

Australian/New Zealand Standard™

AS/NZS 3580.18:2017

Methods for sampling and analysis of ambient air

Method 18: Measurement of road tunnel air quality

PREFACE

This Standard was prepared by the Joint Standards Australia/Standards New Zealand Committee EV-007, Methods for Examination of Air.

The objective of this Standard is to provide regulatory and testing bodies with standard methods for continuously monitoring air in road tunnels for air velocity, carbon monoxide (CO), nitric oxide (NO) and nitrogen dioxide (NO₂) concentrations and visibility.

This Standard has been developed as a performance based Standard that allows for use of a number of direct-reading instrumental methods.

Statements expressed in mandatory terms in notes to tables and figures are deemed to be requirements of this Standard.

FOREWORD

In order to improve traffic flow in central business districts and through sensitive environments, road tunnels are increasingly being used in Australia and New Zealand to achieve the desired outcomes. There are a significant number of tunnels in operation, with a number of others in the planning stages.

Road tunnel projects are subject to environmental and/or planning approval conditions by regulatory authorities that specify the parameters to be monitored in-tunnel, typically including air velocity, CO, NO, NO₂ and visibility, with a requirement that the tunnel ventilation system be controlled to—

- (a) reduce public exposure to CO and NO₂ concentrations within the tunnel, enabling conformity with criteria for various averaging periods;
- (b) prevent or reduce portal emissions and resultant environmental impacts; and
- (c) ensure appropriate visibility for different tunnel operating conditions.

The first requirement is typically determined by averaging measured CO and NO₂ concentrations from a number of instruments located on possible travel paths throughout the tunnel system.

METHOD

1 SCOPE

This Standard describes methods for determining air velocity and flow direction, carbon monoxide (CO), nitric oxide (NO) and nitrogen dioxide (NO₂) concentrations and visibility in road tunnels using direct-reading instruments.

This Standard applies to the measurement of air quality and air velocity inside road tunnels.

2 REFERENCED DOCUMENTS

The following documents are referred to in this Standard:

AS

3580	Methods for sampling and analysis of ambient air
3580.5.1	Method 5.1: Determination of oxides of nitrogen—Direct-reading instrumental method
3580.7.1	Method 7.1: Determination of carbon monoxide—Direct-reading instrumental method

AS/NZS

3580	Methods for sampling and analysis of ambient air
3580.2.2	Method 2.2: Preparation of reference test atmospheres—Compressed gas method

ISO/IEC

Guide 98	Uncertainty of measurement
Guide 98-3: 2008 Part 3:	Guide to the expression of uncertainty in measurement (GUM:1995)

EN

14211	Ambient air. Standard method for the measurement of the concentration of nitrogen dioxide and nitrogen monoxide by chemiluminescence
14626	Ambient air. Standard method for the measurement of the concentration of carbon monoxide by non-dispersive infrared spectroscopy

Austrroads	Guide to Road Tunnels, 2010
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NZ Transport Agency	Guide to Road Tunnels, December 2013
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National Environment Protection Council	National Environment Protection (Ambient Air Quality) Measure, Technical Paper No. 5, Data Collection and Handling.
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3 DEFINITIONS

For the purpose of this Standard, the definitions below apply.

3.1 Accuracy

The degree of closeness of measurements of a quantity to its actual (true) value.

3.2 Certified reference material

Reference material, characterized by a metrologically valid procedure for one or more specified properties, accompanied by a reference material certificate that provides the value of the specified property, its associated uncertainty, and a statement of metrological traceability.

3.3 Check

Confirmation of acceptable instrument response, without adjustment.

3.4 Fall time

The time interval, after a step decrease in input concentration, between initial instrument response and 10% of initial instrument response.

3.5 Full scale

The nominated maximum concentration for which an instrument has been calibrated. The full scale (FS) is selected to cover the normal range of values expected in the sampling environment.

3.6 Interference equivalent

Positive or negative instrument response caused by a substance other than the one being measured.

3.7 Linearity

The deviation of an instrument's output from a linear best fit line when subjected to varying reference test atmospheres.

3.8 Lower detectable limit

The minimum pollutant concentration that produces a signal of exactly twice the noise level.

3.9 Noise

Spontaneous, short duration deviations in instrument output, about the mean output, which are not caused by input concentration changes. Noise level is determined as the standard deviation about the mean and is expressed in concentration units.

3.10 Parameter

One of the characteristics related to an air sample, for example, concentration of constituent or other quantifiable property (e.g. air velocity).

3.11 Parts per million (ppm)

A ratio expressing the volume of gaseous pollutant contained in 1 000 000 volumes of atmosphere. It may be expressed in terms of millilitres per cubic metre as the values are identical. Alternatively, it is one million times the ratio of the partial pressure of gaseous pollutant to the pressure of the atmosphere in which it is contained.

3.12 Precision

Variation about the mean of repeated measurements of the same pollutant concentration on the same instrument, expressed as one standard deviation about the mean.

3.13 Range

Nominal minimum and maximum concentrations that a method is capable of measuring.

NOTE: The nominal range is specified by the lower and upper range limits in concentration units, e.g. 0 to 250 ppm.

3.14 Reference test atmosphere

A test atmosphere containing a known concentration of pollutant, typically generated by diluting the contents of a cylinder containing a gaseous certified reference material.

3.15 Rise time

The time interval, after a step increase in input concentration, between instrument initial response and 90% of final instrument response.

3.16 Road tunnel

Any fully enclosed length of roadway with a minimum length of between 80 m and 150 m, as the length above which the structure is considered to be a tunnel (refer to Austroads, *Guide to Road Tunnels* and NZ Transport Agency, *Guide to Road Tunnels*).

3.17 Span drift

The percentage change in instrument response to an on-scale pollutant concentration over a period of continuous unadjusted operation.

3.18 U_{95}

A measurement of uncertainty at a confidence interval of 95% according to ISO/IEC Guide 98-3.

3.19 Zero air

Air free from contaminants likely to cause a detectable response on the test instrument.

3.20 Zero drift

The change in instrument response to a zero pollutant concentration over a period of continuous unadjusted operation.

4 TEST PARAMETER—AIR VELOCITY

4.1 Scope

This clause describes a continuous, direct-reading instrumental method for determining air velocity and flow direction in road tunnels.

4.2 Principle

Air velocity and flow direction in road tunnels are typically measured as average values over the tunnel width using ultrasonic flow sensors, with transceiver pairs installed on opposing walls at an angle of 45° to 60° to the tunnel axis, at various locations along the tunnel length, including portals and exit ramps. Single point ultrasonic flow sensors can also be used in road tunnels, however it should be recognized that the potential for error in the instantaneous measurement of both air velocity and flow direction is increased due to turbulence created by nearby vehicles.

Ultrasonic sensor systems are based on the principle that the velocity of air movement changes the transit time of a sound pulse across a fixed distance, allowing calculation of the air velocity and determination of flow direction.

Instrument outputs are used to control the direction of operation and speed of the axial flow jet fans installed on the roof of the tunnel. Depending on their location, the jet fans either assist the movement of polluted air in the direction of traffic flow, typically towards the ventilation stack, or reduce or eliminate pollutant emissions from the tunnel portals by creating air movement in the opposite direction to traffic flow.

NOTES:

- 1 Ultrasonic flow sensors are typically located high on tunnel walls; consequently the measured air velocity may not be representative of that for the overall tunnel cross-section.
- 2 In order to eliminate the measuring errors that could be caused by variation of ultrasonic sound speed caused by temperature and pressure, the transceiver units need to be installed on each side of the tunnel wall and the transit time needs to be measured in both directions.

Providing the instrument performance is within the specifications given in Table 4.3.1, alternate methods may be used within the context of this Standard.

4.3 Apparatus

4.3.1 Instrument

A continuous direct-reading instrument that meets or exceeds the specifications given in Table 4.3.1. The manufacturer's published performance specifications shall be deemed as acceptable evidence of conformance to the given requirements, if accompanied by a statement of measurement uncertainty.

TABLE 4.3.1
INSTRUMENT PERFORMANCE SPECIFICATIONS
FOR TUNNEL AIR VELOCITY SYSTEMS

Parameter	Minimum requirements
Range	–20 to 20 m/s
Accuracy	2% of reading or ± 0.2 m/s*
Resolution	≤ 0.1 m/s

* Whichever is the greater.

4.3.2 Reference path length measurement device

A reference path length measurement device traceable to national standards with an uncertainty of $\pm 0.5\%$ U_{95} is required to make an accurate determination of the path length. The reference path length measurement device shall be checked over a path length of at least the instrument measurement path length.

Laboratories performing the tests outlined in this clause shall meet the requirements of AS ISO/IEC 17025.

NOTE: Accreditation bodies who are signatories to the International Laboratory Accreditation Cooperation (ILAC) Mutual Recognition Arrangement (MRA) for testing laboratories are able to offer accreditation against the requirements of AS ISO/IEC 17025. A listing of ILAC signatories is available from the ILAC website (www.ilac.org). In Australia and New Zealand, the National Association of Testing Authorities (NATA) and International Accreditation New Zealand (IANZ) are signatories to the ILAC MRA.

4.3.3 Transfer standard flow sensor

A hand-held vane or hot-wire anemometer, or equivalent, of similar or higher specification to the air velocity sensor traceable to national standards with an uncertainty of $\pm 2\%$ U_{95} is required to check the operation of air velocity sensors. The transfer standard flow sensor shall be calibrated over a range exceeding the maximum air flow experienced in the tunnel.

The transfer standard sensor shall be routinely calibrated such that it is traceable to SI units. This calibration shall be evidenced by a calibration certificate which states the sensitivity of the device by a procedure which establishes traceability to a recognized standard and for which a measurement uncertainty is given at a stated level of confidence, and the period during which the calibration is valid.

4.4 Procedure

The procedure shall be as follows:

- (a) Ensure that the transceivers are installed such that the path for the sonic pulse is unimpeded by tunnel equipment or other obstructions, whilst allowing ease of access for instrument maintenance and calibration.
- (b) Check instrument horizontal and vertical alignment, in accordance with the manufacturer's instructions.

- (c) Accurately measure and record the distance between the transceivers using a reference path length measurement device (Clause 4.3.2).
- (d) Set up the instrument and carry out initial checks in accordance with the manufacturer's instructions (e.g. setting the path length, configuring and scaling of analogue outputs, setting of alarm values and level of damping) and the requirements of Clause 4.5.
- (e) Take measurements in accordance with the manufacturer's instructions and ensure that the values obtained relate to the correct date and time.

4.5 Instrument checks and calibrations

4.5.1 General

Calibration of an instrument establishes the quantitative relationship between the air velocity and the instrument's response.

Instrument checks and calibrations shall be carried out in accordance with the frequencies specified in Table 4.5.6.

In addition, operational precision checks shall be carried out as follows:

- (a) Prior to decommissioning or physical relocation of the instrument, if operational.
- (b) Following physical relocation of the instrument.
- (c) After any repairs that might affect the instrument's response.
- (d) Upon any indication of an instrument malfunction or change in response that may cause the instrument to drift by more than the values given in Table 4.5.6.

NOTE: The air flow and direction monitor may incorporate an automatic daily zero and span check function for daily quality control and assurance purposes.

4.5.2 Measurement path length

The measurement path length is normally defined as the distance between the faces of opposing transceiver units, however this should be confirmed with the manufacturer. The measurement path length shall be determined upon installation (see Table 4.5.6) using a reference distance measurement device as described in Clause 4.3.2.

A check of the measurement path length shall also be conducted whenever an instrument is reinstalled following maintenance or repair, if the maintenance or repair could result in a change of measurement path length.

4.5.3 Initial check

Conduct an initial check on the ultrasonic flow sensor prior to road tunnel opening using a collocated transfer standard (CTS) method at a minimum of three air velocities evenly spread over the tunnel design operational range.

For open path ultrasonic flow sensors, measurements shall be taken at a minimum of two points per trafficable lane over the measurement path. For a single point ultrasonic flow sensor, the CTS needs to be within 1 m of the subject sensor in the horizontal and 0.5 m in the vertical, but the same distance from the tunnel wall.

The CTS method requires a calibrated hand held vane or hot-wire anemometer, or equivalent, of similar or higher specification to the ultrasonic flow sensor, located in the vicinity of the measurement path for the sensor being assessed.

For both single point and open path ultrasonic flow sensors it is important to site the CTS to be representative of the air flow at the subject sensor, without interfering with either instrument's response.

The procedure shall be as follows:

- (a) Ensure that the CTS is oriented such that the reading is obtained in the direction of air flow.
- (b) Connect the CTS to an independent data logger. Record check data for a period of not less than 15 minutes. Simultaneously record the response from the in situ sensor over the same period.
- (c) Average the recorded data over the selected period, and, if applicable, across all CTS measurement points. Calculate the difference between the in situ sensor and CTS average readings.
- (d) Check that the difference conforms to the tolerance given in Table 4.5.6. If the result is not within the prescribed tolerance, conduct repairs and/or instrument calibrations as required and repeat the above procedure until compliance with the specified tolerance is indicated.

4.5.4 Zero check

If a zero air flow environment can be attained, the zero response of the ultrasonic flow sensor shall be checked on a 12-monthly basis, in accordance with the manufacturer's instructions.

Check that the zero response is within the tolerance given in Table 4.5.6. If the result is not within the tolerance, conduct repairs and/or instrument calibrations as required and repeat the procedure until the zero response is within the tolerance.

4.5.5 System component check

Cables, recorders, signal conditioning and data processing devices can corrupt the sensor's output.

A system component check shall be conducted on a 12-monthly basis to ensure the transmitted sensor output matches that received at the data recording device. For example, if the ultrasonic flow sensor gives a 20 mA output with an air velocity of 20 m/s, then apply a 20 mA signal to the system to confirm that 20 m/s is indicated at the data recording device.

Check that the response is within the tolerance given in Table 4.5.6. If the response is not within the tolerance, conduct repairs and/or instrument calibrations as required and repeat the procedure until the response is within the tolerance.

4.5.6 Operational precision check

An operational precision check shall be conducted on the ultrasonic flow sensor on a 12-monthly basis using the CTS method at a minimum of one air velocity, and, for open path ultrasonic flow sensors, a minimum of three equally spaced points over the measurement path. For a single point ultrasonic flow sensor, the CTS shall be within 1 m of the subject sensor in the horizontal and 0.5 m in the vertical, but the same distance from the tunnel wall.

The CTS method requires a calibrated hand-held vane or hot-wire anemometer, or equivalent, of similar or higher specification to the ultrasonic flow sensor, located in the same horizontal plane as the measurement path for the sensor being assessed.

The transfer standard sensor shall be routinely calibrated by a recognized external authority such that the CTS is traceable to SI units. This calibration shall be evidenced by a calibration certificate which states the sensitivity of the device by a procedure which establishes traceability to a recognized standard and for which a measurement uncertainty is given at a stated level of confidence, and the period during which the calibration is valid.

For both single point and open path ultrasonic flow sensors it is important to site the CTS to be representative of the air flow at the subject sensor, without interfering with either instrument's response.

The procedure shall be as follows:

- (a) Ensure that the CTS is oriented such that the reading is obtained in the direction of air flow.
- (b) Connect the CTS to an independent data logger. Record check data for a sufficient period that demonstrates a stable response. Simultaneously record the response from the in situ sensor over the same period.
- (c) Average the recorded data over the selected period, and, if applicable, across the three CTS measurement points. Calculate the difference between the in situ sensor and CTS average readings.
- (d) Check that the difference conforms to the tolerance given in Table 4.5.6. If the result is not within the prescribed tolerance, conduct repairs and/or instrument calibrations as required and repeat the above procedure until compliance with the specified tolerance is indicated.

TABLE 4.5.6
INSTRUMENT CHECK AND CALIBRATION REQUIREMENTS
FOR TUNNEL AIR VELOCITY SYSTEMS

Parameter	Criterion	Frequency
Measurement path length	$\pm 0.5\%$	Initial
Initial check	2% of reading or ± 0.2 m/s*	Initial
Zero check	± 0.2 m/s	≤ 12 -monthly
System component check	$\pm 0.2\%$ FS	≤ 12 -monthly
Operational precision check	6% of reading or ± 0.3 m/s*	≤ 12 -monthly

* Whichever is the greater.

4.6 Maintenance

4.6.1 General

Maintenance should be carried out in accordance with the frequencies specified in Table 4.6.2. Manufacturers may require additional procedures which should also be adhered to.

Where a high degree of data capture is required, back-up or replacement instruments should be available. A detailed log of all performance checks and maintenance undertaken shall be maintained and retained with the initial check air velocity and flow direction data.

4.6.2 On site checks

Maintenance should be carried out in accordance with the frequencies specified in Table 4.6.2. Visual examination of the ultrasonic flow sensors should be conducted on a 3-monthly basis to ensure that physical damage has not occurred. A log of the results of such checks shall be maintained, with routine entries providing the evidence of attendance needed to support data validity claims.

Routine maintenance may include the removal of dirt, bird nests and cobwebs and the checking of transceiver alignment. The maintenance interval is dependent on air quality in the tunnel, but should not exceed six months. Care should be taken when cleaning ultrasonic flow sensor components, in accordance with manufacturer's recommendations.

NOTE: Compressed air should not be used for cleaning ultrasonic flow sensor components.

When establishing a schedule for on-site checks the following should be considered:

- (a) A plot of collected data will indicate how the sensor is performing.

- (b) Faults may be indicated by incorrect zero, noise (which may be evident at low air velocities), low sensitivity (at low air velocities) and low variability of the recorded air velocities.
- (c) Data inter-comparisons between other sensors located within the tunnel.

TABLE 4.6.2
ROUTINE MAINTENANCE
FOR TUNNEL AIR VELOCITY SYSTEMS

Maintenance component	Frequency
Visual inspection	≤3-monthly
Sensor cleaning	≤6-monthly
Alignment check	≤6-monthly

4.7 Calculation and expression of results

Results shall be expressed in units of meters per second. The positive or negative sign of the velocity, with respect to traffic flow or portal flow, shall be clearly defined in the report.

4.8 Measurement uncertainty

The measurement uncertainty of this method will vary for each installation. Factors affecting the overall uncertainty include how representative the ultrasonic flow sensor output is of the tunnel cross sectional area.

As a guide, measurement uncertainties for air velocities corresponding to the greater of ± 0.2 m/s or 2% of reading can be achieved using modern equipment. In all cases, the measurement uncertainty shall be determined based on individual laboratory practices.

NOTE: A suitable method for calculating measurement uncertainty can be found in ISO/IEC 98-3.

5 TEST PARAMETERS—CARBON MONOXIDE, NITRIC OXIDE AND NITROGEN DIOXIDE

5.1 Scope

This Clause describes continuous, direct-reading instrumental methods for determining CO, NO and NO₂ concentrations in road tunnels.

5.2 Principle

CO and NO concentrations in road tunnels are typically measured using open path infra-red instruments, based on gas filter correlation technology, with measurement path lengths normally ranging from 3 m (6 m folded beam) to 10 m (single beam). NO₂ concentrations in road tunnels are typically measured using either a 10 m (20 m folded beam) open path ultra-violet instrument or an electrochemical sensor.

Other measurement techniques, including extractive systems and ambient air quality analysers, may also be used provided they meet the instrument performance specifications contained in either this Standard, AS 3580.5.1 or AS 3580.7.1. Tunnel safety requirements relating to handling, storage and transport of compressed gases also need to be considered.

Unlike ultrasonic flow sensors, the open path instrument transmitter and receiver, or transceiver and retroreflector, are typically mounted on the wall on the same side of the tunnel, preventing potential glare impacts on tunnel users from the light beam.

In the case of transceiver-based instrumentation, the infra-red (CO and NO) or ultra-violet (NO₂) radiation from an element is focused by a lens onto a retroreflector. For both equipment configurations, the received or reflected energy is then focussed by a lens onto an infra-red or ultra-violet detector. For gas filter correlation instruments a rotating wheel containing two

sets of filters is located in front of the detector. On one of each of the pairs of filters sits a sealed reference gas cell containing a very high concentration of the pollutant under consideration and on the other a cell containing nitrogen. The detector compares the two infra-red radiation levels and sends a signal to the electrometer, allowing calculation of the concentration.

The open path measurement technique for all pollutants is based on the Beer-Lambert Law, which relates the absorption of light as a function of the concentration of the absorbing species, the absorption characteristics of that species, and the length of the absorption path.

The Beer-Lambert Law in this instance can be expressed mathematically as follows:

$$I(\lambda) = I_0(\lambda)e^{-\sum c_i a_i(\lambda)L} \quad \dots 5(1)$$

where

$I(\lambda)$ = measured light intensity at specific wavelength λ

$I_0(\lambda)$ = light intensity at specific wavelength λ without any absorption

c_i = concentration of gaseous species i

$a_i(\lambda)$ = absorption cross-section at wavelength λ for gaseous species i (quantifies the probability for light absorption at each wavelength; units are m^2 per molecule, m^2 per μg , or similar, depending on the unit of concentration)

L = the optical path length

An electrochemical sensor consists of a capillary diffusion barrier, a hydrophobic membrane and working and counter electrodes separated by a thin layer of electrolyte. NO_2 passes through the capillary barrier, diffuses across the hydrophobic membrane and reacts at the surface of the working electrode in accordance with the following equation:



As the process is diffusion controlled, the instrument response is directly proportional to the NO_2 concentration, in accordance with the following:

$$R = D \times F \times c_i \times A/t \times e \quad \dots 5(3)$$

where

R = instrument response

D = diffusion coefficient

F = Faraday constant

c_i = concentration of gaseous species i

A = membrane area

t = membrane thickness

e = number of electrons

The limitations of electrochemical sensors include their response to temperature and interferent gases.

Providing the instrument performance is within the specifications given in Table 5.3.1, alternate methods may be used within the context of this Standard.