EDM CALIBRATION HANDBOOK

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Preface

The Surveyor-General of the Australian Capital Territory establishes standards for cadastral surveys pursuant to the *Surveyors (Surveyor-General) Practice Directions 2023*. This includes requirements for the calibration and standardisation of equipment used in surveying. To help registered surveyors meet these standards, the Surveyor-General provides certified calibration facilities and advice to enable practical implementation.

The Surveyors (Surveyor-General) Practice Directions 2023 stipulate that EDM instruments must be calibrated on a certified baseline at intervals not exceeding 12 months, or more frequently if environmental or operational conditions warrant.

This Handbook provides the specification and practice direction for achieving calibration and standardisation of EDM instruments at the ACT's baseline at Watson. The Surveyor-General is a Verifying Authority for length and is responsible for the annual re-certification of the baseline as a subsidiary standard of length.

The Surveyor-General, through the Office of the Surveyor-General and Land Information, provides for the continued certification of the baseline and periodic updates of this Handbook.

Quality Policy Statement

The Office of the Surveyor-General and Land Information of the ACT Government, as a Verifying Authority for Length, is committed to providing quality EDM calibration and testing services to the local surveying industry in a timely manner. This will be achieved through a total and continuous commitment to the Directorate's corporate vision, to our quality principles and to good professional practice.

Our Verifying Authority Management System is designed to comply with the requirements of the international standard ISO/IEC 17025:2017 (*the Australian equivalent is AS ISO/IEC 17025:2018*). The Management System provides the basis for achieving our commitment to provide quality calibration and testing services and to continuously improve all aspects of our products and their delivery to our customers.

The Office of the Surveyor-General and Land Information welcomes customers' suggestions for product improvement, which will then be used to provide our customers with the products and services most suited to their expectations.

All staff within the Office of the Surveyor-General and Land Information are expected to conduct themselves with professionalism, impartiality, and courtesy in all customer interactions. Furthermore, all staff members, particularly those in managerial, technical, and supervisory roles, are responsible for implementing this policy and upholding the integrity of the Management System.

(1) Introduction

(1.1) This handbook provides guidance on the calibration and standardisation of Electro-Optical Distance Meters (EDMs), including the EDM components of electronic tacheometers (total stations). It outlines the constants and error sources associated with EDM instruments and details the procedures required to calibrate these instruments using the EDM Calibration Baseline located in the suburb of Watson, ACT.

In this context:

- Calibration refers to the determination of instrumental errors (see Section 3).
- Standardisation involves comparing the instrument's measurements against a length standard that is traceable to the national standard. For an instrument to be considered standardised, it must be calibrated to within a specified level of precision (see Section 2.2).

Note: throughout this document "EDM" is used generically to denote both stand-alone EDM instruments and total stations.

(1.2) The Watson EDM Baseline is maintained as a Reference Standard for length and is described in Chapter 4. It is set out on the Sprent-Zwart (Hobart) principle as described by Sprent (1980). Index error, scale factor and cyclic error can be determined from measurements taken on this baseline.

(1.3) Once a Certificate of Verification has been issued for this baseline by the ACT Surveyor-General pursuant to Regulation 13 of the *National Measurement Regulations 1999* (Cth), the baseline may be used to verify EDM instruments. This enables traceability of EDM measurements to the national standard of length.

(1.4) Most calibration activities undertaken at the Watson EDM Baseline involve EDM users who require a calibration to comply with Direction 17(b) of the ACT *Surveyors (Surveyor-General) Practice Directions 2023* or Clause 12 of the NSW *Surveying and Spatial Information Regulation 2024*.

The procedures described in this Handbook are for calibrating and standardising EDMs in 'standard' mode using a reflective prism, and not in 'reflectorless' mode. For those interested in reflectorless testing, refer to Evans (2014) as listed in the References.

EDM instruments should be calibrated on a pillared baseline:

- after being repaired or serviced;
- after software or firmware updates;
- after receiving rough treatment or hard knocks;
- before being used for high-accuracy surveys; and
- at regular intervals not exceeding twelve months.

(1.5) The observing procedures outlined in Chapter 5 are based on the "*Instructions on the Verification of Electro-optical Short-Range Distance Meters on Subsidiary Standards of Length in the Form of EDM Calibration Baselines*" (Rüeger, 1984).

(1.6) Reduction of the calibration measurements is explained in Chapter 6. A sample of the calibration certificate is given at Appendix C.

(1.7) A Standard EDM Calibration performed by the customer will satisfy the legislative requirements mentioned in section 1.4 above.

Combination padlocks have been fitted to the pillar lids and the access gate. Access to the Watson Baseline must be booked, and the customer will be provided with the combination code at the time of booking.

This Handbook, the booking sheet and the EDM Calibration software BASELINE are available for download from the City and Environment Directorate website. Email actplasurvey@act.gov.au to obtain the latest copy of the BASELINE distribution software.

Customers are required to supply their own meteorological equipment, umbrellas and printed copies of the booking sheets. A customer's meteorological equipment can be compared to the standardised OSGLI thermometers and barometers upon request (see 5.12).

OSGLI no longer performs EDM instrument calibrations for issuance of Regulation 13 Certificates.

(1.8) The Watson EDM baseline forms part of the ACT GNSS Verification Network (Surveyor-General Guideline No. 9: GNSS Equipment Verification). Customers wishing to use the GNSS Verification Network must also book time on the test network/Watson EDM baseline.

Figure 1: A Leica TC2003 at Pillar 5

(2) Traceability of Measurement of Length to the National Standard

(2.1) The Surveyor-General is appointed as a Verifying Authority for Length, authorised under Regulation 73 of the *National Measurement Regulations 1999* (Cth) of the *National Measurement Act 1960* (Cth). Under Regulation 13 the Surveyor-General can certify reference standards of length at specified levels of precision. Furthermore, the Office of the Surveyor-General and Land Information is accredited by the National Association of Testing Authorities, Australia (NATA) in the Sector of Calibration (Laboratory No. 15005).

(2.2) In 1983 the National Standards Commission (NSC), now incorporated into the National Measurement Institute (NMI), formed a working party on the "Calibration of Electromagnetic Distance Measuring (EDM) Equipment". Following the recommendations of this working party and research by the NSC, it was established that monumented baselines could be certified as subsidiary standards of length under Regulation 13 of the *National Measurement Regulations 1999* to provide legal traceability for EDM measurements.

Recommendations of specific interest from the NSC working party are:

No.2 *To be certified as a subsidiary standard a baseline must be capable of being calibrated with an uncertainty of* $\pm[1.5 + (20 \times 10^{-3} \times L)]$ *mm at the 95% level of confidence where L is the interval length in metres.*

No.8 *It is recommended that, in general, the minimum standard for the uncertainty of calibration of an EDM, assuming calibration against a monumented base, should be* $\pm[4 + (20 \times 10^{-3} \times L)]$ *mm at the 95% level of confidence where L is the interval length in metres.*

(2.3) The Watson EDM Baseline has been certified by the Surveyor-General as a reference standard under Regulation 13 of the *National Measurement Regulations 1999* (Cth). The calibration of the EDM Baseline is certified annually in accordance with Recommendation No.2.

(2.4) The calibration procedures outlined in this Handbook (see Chapter 5) and the analysis techniques contained in the calibration software (see Chapter 6 and Appendix D) are capable of meeting the requirement of Recommendation No.8.

(3) EDM Calibration - Instrument Constants and Errors

(3.1) An EDM instrument is calibrated on a baseline to determine instrument constants and errors. If significant, corrections should be applied to EDM measurements taken subsequent to the calibration.

(3.2) A series of measurements on a baseline can also be used to check the performance and reliability of the instrument over time and to assess its precision against the manufacturer's specifications.

(3.3) The three distinct systematic errors that may occur in EDM are:

- index (or zero) error;
- scale error; and
- cyclic or short periodic error, in instruments of the phase-comparison type.

Note: EDM instruments of the pulse-measurement type typically are free of cyclic errors.

(3.4) **Additive Constant (correction for Zero or Index error)**

(3.4.1) All distances measured by a particular EDM/reflector combination are subject to a constant error. It is caused by three factors:

- electrical delays, geometric detours, and eccentricities in the EDM;
- differences between the electronic centre and the mechanical centre of the EDM; and
- differences between the optical and mechanical centres of the reflector.

(3.4.2) This error may vary:

- with a change of reflectors;
- after the EDM or reflector receives a jolt;
- with different instrument mountings; and
- after servicing.

(3.4.3) The additive constant or zero/index correction is an algebraic constant to be applied directly to every measured distance.

(3.5) **Scale Error**

(3.5.1) Scale error is proportional to the length of the line measured and is caused by:

- the drift in frequency of the quartz crystal oscillator in the instrument;
- errors in the measured temperature, pressure and humidity which affect the velocity of propagation; and
- non-homogeneous emission/reception patterns from the emitting and receiving diodes (phase inhomogeneities).

(3.5.2) The scale error of an EDM can be checked by:

- comparison of the EDM's modulation frequency against a test reference signal; and/or
- a functional test over a pillared baseline of known distance.

(3.6) **Cyclic Error (or Short Periodic Error)**

(3.6.1) Cyclic error is caused by the non-linearity in amplitude modulation of the carrier wave and phase measurement. This cyclic error varies across the modulated wavelength.

(3.6.2) For an instrument in good adjustment this error is normally small. However, its presence must be determined as an indication of the instrument's adjustment.

(3.6.3) Cyclic error is usually sinusoidal in nature, with a wavelength equal to the unit length of the EDM. The unit length is the scale on which the EDM measures the distance, and is derived from the fine measuring frequency. Unit length is equal to one half of the modulation wavelength of an EDM (Rüeger, 1990).

(3.6.4) As cyclic error repeats itself for every unit length contained within a measured distance, its sign and magnitude varies depending on the length measured. The magnitude of the error could be in the order of 5-10mm, however in modern EDM instruments it is usually less than 2mm (negligible). Cyclic error can increase in magnitude as an EDM's components age.

(3.6.5) Cyclic error can be determined by a series of check measurements made on EDM baselines of the Sprent-Zwart or Schwendener designs (Sprent & Zwart, 1978).

(3.6.6) The Sprent-Zwart design of the Watson Baseline allows for index and scale errors to be determined free of the effect of any cyclic error present in the EDM.

A series of measurements is made from the first pillar and then a second series is made from the second pillar, which is at a distance (D) from the first pillar:

$$D = (x + 0.5)\ U$$

Where: U = the instrument's unit length (m), and
x = an integer representing a whole number of unit lengths.

Cyclic error thus cancels out due to the errors affecting the distances being equal in magnitude but opposite in sign. The index error and scale error can thus be determined unaffected by the cyclic error.

Refer to 4.7 and Table 1 to determine which two pillars are to be occupied by the EDM.

(4) Watson EDM Baseline

(4.1) The EDM baseline is situated on Block 3 Section 65 Watson. Access is via a locked gate off Antill Street (see locality plan - Appendix A).

(4.2) This baseline is a modification of the original Sprent-Zwart (Hobart) design (Sprent & Zwart, 1978) consisting of 11 forced centring pillars spread over approximately 1118 metres.

(4.3) The forced-centring pillars were installed to obtain high set-up accuracy as well as for convenience and time saving. On the top of each pillar is a brass plate containing a 5/8 inch UNC threaded bolt and is protected by a lockable cap. Three sets of 3 deep driven rods have been placed along the baseline to monitor pillar movement.

(4.4) The baseline has been constructed on a sloping site with a concave profile, which allows for intervisibility between pillars, and eliminates the need for them to be horizontally offset.

(4.5) The calibration of the EDM baseline is made in accordance with Recommendation No.2 of the National Standards Commission's Working Party (see 2.2 above). The baseline has been measured by a prescribed instrument and absolute distances have been given to the pillar intervals. These absolute distances are used to determine the scale error.

Note: A **prescribed instrument** is a distance measuring instrument of a type approved by the National Measurement Institute for the calibration of EDM baselines, and one that holds current certification under Regulation 13 of the *National Measurement Regulations 1999*.

(4.6) On 24 January 1987, a Certificate of Verification under Regulation 80 of the *National Measurement Act 1960* was first issued for the Watson Baseline by the Commonwealth Surveyor-General. This Certificate of Verification was renewed annually.

Since 1999, this certification is now made under Regulation 13 of the *National Measurement Regulations 1999* (Cth) and is usually renewed annually by the ACT Surveyor-General, whom the National Measurement Institute (formerly the National Standards Commission) has appointed as a Verifying Authority for Length.

(4.7) The first 3 pillars of the Watson Baseline have been placed at chainages 0m, 5m, and 7.5m, while Pillar 4 is at chainage 54.8m. The unit length (see 5.2) of the EDM being calibrated will govern which two pillars are to be occupied (see Table 1 below).

Table 1: Pillars to be occupied by the EDM

PILLARS	UNIT LENGTH (m)
1 and 2	0.32; 0.37; 2; 10
1 and 3	1; 3; 5
1 and 4	0.5; 0.8; 1.5
1 and 5	20
1 and 4	N/A (Pulse Meters)

(4.8) Higher accuracy calibrations can be obtained by occupying all pillars and measuring all distances. Additionally, taking greater care in observing meteorological conditions, and performing the EDM observations soon after the annual re-certification of the Watson baseline will result in higher accuracy calibrations.

(4.9) The baseline has been constructed adjacent to 132kV and 11kV transmission lines. Opinion from experts in this field is that the transmission lines would have no significant effect on distances measured by EDM instruments on the baseline.

(4.10) Should pillar movement be proven by a full re-measurement of the baseline using a prescribed instrument carrying Regulation 13 certification, the known distances in the EDM reduction software program are updated with the distances obtained in that re-measurement.

(4.11) The EDM baseline is available to support the testing and calibration needs of all EDM users. Access to the baseline is through the locked gate off Antill Street, Watson. Combination padlocks have been installed on the pillar lids and the access gate. The customer must supply their own ancillary equipment, including umbrellas, booking sheets, and meteorological equipment (see 1.7).

(4.12) Users of the Watson EDM baseline are required to observe the following points:

- no rubbish is to be left in the area;
- to avoid loss or theft do not leave padlocks unlocked at the pillars;
- vehicles are to be driven at low speeds and are to keep well clear of pillars; and
- report to OSGLI any factors that may affect the use of the baseline.

(5) Standard EDM Calibration: General Procedure

When testing or calibrating EDM instruments the following procedures are to be followed (see 1.4 above):

(5.1) **Booking Sheets or Recording Data**

All observations shall be recorded on the EDM Calibration booking sheet at the time they are made. When mistakes occur, each mistake should be crossed out, not erased or made illegible, and the correct value entered alongside. All such alterations should be signed or initialled by the person making the correction, and the date of change should also be recorded.

Comparisons between field and OSGLI standard meteorological equipment can be made by OSGLI and be recorded on the reverse page (p2) of the booking sheet prior to, or after the observations.

All details must be recorded and signed and dated by the operator. Scanned copies of completed booking sheets should be forwarded to OSGLI for records maintenance and monitoring of the baseline (see 6.4).

Units of measurement used are: metres (m) for distance, degrees Celsius (°C) for temperature, millibars (mb) for atmospheric pressure, and if measured, relative humidity (%). (The BASELINE software refers to hectopascals for units of atmospheric pressure.)

Note: 1 millibar (mb) = 100 pascals (Pa)
= 1 hectopascal (hPa)
= 0.750 28 mm Hg
= 0.029 53 in Hg

(5.2) **EDM Specifications**

Ascertain the unit length (m) of the instrument (half of the modulation wavelength of the fine measurement) prior to arriving at the EDM baseline, as this influences the measuring procedure. This unit length is generally quoted in the technical specifications in the instrument manufacturer's handbook. Record the unit length on the booking sheet.

Likewise ascertain the frequency (Hz), carrier wavelength (nm), and the manufacturer’s stated standard deviations of the EDM and record these on the booking sheet.

For time-of-flight EDMs (pulse distance meters), ascertain the carrier wavelength (nm) and record this on the booking sheet.

(5.3) **Preparation of Equipment**

Check the levelling bubbles on all tribrachs, reflectors and the total station, and if necessary, adjust before observing distances.

(5.4) **Set-up and Shade**

Set the instrument on pillar 1. An umbrella must shade the instrument for the duration of the calibration observations as well as during the warm-up period prior to the commencement of readings. To improve the accuracy of the calibration an umbrella may also be used to shade the reflector.

(5.5) **Atmospheric Correction Control**

Determine if the EDM is a phase-comparator type or a pulse distance meter.

If the EDM is a **phase-comparator**, then the atmospheric correction control (ppm) should be set to zero if possible. For instruments requiring meteorological observations to be input, enter the temperature and pressure for which the instrument is standardised (i.e. ppm = 0).

If the EDM is a **pulse distance meter**, distance readings should be first-velocity corrected by the on-board EDM software. In this case, the ambient temperature and pressure must be entered into the EDM before observing each inter-pillar distance. It is therefore essential that any corrections to the meteorological observations are applied before inputting into the instrument.

Alternatively, the instrument could be set such that ppm = 0, and the measured distances are subsequently reduced for the first velocity correction prior to upload into the BASELINE software for reduction. This procedure eliminates the possibility of entering erroneous meteorological observations into the instrument. A spreadsheet written for this purpose is now provided with the BASELINE reduction software.

(5.6) **Additive Constant/Reflector Type**

Modern total stations have pre-defined reflector options, with their default additive constants stored onboard. Ensure that the appropriate Reflector Type is selected.

Record the setting of the reflector additive constant on the booking sheet. *Alternatively*, set the additive constant to zero if possible.

Note: Generally, the accuracy of standard 'circular' reflector is better than 360° prisms, therefore the calibration of an EDM should be undertaken using a standard 'circular' reflector that is uniquely numbered. See (5.15) Comparison of Reflectors.

(5.7) **Distance Measurement Mode**

Review that the selected distance measurement mode is appropriate for the test observations, i.e. either single or averaged measurements.

Note: do not observe to a reflector in 'reflectorless' mode (Evans, 2014).

(5.8) **Power**

The EDM's battery should be fully charged prior to performing the calibration. If possible, the instrument should remain switched on during the whole calibration.

(5.9) **Height of Instrument**

With the EDM instrument levelled, measure the height of the instrument (height of the trunnion axis) above the brass pillar plate. Record this height at each occupied pillar.

(5.10) **Reflector Mountings**

The same reflector-tribrach combination should be used for all measurements, to eliminate reflector and/or tribrach eccentricity errors from the calibration. If it is not possible to measure the longer distances with one reflector, use a multiple-reflector mounting. With this arrangement it will be necessary to remove or block out some reflectors for the shorter distances.

The height of the centre of the reflector prism above the brass pillar plate must be measured and recorded for each pillar. If a multiple reflector arrangement is used, the reflector height in both the single and multiple configurations is recorded on the booking sheet.

The reflector must have a unique identification, which must be recorded on the booking sheet (see 5.15 below).

(5.11) **Levelling of Equipment**

All bubbles must be carefully levelled before distances are observed (see 5.3 above).

(5.12) **Meteorological Observations**

Field meteorological equipment can be compared to standardised OSGLI thermometers and barometers. Comparisons between field and standardised equipment will be recorded on the booking sheets.

Temperature (°C) must be measured in the shade at both the instrument and the reflector. Temperature is measured at instrument/reflector height to minimise the effect of radiated heat from the ground, and is to be observed for each inter-pillar interval.

The atmospheric pressure (mb or hPa) must be measured in the shade at the instrument station for each inter-pillar distance. To obtain a higher accuracy calibration, atmospheric pressure can also be observed in the shade at the reflector, for each inter-pillar interval.

Note: the typical atmospheric pressure readings at the Watson EDM Baseline are between 930 – 970mb, depending on meteorological conditions.

The significance of errors in the meteorological observations on the EDM distance measurement can be summarised as follows (for red laser/near infra-red type EDMs):

- An error in temperature of 1°C affects the distance by ~1ppm
- An error in pressure of 1hPa/1mb affects the distance by ~0.3ppm

Although humidity has an even smaller effect on measurements taken by infra-red or laser EDMs, relative humidity (%), or psychrometric observations can be taken to further improve the accuracy of the calibration.

Radio frequency (RF) interference is the radiation of RF energy that can interfere with the proper functioning of nearby devices. Some digital thermometers and hand-held weather stations used to measure temperature and pressure are susceptible to this interference. Thus, when radioing in meteorological readings using UHF transceivers, keep the transceiver well away from your meteorological equipment.

OSGLI meteorological equipment will not be loaned out. Users will need to provide their own meteorological equipment, and may compare their equipment to standardised OSGLI equipment before or after fieldwork.

(5.13) **Distance Measurements**

For each inter-pillar distance, a minimum of five (5) individual *slope* distance measurements are made, re-pointing after each measurement. Pointing can be made optically or electronically as prescribed by the instrument manufacturer. To improve the accuracy of the calibration, additional distances may be measured.

(5.14) **Sequence**

From pillar 1, measure distances to pillars 4 - 11 in turn. Then:

- If the instrument has a unit length of 0.32, 0.37, 2 or 10m, shift to pillar 2.

- If the unit length is 1, 3 or 5m, shift to pillar 3.

Then measure to pillars 11 - 4 in turn. The sequence requires the field assistant to move up-and-down the baseline only once.

For instruments with a unit length of 0.5, 0.8 or 1.5m or pulse meters, measure from pillar 1 to pillars 4 - 11 and from pillar 4 to pillars 11 - 5, and then measure to 3 – 1 in turn.

For instruments with a unit length of 20m, measure from pillar 1 to pillars 4 - 11 and from pillar 5 to pillars 11 - 6, and then measure to pillars 4 - 1 in turn.

Note: Refer to Table 1 in section 4.7 to determine which two pillars to occupy.

Higher order calibrations will be obtained by setting up on all pillars and measuring to all other pillars (the short distances between pillars 1, 2 and 3 are not observed).

(5.15) **Comparison of Reflectors**

Once all inter-pillar distances have been measured to the **one** uniquely identified reflector, compare this reflector with the remaining reflectors by measuring to each in turn (i.e. other standard 'circular', 360°, and mini reflector prisms). This should be performed on a short line (e.g. pillar 4 to pillar 3) by comparing the slope distances. However, if reflectors vary in height, horizontal distances should be observed, including the reflector used for the calibration.

Where found to be significant, variations should be applied as corrections to the additive constant. It is for this reason that all reflectors should be uniquely numbered.

Subsequent calibrations of the EDM should be performed using the same uniquely numbered reflector, in order to compile a calibration history for the instrument-reflector combination.

Note: Some users of the baseline set reflectors on every pillar to speed up the process when calibrating multiple EDMs on the one day.

However, this practice might not give reliable calibration results, even if all reflector-tribrach combinations are of an identical make. This is because there may be small variations in the index errors of the reflectors.

Although the results of the instrument constant comparison against NMI's minimum standards (±(4mm + 20ppm)) may result in a "PASS", it will not reflect the EDM's true precision unless the same reflectors are used for each calibration, AND that these same reflector-tribrach combinations be placed on the same pillars year after year.

(5.16) **Re-setting Instrument Settings**

It is recommended that upon completion of the EDM calibration observations, the ppm and additive constant settings should be re-set to the customers' typical EDM configuration, prior to the BASELINE software processing.

(6) Reduction and Interpretation

(6.1) The EDM Calibration software BASELINE developed by Landgate, Western Australia, is used to determine the instrument constants, errors and their associated uncertainties from field observations for individual EDM instruments. The National Measurement Institute and the ICSM Geodesy Working Group have approved the use of this software.

(6.2) Instrument details and measured distances (and observed meteorological details for phase-comparator EDMs) are entered interactively, or via upload of a text file correctly formatted for BASELINE. After the observed data is reduced to obtain horizontal distances and their associated standard deviations, a least squares adjustment is performed by the software. This computes the instrument corrections and their associated uncertainties. The adjustment is made as described in Rüeger (1996) for modelling systematic errors in EDM measurements.

(6.3) BASELINE generates an EDM Calibration Report, which includes baseline data, equipment details, observed data, adjusted observations, index correction, scale factor, (cyclic error for phase-comparator types) and variance factor. It also states the calculated uncertainty of the instrument correction at the 95% confidence level for standardised intervals.

(6.4) BASELINE also generates a concise EDM Calibration Certificate (see Appendix C). The Calibration Certificate contains the following:

- Associated information including the surveyor's name, date of measurements, baseline details and details of the EDM and reflector. The job identification name is also given.

- The Instrument Correction (IC) equation. From this IC equation, a correction (in millimetres) can be calculated for any distance measured by the EDM in the range of the calibration. A note regarding significant/insignificant cyclic errors is given if appropriate.

- The instrument calibration parameters (index error, scale error and if significant, the 4 terms modelling the cyclic error), and their uncertainties at the 95% confidence level are listed.

- Uncertainty - the uncertainty of the instrument correction at the 95% confidence level is listed for various distances. A pass result is given if the instrument uncertainty is less than that prescribed by Recommendation No.8 of the Working Party of the National Standards Commission on the calibration of EDM Equipment (see 2.2).

- The First Velocity Correction formula is provided if the EDM is a phase-comparator type.

The recommended procedure for evaluating the results of an EDM calibration is provided at Appendix D.

Where the statistical analysis reveals the calibration to be outside tolerances (see Appendix D), adherence to the test method, equipment settings and observation data shall be reviewed to determine the source of the inaccurate results. If changes are made, the calibration shall be re-run in the software and further reviewed. If the statistical analysis continues to fall outside of the tolerance, then the calibration is deemed to be nonconforming.

When the statistical analysis indicates that the calibration is within tolerance, the EDM Calibration Certificate can be signed by the surveyor.

In the event of a calibration found to be nonconforming, OSGLI shall be contacted to determine the required course of action. This may include a review of field practices and observation techniques used by the surveyor, or the suspension of calibration activities at the EDM baseline.

Upon a successful calibration, the instrument owner must send via email to: actplasurvey@act.gov.au a PDF file of the calibration report and certificate for each instrument calibrated, along with colour PDFs of the observation booking sheets.

Providing this information to OSGLI is vital as it allows ongoing crowd-sourced monitoring for any pillar movement at the baseline, and to maintain reassurance in the calibration process. Assistance to surveyors having issues with calibrations is also facilitated.

The recommended file-naming convention is: Date (*yyyymmdd*); Instrument Owner; Serial Number, e.g. *20240202 OSG 100614*. For booking sheets, the preferred style is similar, e.g. *20240202 Booking Sheet* i.e., the date links the calibration outputs to the observation data.

(6.5) A working knowledge of the instrument correction (IC) can be obtained from the field measurements by a simple linear regression analysis of index error and scale factor.

(7) Work Health and Safety

(7.1) Persons using the Watson EDM Baseline must comply with the requirements of the current ACT Work Health and Safety Act, Work Health and Safety Regulations and all relevant WorkSafe ACT guidelines.

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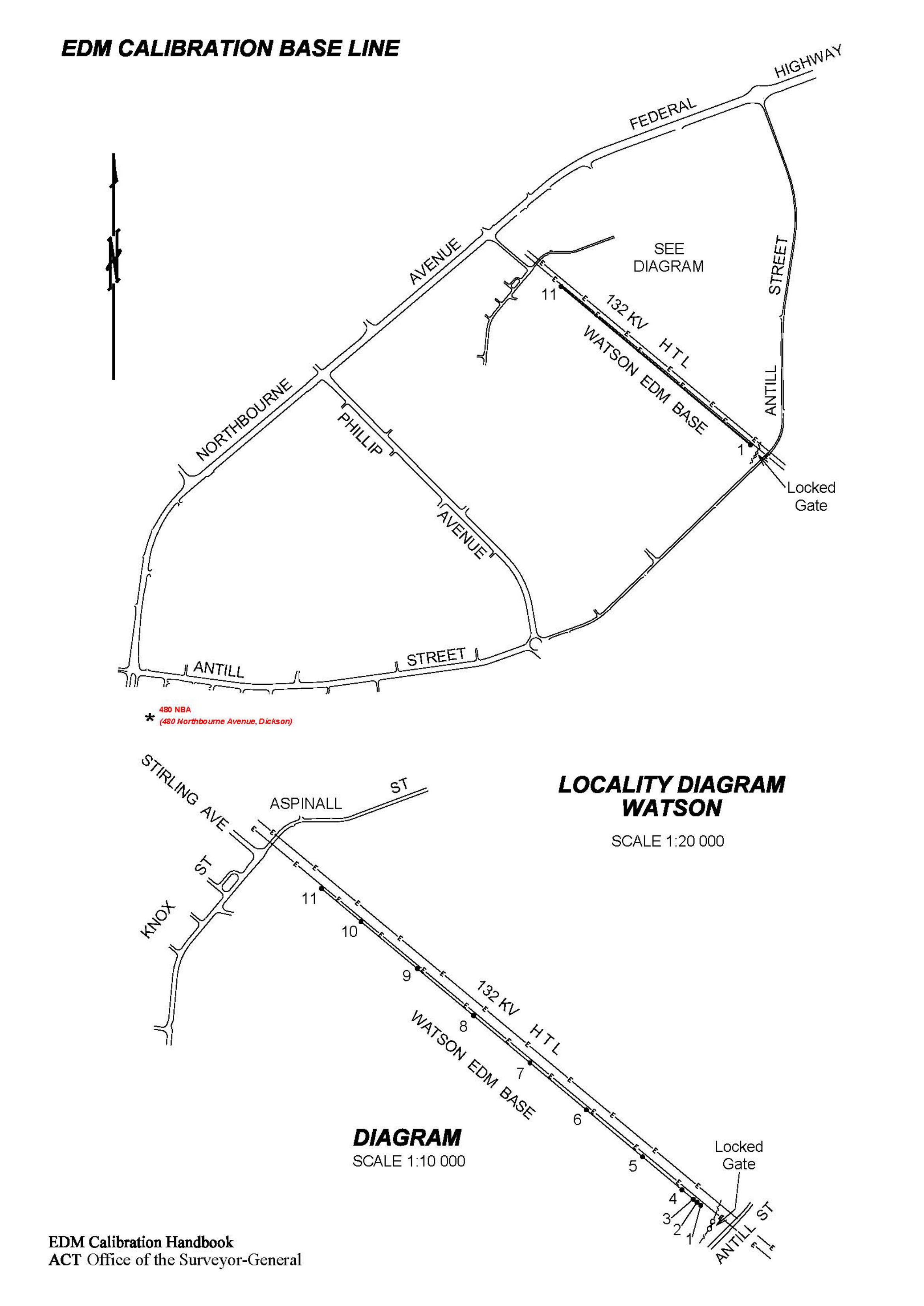
Appendix A - Locality Plan of the Watson EDM Baseline



Appendix B - Sample Booking Sheet (page 1 of 2)

EDM CALIBRATION SHEET – WATSON BASE

DATE	OBSERVER	ASSISTANT	ORGANISATION

INSTRUMENT

INSTR. MAKE	MODEL	SERIAL No.

(SEE OVER FOR ADDITIONAL REQUIRED EDM DETAILS)

REFLECTOR

REFL. MAKE	MODEL	SERIAL No.	CONSTANT

THERMOMETERS

INSTR. MAKE	SERIAL No.	CORR'N
(I)		± °C
(R)		± °C

BAROMETERS

INSTR. MAKE	SERIAL No.	CORR'N
(I)		± mb
(R)		± mb

WEATHER CONDITIONS

CHECKLIST ☐ Instrument shaded ☐ Mets. Equipment shaded ☐ Index constant set to ZERO ☐ Instr. Re-pointed for each meas. ☐ ***SLOPE DISTANCES***

Is the EDM a Pulse Distance Meter? ☐ NO: PPM set to **ZERO** ☐ YES: Enter Mets into EDM for each inter-pillar distance ☐ Reflector type correctly set in Instrument

FROM **PILLAR**	***TO*** **PILLAR**	**Ht. of Instr.**	**Ht. of Reflector**	**INSTR. TEMP** (°C)	**REFL. TEMP** (°C)	**MEAN TEMP** (°C)	**PRESSURE Instr** (mb)	**PRESSURE Refl** (mb)	**SLOPE DISTANCES** (1)	(2)	(3)	(4)	(5)	**TIME**	**COMMENTS**

Signed: ………………………….. Postal Address: …………………………………………………………………………… Sheet ……. of ……..

Appendix B - Sample Booking Sheet (page 2 of 2)

EDM CALIBRATION SHEET (*continued*)

Please complete the following EDM details required for the calibration software. These values can be found in the instrument documentation, or can be obtained from the dealer where the instrument was purchased, or may be available from the instrument maker's website.

EDM DETAILS

Make		Carrier Wave Length (λ)	nm
Model		Pulse Distance Meter?	YES / NO
Serial No.		Manufacturer's Std. Dev. Additive Constant	mm
Unit Length *(Modulation Wavelength ⁄ 2)*	metres	Manufacturer's Std. Dev. PPM	ppm
Frequency	MHz	Comments	

THERMOMETER COMPARISON

BEFORE FIELDWORK

THERMOMETER	SERIAL No.	OBSERVED TEMP (°C)	CORR'N	ADJUSTED TEMP (°C)
FLUKE 51 II Digital (office standard)	13130032			
FLUKE 51 II Digital (office standard)	13130033			

AFTER FIELDWORK

THERMOMETER	SERIAL No.	OBSERVED TEMP (°C)	CORR'N	ADJUSTED TEMP (°C)
FLUKE 51 II Digital (office standard)	13130032			
FLUKE 51 II Digital (office standard)	13130033			

BAROMETER COMPARISON

BEFORE FIELDWORK

BAROMETER	SERIAL No.	OBSERVED PRESSURE (mb)	CORR'N	ADJUSTED PRESSURE (mb)
Wallace & Tiernan (office standard)	13507			
Wallace & Tiernan (office standard)	13508			

AFTER FIELDWORK

BAROMETER	SERIAL No.	OBSERVED PRESSURE (mb)	CORR'N	ADJUSTED PRESSURE (mb)
Wallace & Tiernan (office standard)	13507			
Wallace & Tiernan (office standard)	13508			

Appendix C – Sample EDM Calibration Certificate (page 1 of 2)

ACT Government
Environment, Planning and Sustainable Development

Page 1 of 2

Job Identification: 20181019 OSG 1667901

EDM Calibration Certificate

This report has been generated by program Baseline Version 6.1.0.3, developed by the Western Australian Land Information Agency.

Use of this application elsewhere should rely on baseline distances certified by the relevant authority.

Observation Date: 19/10/2018
Instrument Operator: R. Bugg
Computation Date: 22/10/2018
Computation Time: 3:03:21 PM

Equipment Details

Instrument Owner: Office of the Surveyor-General
Owner Address: GPO Box 158 Canberra ACT 2601
EDM Instrument Make: Leica
EDM Instrument Model: TS15
EDM Serial Number: 1667901

Reflector Make: Sokkia
Reflector Model: APS12
Serial Number: No. 1
Reflector Constant: 0 mm

Baseline Details

Name Watson
Location: Antill St Watson, ACT
Authority: Surveyor-General of the ACT
Last calibration Date: 20/08/2018
Authority Address: GPO Box 158 Canberra ACT 2601

This baseline consists of known lengths, which are the certified distances between the pillars of the baseline. All certified distances are on the same horizontal plane and on the same vertical plane running through the first and last stations.

The baseline distances are traceable to standards specified by the Verifying Authority.

Instrument Correction (IC) in mm (to be added to the instrument reading)

IC = -2.23 - 0.00056 L + Reflector Constant(mm)

Where L = distance in metres

The reflector constant has not been entered into the instrument

CYCLIC ERRORS ARE INSIGNIFICANT

Calibration Parameters	Value	Uncertainty(95%)
Index	-2.23 mm	± 0.60 mm
Scale	-0.56 ppm	± 2.00 ppm

The instrument correction has been determined from measurements in the range of 47 to 1118 metres

Accredited for compliance with ISO/IEC 17025. The results of the tests, calibrations and/or measurements included in this document are traceable to Australian/national standards. This document shall not be reproduced, except in full.

NATA Accreditation Number 15005

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Appendix C – Sample EDM Calibration Certificate (page 2 of 2)

ACT Government
Environment, Planning and Sustainable Development

Job Identification: 20181019 OSG 1667901

EDM Calibration Certificate

This report has been generated by program Baseline Version 6.1.0.3, developed by the Western Australian Land Information Agency.

Use of this application elsewhere should rely on baseline distances certified by the relevant authority.

Uncertainty of the Instrument Correction

Minimum standard for the uncertainty of calibration of an EDM instrument is ±(4.00 mm + 20.00 ppm) as described in terms of Recommendation No.8 of the Working Party of the National Standards Commision on the calibration of EDM Equipment of 1 February, 1983. All uncertainties are specified at the 95 % confidence level. A coverage factor of 2 has been used for the uncertainty computations. The Least Uncertainty of Measurement as specified by the Accreditation Authority has been used for the uncertainty of the instrument correction.

Uncertainty of instrument correction: ±(0.60 mm + 2.00 ppm)

Distance (metres)	Instrument Uncertainty (mm)	Minimum Standard (mm)	Comparison Test
50	±0.70	±5.00	PASS
100	±0.80	±6.00	PASS
300	±1.20	±10.00	PASS
500	±1.60	±14.00	PASS
800	±2.20	±20.00	PASS
1100	±2.80	±26.00	PASS

This instrument satisfies the National Measurement Institute standards.

First Velocity Correction (Atmospheric Correction)

$$\text{Correction} = \left(286.34 - \frac{80.68\,P}{(273.15 + Td)} + \frac{11.27\,e}{(273.15 + Td)} \right) .\,\text{distance}/1000000$$

Where Td = Dry Temperature(Celsius), P = Barometric pressure(hectapascals)
e = partial Vapour Pressure (hectapascals)

The first velocity correction is based on a velocity of light of 299792458.00 m/s and on the refractive index formulae recommended by the International Association of Geodesy in 1999.

The calibration of the EDM Instrument has been carried out according to Work Instructions provided by the Office of the Surveyor-General & Spatial Information, ACT Government.

Data entry by: ____________________ Results checked by: ____________________

Position: ____________________ Position: ____________________

Signature: ____________________ Approved Signatory: ____________________

Date: ____________________ Date: ____________________

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NATA
NATA Accreditation Number 15005

22/10/2018 3:05:17 PM

Appendix D - Procedure for Evaluating an EDM Calibration Report

The procedures detailed below are recommended for evaluating each EDM calibration to determine if it is a conforming result. Use the detailed EDM Calibration Report for the evaluation:

1. Review that the header information is correct for the EDM instrument undergoing test.

Observation Date:	23/05/2023	**Computation Date:**	28/06/2023
Instrument Operator:	G. Evans	**Computation Time:**	2:10:03 PM
Instrument Owner:	Office of the Surveyor-General	**Reflector Make:**	Leica
Owner Address:	480 Northbourne Ave, Dickson ACT 2602	**Reflector Model:**	GPH 1P
EDM Instrument Make:	Leica	**Serial Number:**	439845P1
EDM Instrument Model:	TS15	**Reflector Constant:**	0 mm
EDM Serial Number:	1667901		

2. Review that the Instrument Parameters and the meteorological setting (i.e. ppm settings) are correct (page 1).

INSTRUMENT PARAMETERS	
EDM additive constant	0.000
Reflector additive constant	0.000
Unit length in metres	1.50000
Modulation frequency in Hertz	99902214
Carrier wavelength in nanometres	658.000
Manufacturer's EDM std dev constant	0.001
Manufacturer's EDM std dev PPM	1.500
Std dev centring of instruments	1.0000
Mets dial is not set	
Thermometer correction in Celsius	0.000
Barometer correction in hectapascals	0.000

3. Check that you are using the latest Baseline Distribution file (page 2). The Watson EDM Baseline is usually re-calibrated annually.

BASELINE DETAILS	
Baseline name	Watson
Baseline location	Antill St Watson, ACT
Baseline authority	Surveyor-General of the ACT
Authority Address	GPO Box 158 Canberra ACT 2601
Baseline calibration date	1/06/2022
Baseline reference	File 02/13225

4. Check that C and D terms agree with those provided by the instrument manufacturer (page 4).
    - This is necessary for the First Velocity (atmospheric) correction to be correctly applied to the observed distances.
    - Note, the Meteorological Parameters are not displayed in the Calibration Report if the temperature and atmospheric pressure were entered into the EDM when observing the inter-pillar distances (i.e. the atmospheric corrections were applied on-board).

```
-------------------------------------------------------------------
|                                                                 |
|                  METEOROLOGICAL PARAMETERS                      |
|                                                                 |
|-----------------------------------------------------------------|
|  Weather conditions                  |20% overcast, 5-10kt westerly |
|  Mean dry Temperature 'Td'           |         8.39  Celsius    |
|  Mean Humidity                       |        52.98  %          |
|  Mean Pressure  'P'                  |       943.44  hPa        |
|  Partial Water Vapour Pressure 'e'   |         5.81  hPa        |
|  Reference Refractive Index          |    1.0002863             |
|  First velocity term 'C'             |       286.34             |
|  First Velocity term 'D'             |        80.68             |
|-----------------------------------------------------------------|
|                                                                 |
|          FIRST VELOCITY CORRECTION APPLIED                       |
|                                                                 |
|                D.P            11.27 e                          |
|  K = ( C - ------------- + ------------- ).distance/1000000     |
|            (273.15 + Td)    (273.15 + Td)                       |
|                                                                 |
-------------------------------------------------------------------
```

5. For each inter-pillar distance, check:
    - The observed distances are entered correctly
    - The temperature and atmospheric pressure are entered correctly
    - Five distances have been entered
    - The standard deviation is small (usually sub-millimetre)
    - Depending on the number of inter-pillar observations, these are shown on pages 5 to 13 (approximately)

```
========================================================================
            FROM PILLAR                             TO PILLAR
-------------------------------------   ------------------------------
Pillar ID            :      1           Pillar ID            :     5
Height above pillar:     0.239 m        Height above pillar:     0.238 m

Dry Temperature      :       7.0 Celsius
Humidity             :     61.00 %
Pressure             :     942.7 millibars

                     DISTANCE OBSERVATIONS (metres)
------------------------------------------------------------------------
  1   Observed distance           171.3370
  2   Observed distance           171.3360
  3   Observed distance           171.3360
  4   Observed distance           171.3360
  5   Observed distance           171.3360
                                  ---------
Mean observed slope distance :    171.3362      Std Dev =     0.0004
```

6. Check the a-priori standard deviation of the observed distance measurements (page ~15).
    - Modern EDMs usually return precise observations with a small range in each observation set, therefore the a-priori standard deviation of the measurements should be small.

```
---------------------------------------------------------------------
                  SUMMARY OF A PRIORI STANDARD DEVIATIONS
---------------------------------------------------------------------

The following a priori standard deviations have been adopted:

    EDM Distance measurements       :  0.29 mm +   0.000 ppm
    Baseline Interval               :  0.25 mm +   1.221 ppm
    Centring EDM Instrument         :  0.50 mm
    Centring reflector              :  0.50 mm
    Offset                          :  0.50 mm
    EDM Height above pillar         :  1.00 mm
    Reflector Height above pillar   :  1.00 mm
    Pillar Height difference        :  0.50 mm
    Temperature                     :  0.8 Celsius
    Pressure                        :  1.0 hPa
    Humidity                        :  3.0 %
```

7. Check the Summary of Linear Miscloses (page ~16). The Observed Distance values are the unadjusted distance observations reduced for the First Velocity Correction and slope only:
    - The Misclose and a-priori standard deviation should be commensurate with the instrument manufacturer's standard deviation of the additive and scale constants (e.g. 2mm + 2ppm).
    - A larger than expected unadjusted misclose may indicate an error has occurred entering any one of the field observations (i.e. distance, temperature, pressure, instrument height or target height).
    - A large misclose may indicate potential pillar movement, especially if it is repeated a second time to that pillar.

SUMMARY OF LINEAR MISCLOSES

PILLAR NUMBERS INSTR	REFL	FIXED DISTANCE (m)	OBSERVED DISTANCE (m)	MISCLOSE (m)	A PRIORI STD. DEV. (m)
1	4	54.7763	54.7773	-0.0010	0.00083
1	5	171.2109	171.2115	-0.0006	0.00090
1	6	337.0098	337.0108	-0.0010	0.00105
1	7	503.0111	503.0125	-0.0014	0.00122
1	8	668.9794	668.9799	-0.0005	0.00141
1	9	835.0251	835.0264	-0.0013	0.00162
1	10	1001.0347	1001.0353	-0.0007	0.00183
1	11	1117.5166	1117.5169	-0.0003	0.00199
4	11	1062.7403	1062.7405	-0.0002	0.00191
4	10	946.2584	946.2594	-0.0010	0.00176
4	9	780.2488	780.2501	-0.0013	0.00155
4	8	614.2031	614.2041	-0.0010	0.00135
4	7	448.2348	448.2351	-0.0003	0.00116
4	6	282.2336	282.2344	-0.0009	0.00099
4	5	116.4346	116.4348	-0.0002	0.00086
4	3	47.2769	47.2775	-0.0006	0.00083
4	2	49.7764	49.7765	-0.0002	0.00083
4	1	54.7763	54.7766	-0.0003	0.00083

8. Verify that the Estimated Calibration Parameters are commensurate with the model of EDM under test (page ~17):
    - As a guide, the estimated Index parameter should not exceed ± a few millimetres.
    - The estimated Scale parameter should not exceed ±3 – 4ppm. Note that a large scale error is often the result of poor modelling of the meteorological conditions.
    - If the EDM has previously undergone calibration, check if these estimated parameters are of a similar order of magnitude.
    - When calibrating EDMs, the Office of the Surveyor-General uses a Least Uncertainty of Measurement (LUM) of 0.6mm + 2ppm (at the 95% confidence interval). If the calculated standard deviations are smaller than the LUM, then the reported standard deviations of the instrument parameters are expanded to the LUM (i.e. 0.3mm + 1ppm). The standard deviations stated in the Report are expanded to the 95% confidence interval on the EDM Calibration Certificate.
    - When combined together, the calculated standard deviations are referred to as the Uncertainty of the Instrument Correction (see section 9 below).

```
LEAST SQUARES ESTIMATED CALIBRATION PARAMETERS

        Parameter          |    Value              |   Std Dev
     Index                 |   -0.52 mm            |    0.30 mm
     Scale                 |   -0.43 ppm           |    1.00 ppm

                 FULL INSTRUMENT CORRECTION IN MM
                 (TO BE ADDED TO INSTRUMENT READING)

     IC =  -0.5 -   0.0004 L

  Where L = distance in metres
 The prism constant has been entered into the instrument
```

9. Check that the Uncertainty of the Instrument Correction passes the comparison test against the prescribed standards (page ~18):
    - Note that the minimum standard of ±(4mm + 20ppm) at the 95% confidence interval is very loose. Usually only very old EDMs fail this test due to aging electronic components.

UNCERTAINTY OF THE INSTRUMENT CONSTANT AGAINST PRESCRIBED STANDARDS

Minimum standard for the uncertainty of calibration of an EDM instrument is described in terms of Recommendation No.8 of the Working Party of the National Standards Commision on the calibration of EDM Equipment of 1 February, 1983.

All uncertainties are specified at 95% confidence.

Minimum Standard's specifications : ±(4.00 mm + 20.00 ppm)
Uncertainty of instrument correction : ±(0.25 mm + 0.57 ppm)

DISTANCE (metres)	INSTRUMENT UNCERTAINTY (mm)	MINIMUM STANDARD (mm)	COMPARISON TEST
50	± 0.27	± 5.00	PASS
100	± 0.30	± 6.00	PASS
300	± 0.42	± 10.00	PASS
500	± 0.53	± 14.00	PASS
800	± 0.70	± 20.00	PASS
1100	± 0.87	± 26.00	PASS

The uncertainty of the instrument constant satisfies the National Measurement Institute recommended minimum standard where a 'PASS' is indicated.

10. Review the Least Squares Statistical Analysis (page ~19):
    - The chi-square (χ2) test on the variance factor will fail if the a-posteriori variance factor is too high, indicating that larger than expected least squares residuals are present.
    - The chi-square (χ2) test on the variance factor will also fail if the a-posteriori variance factor is too low, and often occurs when calibrating a modern EDM shortly after the Watson EDM Baseline has been re-calibrated In this case, the histogram of the standardised residuals (page ~21) will display a high peak and does not conform to a Normal distribution (see below). This indicates that the weighting of the observations may have been more stringent, with the failure being caused by the a-posteriori variance factor being 'too good'.

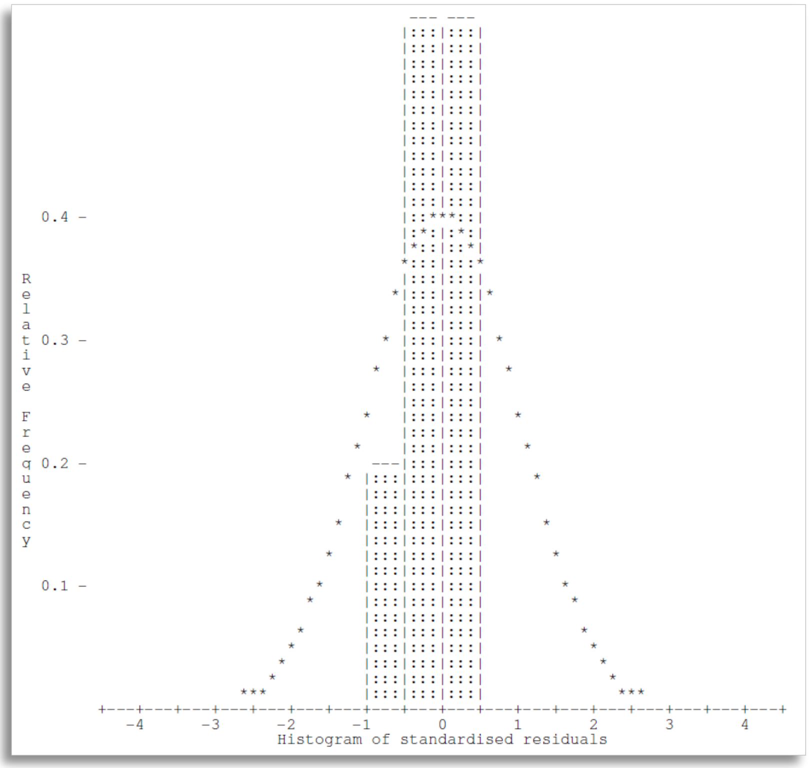
LEAST SQUARES STATISTICS

Number of observed baselines	18
Number of parameters	2
Confidence level	95.00 %
Coverage factor	2.00
Degrees of freedom	16
Critical t value	2.120
Minimum	1.901
A posteriori variance factor	0.119

Chi-Square Test on the Variance Factor

6.592E-002 < 1.000 < 2.712E-001 ?

THE TEST FAILS



11. Review the Summary of the Least Squares Estimated Residuals (page ~20):
    - Gross and systematic errors are detected by analysing the residuals and standardised residuals. Check the size of the residuals, which should be commensurate with the instrument specifications.
    - Observations with very large residuals should be rejected, however for the smaller standardised residuals you must decide whether they are caused by:
        - Large random errors, in which case you should retain the observation.
        - Systematic errors, in which case it should be rejected.
    - Note that a large residual may indicate potential pillar movement, especially if it is repeated a second time to that pillar.
    - Inter-pillar distances containing standardised residuals which exceed the 3σ residual rejection criterion (i.e. outliers) are flagged by asterisks.

SUMMARY OF LEAST SQUARES ESTIMATED RESIDUALS

PILLAR NO INST	PILLAR NO REFL	CERTIFIED DISTANCE (m)	OBSERVED DISTANCE (m)	STD DEV OBSERV (m)	ADJUSTED DISTANCE (m)	STD DEV RESIDUAL (m)	RESIDUAL (m)	STANDARD RESIDUAL
1	4	54.7763	54.7773	0.0008	54.7767	0.0008	-0.0005	-0.56
1	5	171.2109	171.2115	0.0009	171.2109	0.0009	0.0000	-0.03
1	6	337.0098	337.0108	0.0010	337.0102	0.0010	-0.0003	-0.31
1	7	503.0111	503.0125	0.0012	503.0118	0.0012	-0.0007	-0.58
1	8	668.9794	668.9799	0.0014	668.9791	0.0014	0.0003	0.20
1	9	835.0251	835.0264	0.0016	835.0255	0.0016	-0.0004	-0.26
1	10	1001.0347	1001.0353	0.0018	1001.0344	0.0018	0.0003	0.16
1	11	1117.5166	1117.5169	0.0020	1117.5159	0.0020	0.0007	0.34
4	11	1062.7403	1062.7405	0.0019	1062.7396	0.0019	0.0007	0.39
4	10	946.2584	946.2594	0.0018	946.2584	0.0017	-0.0001	-0.04
4	9	780.2488	780.2501	0.0015	780.2493	0.0015	-0.0004	-0.29
4	8	614.2031	614.2041	0.0013	614.2033	0.0013	-0.0003	-0.19
4	7	448.2348	448.2351	0.0012	448.2344	0.0012	0.0004	0.37
4	6	282.2336	282.2344	0.0010	282.2338	0.0010	-0.0002	-0.23
4	5	116.4346	116.4348	0.0009	116.4342	0.0009	0.0004	0.42
4	3	47.2769	47.2775	0.0008	47.2770	0.0008	0.0000	-0.04
4	2	49.7764	49.7765	0.0008	49.7760	0.0008	0.0004	0.45
4	1	54.7763	54.7766	0.0008	54.7761	0.0008	0.0002	0.27

12. Following the above-mentioned evaluation of the EDM Calibration report, and when the statistical analysis indicates that the calibration is within tolerance, the EDM Calibration Certificate can be signed by the surveyor. Contact the Office of the Surveyor-General and Land Information if you have any unresolved issues with a EDM calibration.