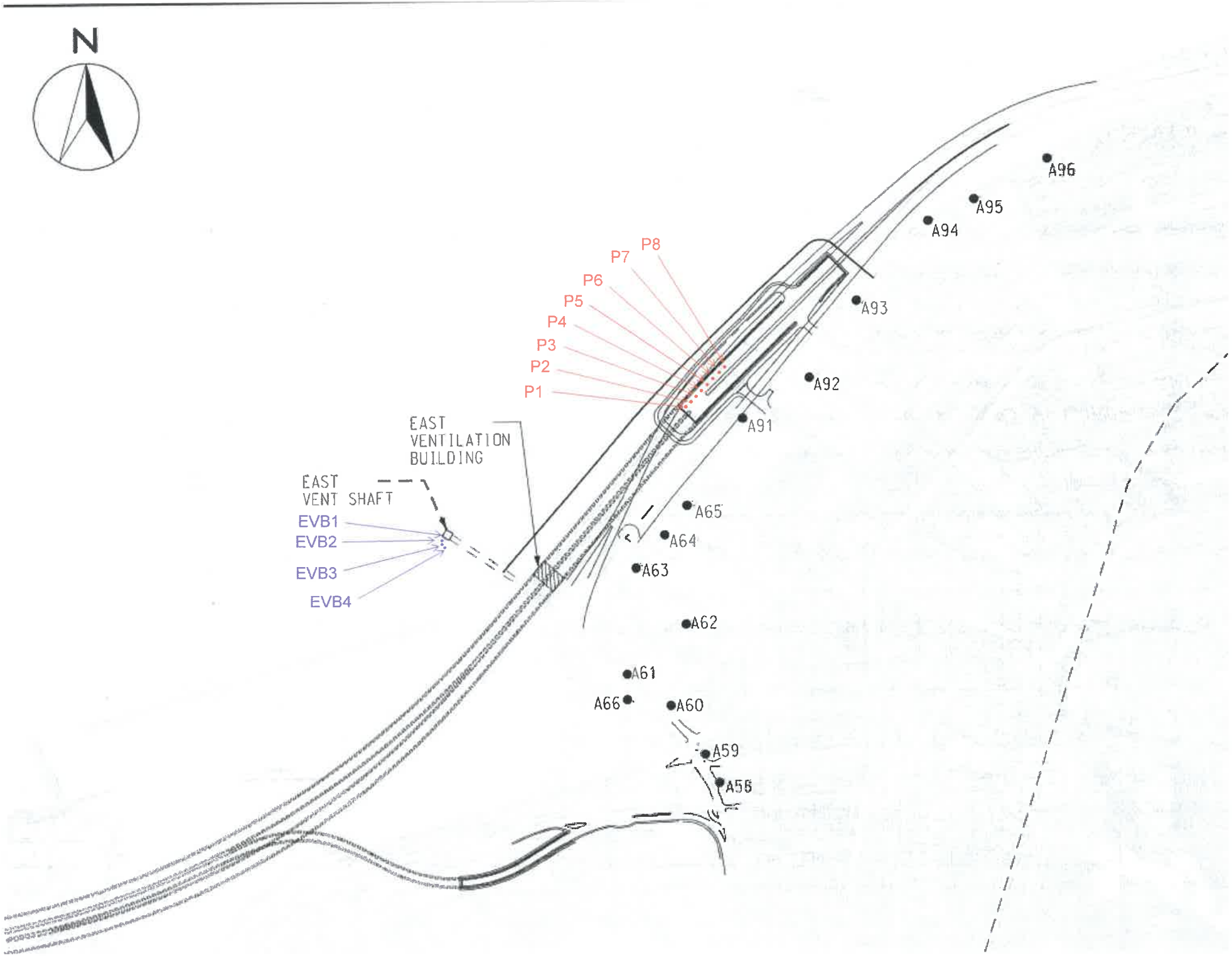
Calculation of Portal Emission and Emissions of Ventilation Buildings

Abnormal Scenario
Hourly Profile for Portals

Hour	Central-Wan Chai Bypass (Eastbound) Portal		
	NO_2	NO	RSP
Hour 1	0.7%	0.9%	0.7%
Hour 2	0.4%	0.5%	0.4%
Hour 3	0.3%	0.3%	0.3%
Hour 4	0.2%	0.2%	0.2%
Hour 5	0.2%	0.2%	0.2%
Hour 6	0.3%	0.3%	0.3%
Hour 7	0.7%	0.9%	0.8%
Hour 8	4.2%	4.2%	4.4%
Hour 9	9.0%	9.0%	9.3%
Hour 10	11.2%	11.0%	11.6%
Hour 11	10.0%	9.4%	9.5%
Hour 12	8.0%	7.7%	7.8%
Hour 13	7.0%	6.4%	6.8%
Hour 14	6.1%	5.7%	5.9%
Hour 15	6.3%	6.0%	6.0%
Hour 16	8.2%	7.5%	7.9%
Hour 17	7.2%	6.7%	6.8%
Hour 18	6.3%	6.0%	6.2%
Hour 19	4.2%	4.7%	4.4%
Hour 20	3.3%	4.2%	3.6%
Hour 21	2.1%	2.7%	2.3%
Hour 22	1.5%	1.9%	1.6%
Hour 23	1.6%	2.0%	1.7%
Hour 24	1.1%	1.4%	1.2%

Normal Scenario
Hourly Profile for Ventilation Buildings

Hour	Central-Wan Chai Bypass (Eastbound) VB		
	NO_2	NO	RSP
Hour 1	0.7%	0.9%	0.7%
Hour 2	0.4%	0.5%	0.4%
Hour 3	0.3%	0.3%	0.3%
Hour 4	0.2%	0.2%	0.2%
Hour 5	0.2%	0.2%	0.2%
Hour 6	0.3%	0.3%	0.3%
Hour 7	0.7%	0.9%	0.8%
Hour 8	4.2%	4.2%	4.4%
Hour 9	9.0%	9.0%	9.3%
Hour 10	11.2%	11.0%	11.6%
Hour 11	10.0%	9.4%	9.5%
Hour 12	8.0%	7.7%	7.8%
Hour 13	7.0%	6.4%	6.8%
Hour 14	6.1%	5.7%	5.9%
Hour 15	6.3%	6.0%	6.0%
Hour 16	8.2%	7.5%	7.9%
Hour 17	7.2%	6.7%	6.8%
Hour 18	6.3%	6.0%	6.2%
Hour 19	4.2%	4.7%	4.4%
Hour 20	3.3%	4.2%	3.6%
Hour 21	2.1%	2.7%	2.3%
Hour 22	1.5%	1.9%	1.6%
Hour 23	1.6%	2.0%	1.7%
Hour 24	1.1%	1.4%	1.2%


N
A96
A95
A94
P8
P7
P6
P5
P4
P3
P2
P1
A93
A92
A91
EAST
VENTILATION
BUILDING
EAST
VENT SHAFT
EVB1
EVB2
EVB3
EVB4
A65
A64
A63
A62
A61
A66
A60
A59
A56

Appendix 3.2 – Cumulative Assessment Results

ASR	Height	Description	Predicted Cumulative Concentration - Abnormal Scenario		Predicted Cumulative Concentration - Normal Scenario	
			NO_2	RSP	NO_2	RSP
			19th Highest 1-hr Avg. NO_2 Conc. in µg/m³	10th Hightest 24-hr Avg. RSP Conc. in µg/m³	19th Highest 1-hr Avg. NO_2 Conc. in µg/m³	10th Hightest 24-hr Avg. RSP Conc. in µg/m³
AQOs			200	100	200	100
A58	1.5	Mayson Garden	137	78	137	78
A58	5	Mayson Garden	135	77	135	77
A58	10	Mayson Garden	134	77	134	77
A58	20	Mayson Garden	132	77	132	77
A58	30	Mayson Garden	132	76	132	76
A58	40	Mayson Garden	132	76	132	76
A59	1.5	Gordon House	137	78	137	78
A59	5	Gordon House	134	77	135	77
A59	10	Gordon House	133	77	132	77
A59	20	Gordon House	132	77	132	77
A59	30	Gordon House	132	76	132	76
A59	40	Gordon House	132	76	132	76
A60	1.5	Belle House	158	80	158	80
A60	5	Belle House	156	80	156	80
A60	10	Belle House	154	80	155	80
A60	20	Belle House	154	79	154	79
A60	30	Belle House	152	79	152	79
A60	40	Belle House	152	79	152	79
A61	1.5	Citicorp Centre	158	80	158	80
A61	5	Citicorp Centre	154	80	156	80
A61	10	Citicorp Centre	154	80	155	80
A61	20	Citicorp Centre	154	79	154	79
A61	30	Citicorp Centre	152	79	152	79
A61	40	Citicorp Centre	151	79	151	79
A62	1.5	Hoi Tao Building	157	81	157	81
A62	5	Hoi Tao Building	154	80	154	80
A62	10	Hoi Tao Building	154	80	154	79
A62	20	Hoi Tao Building	154	79	154	79
A62	30	Hoi Tao Building	152	79	152	79
A62	40	Hoi Tao Building	152	79	152	79
A63	1.5	Victoria Centre	152	80	153	80
A63	5	Victoria Centre	152	80	153	80
A63	10	Victoria Centre	152	80	154	80
A63	20	Victoria Centre	152	80	152	80
A63	30	Victoria Centre	152	79	152	79
A63	40	Victoria Centre	151	79	152	79
A64	1.5	Seaview Estate	153	80	153	80
A64	5	Seaview Estate	154	80	153	80
A64	10	Seaview Estate	153	80	153	80
A64	20	Seaview Estate	152	80	153	80
A64	30	Seaview Estate	152	79	152	79
A64	40	Seaview Estate	151	79	152	79
A65	1.5	Harbour Heights	155	80	153	80
A65	5	Harbour Heights	155	80	153	80
A65	10	Harbour Heights	154	80	154	80
A65	20	Harbour Heights	152	80	153	80
A65	30	Harbour Heights	152	79	152	79
A65	40	Harbour Heights	151	79	152	79
A66	1.5	Whitfield Road Rest Garden	155	81	156	81
A66	5	Whitfield Road Rest Garden	154	80	155	80
A66	10	Whitfield Road Rest Garden	154	80	155	80
A66	20	Whitfield Road Rest Garden	154	79	154	79
A66	30	Whitfield Road Rest Garden	152	79	152	79
A66	40	Whitfield Road Rest Garden	151	79	151	79
A91	1.5	Harbour Grand Hong Kong	160	80	155	80
A91	5	Harbour Grand Hong Kong	161	81	155	81
A91	10	Harbour Grand Hong Kong	159	81	157	81
A91	20	Harbour Grand Hong Kong	152	80	152	80
A91	30	Harbour Grand Hong Kong	152	79	152	79
A91	40	Harbour Grand Hong Kong	152	79	152	79
A92	1.5	Harbour Glory	159	80	157	80
A92	5	Harbour Glory	159	80	156	80
A92	10	Harbour Glory	158	80	155	80
A92	20	Harbour Glory	154	79	152	79
A92	30	Harbour Glory	152	79	152	79
A92	40	Harbour Glory	152	79	152	79
A93	1.5	City Garden (Block 11)	158	80	158	80
A93	5	City Garden (Block 11)	158	80	158	80
A93	10	City Garden (Block 11)	158	80	156	80
A93	20	City Garden (Block 11)	155	80	152	80
A93	30	City Garden (Block 11)	152	79	152	79
A93	40	City Garden (Block 11)	152	79	152	79
A94	1.5	City Garden (Block 6)	158	80	158	80
A94	5	City Garden (Block 6)	158	81	157	81
A94	10	City Garden (Block 6)	156	80	155	80

ASR	Height	Description	Predicted Cumulative Concentration - Abnormal Scenario		Predicted Cumulative Concentration - Normal Scenario	
			NO_2	RSP	NO_2	RSP
			19th Highest 1-hr Avg. NO_2 Conc. in $\mu g/m^3$	10th Hightest 24-hr Avg. RSP Conc. in $\mu g/m^3$	19th Highest 1-hr Avg. NO_2 Conc. in $\mu g/m^3$	10th Hightest 24-hr Avg. RSP Conc. in $\mu g/m^3$
AQOs			200	100	200	100
A94	20	City Garden (Block 6)	154	80	152	80
A94	30	City Garden (Block 6)	152	79	152	79
A94	40	City Garden (Block 6)	152	79	152	79
A95	1.5	Hong Kong Baptist Church Henrietta Secondary School	156	80	155	80
A95	5	Hong Kong Baptist Church Henrietta Secondary School	155	81	155	81
A95	10	Hong Kong Baptist Church Henrietta Secondary School	155	81	154	81
A95	20	Hong Kong Baptist Church Henrietta Secondary School	155	80	152	80
A95	30	Hong Kong Baptist Church Henrietta Secondary School	152	79	152	79
A95	40	Hong Kong Baptist Church Henrietta Secondary School	152	79	152	79
A96	1.5	Provident Centre (Block 1)	155	81	155	81
A96	5	Provident Centre (Block 1)	155	81	155	81
A96	10	Provident Centre (Block 1)	156	81	156	81
A96	20	Provident Centre (Block 1)	154	80	154	80
A96	30	Provident Centre (Block 1)	152	79	152	79
A96	40	Provident Centre (Block 1)	152	79	152	79

Appendix 4

Air Quality Monitoring Location Plan, Calibration Results, Preliminary Monitoring Results together with Data Analysis and Interpretation

Wan Chai Bypass Tunnel
AQ Monitoring Record

香港科技大學
THE HONG KONG
UNIVERSITY OF SCIENCE
AND TECHNOLOGY

Prof. Zhi Ning
ENVR/HKUST

Update 1. 2019 APRIL 05, 15:00 PM
Update 2. 2019 APRIL 05, 23:30 PM
Update 3. 2019 APRIL 06, 15:30 PM
Update 4. 2019 APRIL 07, 09:00 AM
Update 5. 2019 APRIL 07, 15:30 PM
Update 6. 2019 APRIL 07, 23:30 PM
Update 7. 2019 APRIL 08, 12:30 PM
Update 8. 2019 APRIL 09, 00:00 AM
Update 9. 2019 APRIL 09, 12:00 PM
Update 10. 2019 APRIL 10, 01:00 AM
Update 11. 2019 APRIL 11, 02:00 AM
Update 12. 2019 APRIL 11, 17:00 PM
Update 13. 2019 APRIL 12, 15:00 PM
Update 14. 2019 APRIL 13, 17:00 PM
Update 15. 2019 APRIL 14, 23:30 PM
Update 16. 2019 APRIL 15, 19:00 PM
Update 17. 2019 APRIL 17, 00:00 AM
Update 18. 2019 APRIL 17, 20:00 PM
Update 19. 2019 APRIL 18, 23:30 PM
Update 20. 2019 APRIL 20, 23:30 PM
Update 21. 2019 APRIL 23, 00:00 AM
Update 22. 2019 APRIL 24, 00:00 AM
Update 23. 2019 APRIL 24, 22:00 PM
Update 24, 2019 APRIL 26, 12:00 PM
Update 25, 2019 APRIL 29, 10:00 AM
Update 26, 2019 MAY 03. 00:00 AM

Wan Chai Bypass Tunnel
AQ Monitoring Record

香港科技大學
THE HONG KONG
UNIVERSITY OF SCIENCE
AND TECHNOLOGY

Prof. Zhi Ning
ENVR/HKUST

Update 27. 2019 MAY 05, 18:00 PM
Update 28. 2019 MAY 07, 17:00 PM
Update 29. 2019 MAY 10, 10:00 AM
Update 30. 2019 MAY 13, 17:00 PM
Update 31. 2019 MAY 15, 18:00 PM

MINI AIR STATION INSTALLATION AND SETUP

Monitoring arrangement for Wan Chai Bypass (Final)
2019/04/05 03:00 AM update

現有高架行車道將予拆卸
EXISTING ELEVATED CARRIA

現有高架行車道將予拆卸及
RECONSTRUCTED

維多利亞海港
CTORIA HARBOUR

81660

#15 MAS
19/04/05 02:20 AM
Site 5

#16 MAS
19/04/05 01:45 AM
Site 3

園林綠化平台
ELEVATED LANDSCAPED
DECK

主幹道隧道
TRUNK ROAD
TUNNEL

東區走廊東行路
ASTBOUND

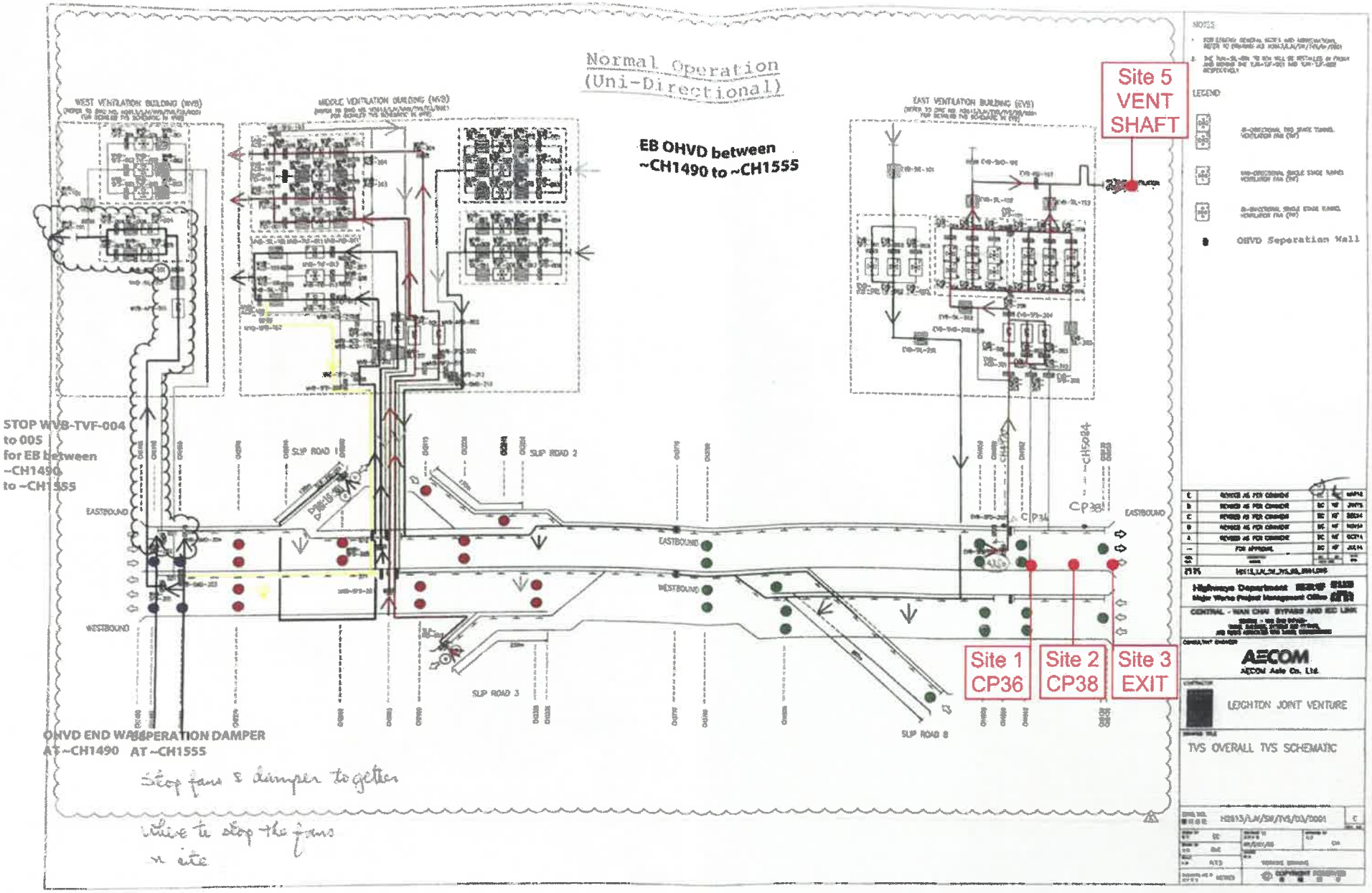
#8 MAS
19/04/05 01:34 AM
Site 2

#7 MAS
19/04/05 01:20 AM
Site 1

#21 MAS
19/04/05 09:30 AM
Site 4

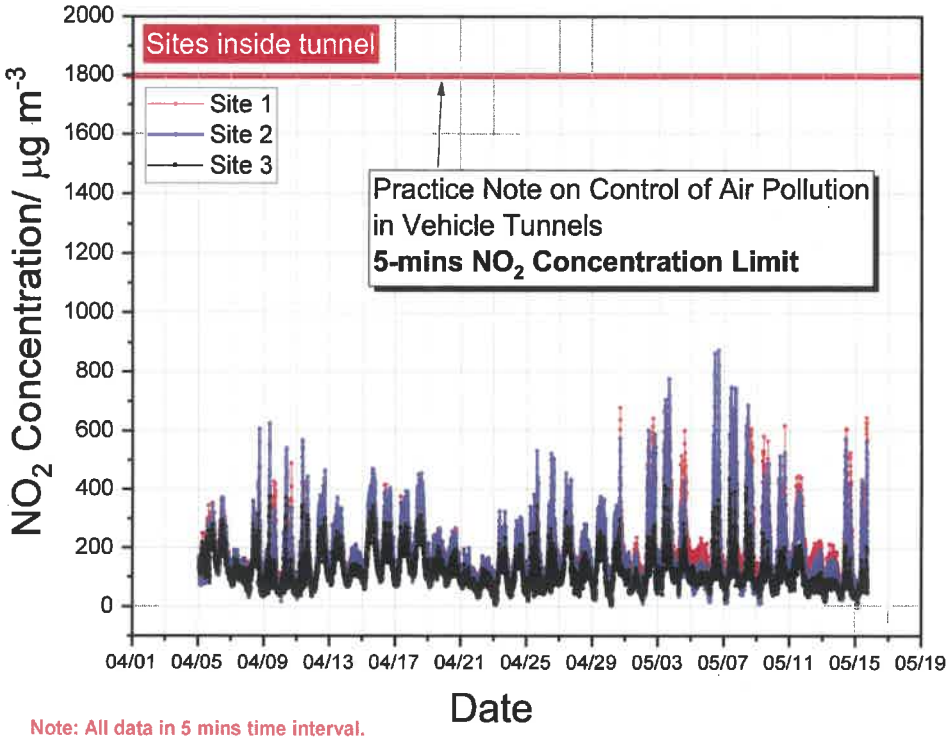
東區走廊西行路
TEC WESTBOUND

81640

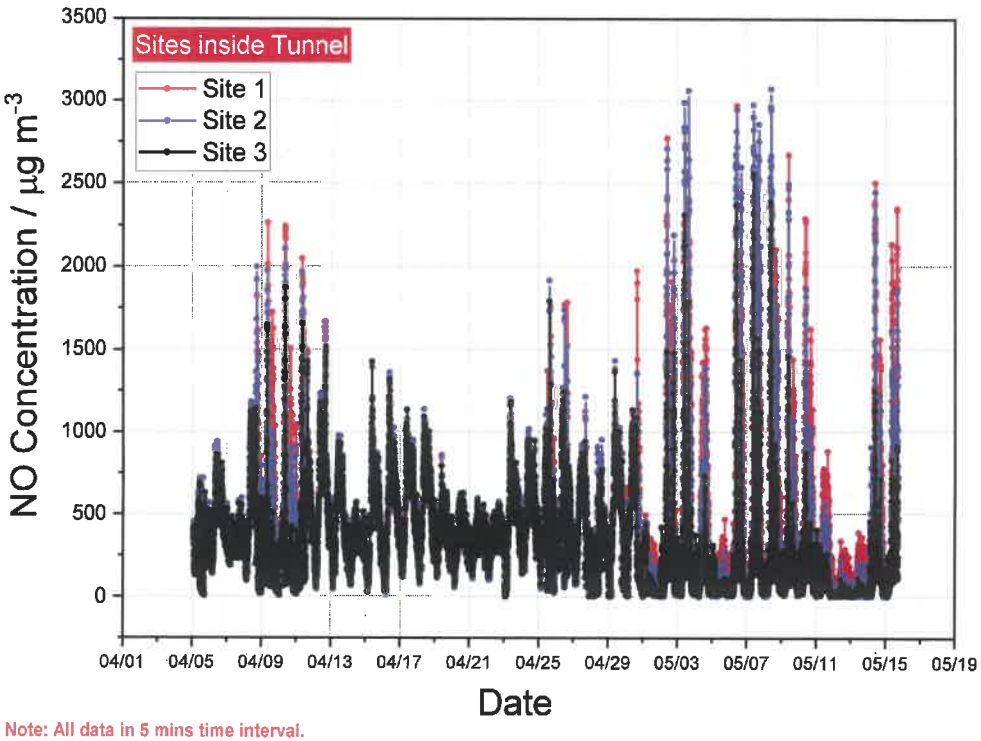

Normal Operation
(Uni-Directional)
EB OHVD between
~CH1490 to ~CH1555
Site 5
VENT
SHAFT
Site 1
CP36
Site 2
CP38
Site 3
EXIT
STOP WVB-TVF-004
to 005
for EB between
~CH1490
to ~CH1555
OHVD END WASSPERATION DAMPER
AT ~CH1490 AT ~CH1555
Stop fans & damper to getter
Drive to stop the fans
on site
WEST VENTILATION BUILDING (WVB)
MIDDLE VENTILATION BUILDING (MVB)
EAST VENTILATION BUILDING (EVB)
SLIP ROAD 1
SLIP ROAD 2
SLIP ROAD 3
SLIP ROAD 8
EASTBOUND
WESTBOUND
CP34
CP38
LEGEND
OHVD Separation Wall
AECOM
LEIGHTON JOINT VENTURE
TVS OVERALL TVS SCHEMATIC

UPDATE 31
2019 MAY 15, 18:00 PM

- **NO_2 and NO data inside the tunnel showed consistent trend by report date on May, 15.**

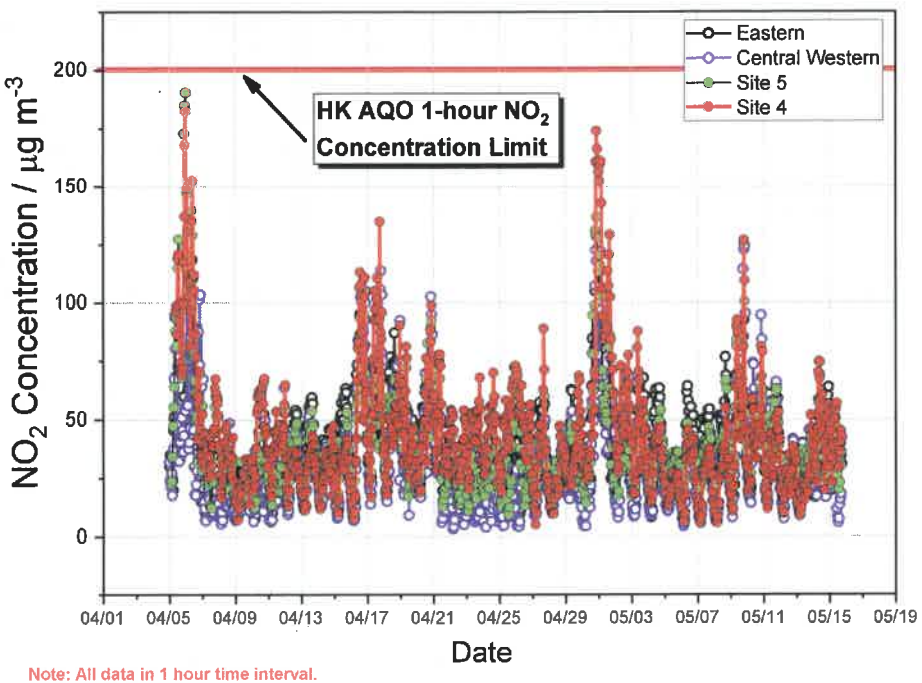


Note: All data in 5 mins time interval.

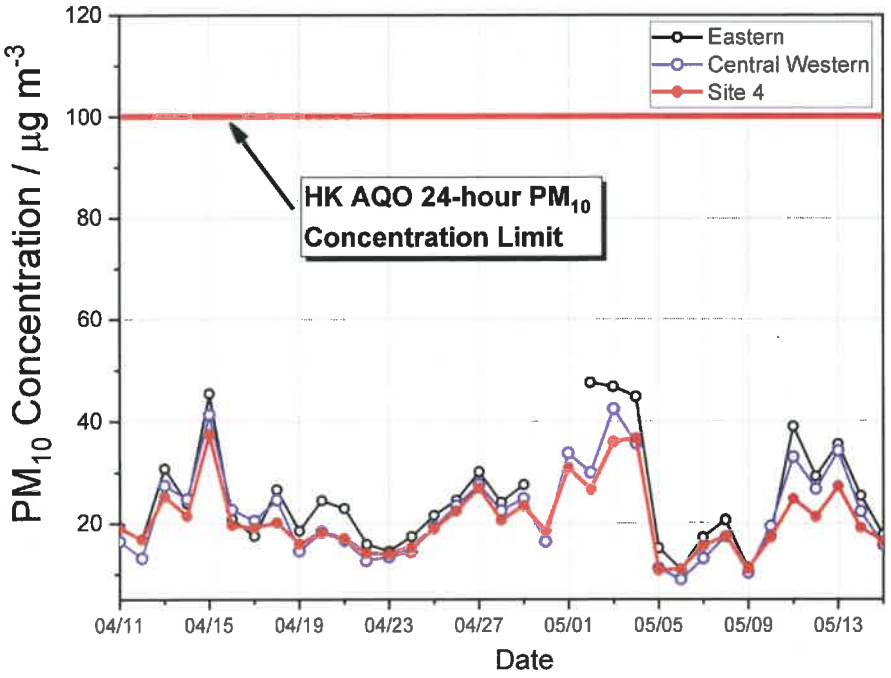


Note: All data in 5 mins time interval.

- **The ambient sites 4 and 5 showed consistent levels, overall in the same trend with the general ambient air monitoring stations in Central Western and Eastern.**

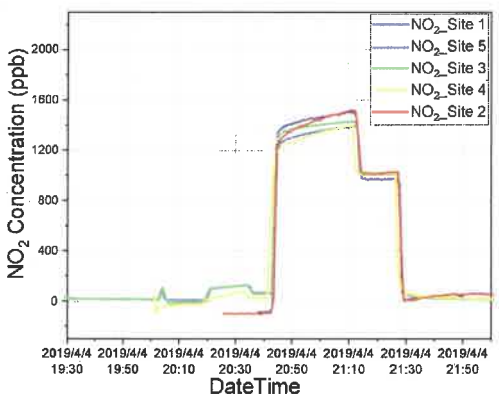


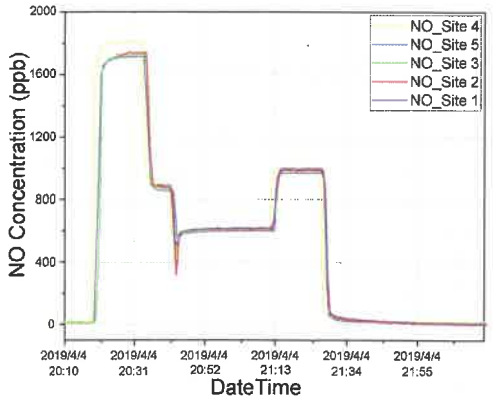
Note: All data in 1 hour time interval.



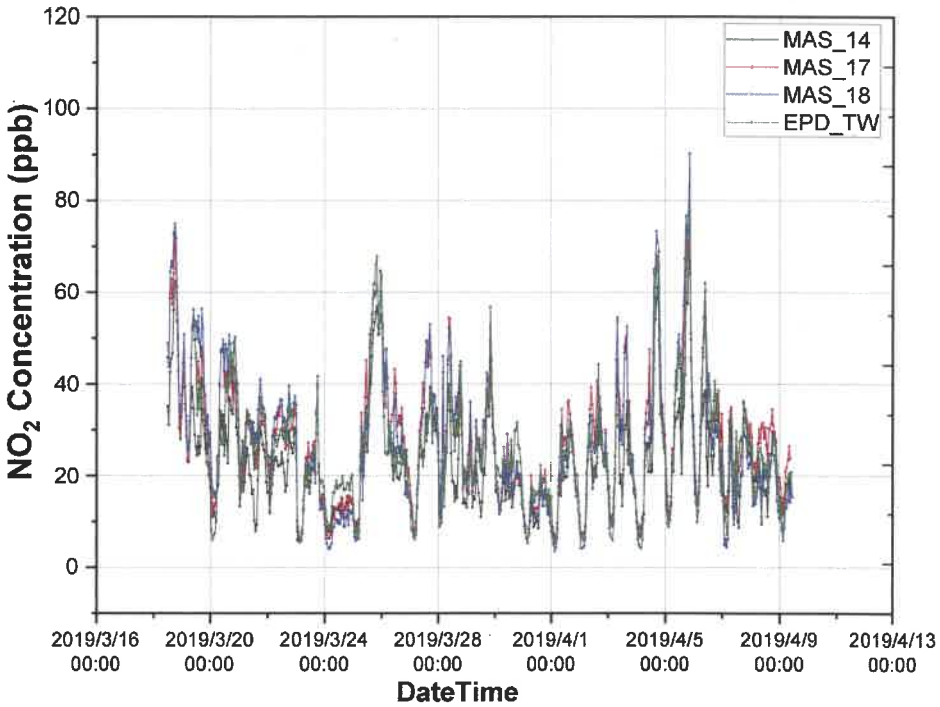
Note: All data in 24 hour time interval. The missing data results from unavailable reference data.

1. NOx calibration:





2. Validation test:



3. PM calibration :