Best Practice: Performing EDM Calibrations in NSW

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ABSTRACT

The Surveyor General of New South Wales is a verifying authority for reference standards of length measurements under the National Measurement Act 1960 and responsible for ensuring that surveyors use verified measuring equipment. To this end, the Surveying and Spatial Information Regulation 2012 requires surveyors to verify their Electronic Distance Measurement (EDM) equipment in relation to an Australian standard of measurement of length at least once a year. In order to assist the profession in meeting this requirement, Land and Property Information (LPI) provides and maintains several EDM baselines across the state. LPI is currently in the process of improving this infrastructure by upgrading existing baselines and building new baselines for the calibration of EDM instruments. This paper briefly presents the current status of EDM baseline infrastructure in NSW and outlines best practice guidelines for EDM calibrations in NSW. These proposed guidelines are expected to flow on into the next update of Surveyor General's Direction No. 5 (Verification of Distance Measuring Equipment).

KEYWORDS: *EDM, calibration, best practice, metrology, NSW.*

1 INTRODUCTION

Legal metrology covers all measurements carried out for any legal purpose, including measurements that are subject to regulation by law or government decree. The National Measurement Act 1960 provides the legal basis for a national system of units and standards of measurement of physical quantities (Australian Government, 2013). This Act is administered by the National Measurement Institute (NMI), which may in turn appoint organisations as verifying authorities under the provisions of Regulation 73 of the National Measurement Regulations 1999 (Australian Government, 2014). As such, the office of the Surveyor General of New South Wales (NSW) has been appointed as a verifying authority for length measurement standards and is formally accredited by the National Association of Testing Authorities (NATA) for its technical competence in providing calibration services in accordance with the requirements of AS ISO/IEC 17025 *General Requirements for the Competence of Testing and Calibration Laboratories*.

Practising surveyors in NSW are subject to the Surveying and Spatial Information Act 2002 (NSW Legislation, 2014a) and the Surveying and Spatial Information Regulation 2012 (NSW Legislation, 2014b). The latter states, among other things, that a surveyor must not use any Electronic Distance Measurement (EDM) equipment unless it is verified against the state primary standard of measurement of length by using pillared baselines, at least once every year and immediately after any service or repair. Verification is also strongly advised after the instrument receives rough treatment or hard knocks, or before it is being used for highaccuracy surveys. This instrument verification establishes traceability of its measurements to the national standard, and consequently strengthens the validity of these measurements if questioned in a court of law.

In order to assist the surveying profession in meeting the legal requirements, the Surveyor General has established and continues to maintain several EDM baselines throughout the state. The field procedures prescribed for EDM calibrations in NSW are documented in Surveyor General's Direction No. 5: Verification of Distance Measuring Equipment (LPI, 2009). This paper provides updated best practice guidelines for EDM calibrations in NSW, which are expected to flow on into the next update of Surveyor General's Direction No. 5. It should be noted that these guidelines do not include reflectorless EDM observations.

2 EDM INSTRUMENT ERRORS AND CORRECTIONS

The calibration of an EDM instrument is performed in order to determine the instrument errors, which can be used to monitor the performance and reliability of the EDM instrument over time and assess its precision against the manufacturer's specifications. If significant, these instrument errors should be accounted for by applying corrections to measurements taken subsequent to the calibration. If the calibration is performed on a verified baseline (i.e. a baseline with a current Regulation 13 certificate) to a prescribed level of precision, the EDM instrument is considered to be standardised. The three distinct systematic errors that may occur in EDM instruments are the zero error (also known as index error), the scale error, and the cyclic error (also known as short periodic error) (Rüeger, 1996).

2.1 Additive Constant (Correction to Zero Error or Index Error)

All distances measured by a particular instrument/reflector pair are subject to a constant error, which is caused by three factors:

- Electrical delays, geometric detours and eccentricities in the EDM instrument.
- Differences between the electronic and mechanical centres of the EDM instrument.
- Differences between the optical and mechanical centres of the reflector.

In other words, the error is mainly caused by the distance measuring reference points in the EDM instrument and at the reflector not being coincident with the vertical axes at either end of the measured line. This error may vary with a change of reflector, after receiving jolts, with different instrument mountings and after service. The additive constant or zero/index correction is an algebraic constant (often stated in mm) to be applied directly to every measured distance.

2.2 Scale Error

The scale error is linearly proportional to the length of the measured line and is caused by:

- Variations in the modulation frequency of the EDM instrument.
- Incorrect modelling of the atmosphere, i.e. errors in the measured temperature, atmospheric pressure and humidity, which affect the velocity of the signal propagation.
- Non-homogeneous emission/reception patterns from the emitting and receiving diodes (phase inhomogeneities).

The scale factor (or scale correction) is generally expressed in parts per million (ppm) and also applied directly to every measured distance.

2.3 Cyclic Error (or Short Periodic Error)

The cyclic error is caused by electrical and optical interference within the EDM instrument. It varies across the modulated wavelength and is usually sinusoidal in nature with a wavelength equal to the unit length of the EDM instrument. The unit length is the scale on which the EDM instrument measures the distance and is derived from the fine measuring frequency. The unit length is equal to exactly one half of the EDM instrument's modulation wavelength (Rüeger, 1996).

As the cyclic error repeats itself for every unit length contained within a measured distance, its sign and magnitude vary depending on the length measured. The magnitude of the error could be in the order of 5 mm to 10 mm. However, in modern EDM instruments it is usually less than 2 mm and therefore negligible. It should be noted that the cyclic error can increase in magnitude as the instrument's components age.

3 CURRENT AND FUTURE EDM BASELINE INFRASTRUCTURE

The Surveyor General has established several EDM baselines consisting of between four and seven concrete pillars throughout NSW. Current best practice has established that EDM baselines should consist of at least five (and preferably six or seven) pillars to increase the number of distances observed, thereby allowing a more reliable determination of the instrument correction due to higher redundancy. As a result, and on behalf of the Surveyor General, Land and Property Information (LPI) is currently in the process of rationalising and improving its EDM baseline infrastructure by upgrading existing baselines to include more pillars and/or building new 7-pillar baselines. A detailed description of the substantial issues that need to be considered in the design and construction of a state-of-the-art EDM baseline is given in Ellis et al. (2013). Depending on the location of the baseline, particular environmental aspects may also have to be considered (Janssen, 2013). It should be noted that the use of longer EDM baselines allows more distances to be observed, thus increasing redundancy and providing considerably more reliable EDM calibration results.

Figure 1 illustrates the location of the 15 EDM baselines presently maintained in NSW. The latest addition is the new 7-pillar Seaham baseline (released in December 2014), replacing the 4-pillar baseline at Newcastle. Efforts to upgrade the 4-pillar Armidale baseline to include seven pillars and establish a new 7-pillar baseline at Coffs Harbour (replacing the 4-pillar baseline at Grafton) are well underway. In addition, it is planned to upgrade the 4-pillar Wollongong baseline to 7 pillars and establish at least two 7-pillar baselines on the South Coast.

All EDM baselines in NSW (current and those under construction) follow the Heerbrugg design (also known as Schwendener design), which features an almost equal distribution of the distances measured in all combinations over the baseline length as well as over the unit length of the EDM instrument and permits the detection of all distance-dependent errors, including cyclic errors (e.g. Schwendener, 1972; Rüeger, 1996).

Figure 1: Location of current EDM baselines in New South Wales.

LPI verifies these baselines on a 2-yearly basis with precise EDM instrumentation carrying a current Regulation 13 certificate issued by the National Measurement Institute (NMI). It should be noted that the associated meteorological equipment is also calibrated against industry standards. This process determines the 'true' inter-pillar distances and establishes traceability because the EDM baseline becomes a subsidiary standard of the International Metre. In accordance with the appointment as a verifying authority for length measurement standards, the least uncertainty quoted for the verified inter-pillar distances is currently 0.5 mm + 1.3 ppm at the 95% confidence interval. The current measurement report for each baseline can be found on the LPI website (LPI, 2015a).

4 ACCESS TO EDM BASELINES IN NSW

Access to all EDM baselines in NSW is restricted to authorised personnel, and it is mandatory to book access via the EDM Baseline Booking System. This free online booking system is available on the LPI website (LPI, 2015b) and allows registered users to reserve a particular time slot at the desired baseline in advance.

The booking process is simple and straightforward, comparable to booking a hotel room online. It consists of the following three simple steps (Figure 2):

1. Select a booking date.
2. Select an EDM baseline.
3. Select an available booking time slot.

Once the booking is finalised, an automatic confirmation will be sent by email, also outlining the general and baseline specific conditions of use that had to be accepted during the booking process. The user is required to carry a printout of this booking confirmation with them at all times when on the baseline site. This will provide proof of approved access to the baseline for the specified time period.

The EDM Baseline Booking System facilitates efficient and effective use of existing and future baseline infrastructure in NSW. By allowing LPI to monitor the frequency of use of each baseline, it also assists LPI in making more informed decisions regarding the state's EDM baseline infrastructure.

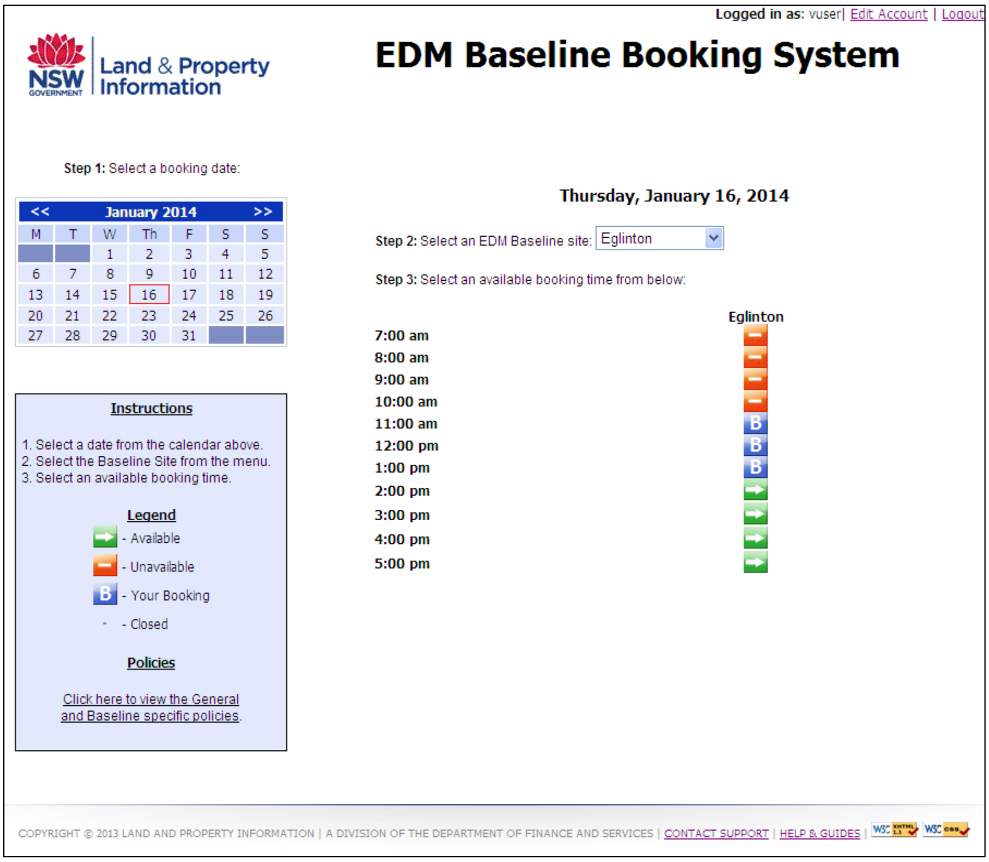

Figure 2: Main page of the online EDM Baseline Booking System (http://lpi.nsw.gov.au/edmbooking).

5 BEST PRACTICE FOR EDM CALIBRATIONS IN NSW

The calibration of an EDM instrument on a verified baseline determines the corrections that need to be applied to the instrument in order to obtain the 'true' inter-pillar distances, thereby establishing traceability of its measurements to the national standard. Most jurisdictions have produced guidelines on how to perform EDM calibrations (e.g. LPI, 2009; Queensland Government, 2012; ACT Government, 2014; Land Victoria, 2014), based on the recommendations made by Rüeger (1984). This section updates and expands the current best practice guidelines available in NSW.

It is assumed that there is no pillar movement between the time of baseline verification (performed by LPI) and the time of the EDM calibration undertaken by the user. While it is recognised that pillars do demonstrate seasonal movement in some cases, generally this movement is too small to have any significant effect. Baseline stability is closely monitored by LPI to ensure that calibrations can be performed to the required precision. If it is suspected that pillar movement has occurred, it should be reported to LPI via EDMcal@lpi.nsw.gov.au for immediate action and resolution.

5.1 Preparation of Equipment

1. Obtain the latest EDM baseline measurement report detailing the current distances, reduced levels and access details from the LPI website (LPI, 2015a).
2. Use the EDM Baseline Booking System (LPI, 2015b) to book access to the baseline (see section 4).
3. Check the levelling bubbles on all tribrachs, reflectors and the total station, and adjust if necessary before observing the baseline. Levelling of the instrument and reflectors is critical during calibration.
4. Verify the thermometer(s) and barometer(s) against a certified standard. The collection of accurate meteorological data is essential for a reliable EDM calibration.
5. Ensure that the EDM battery is fully charged prior to carrying out the calibration.
6. All reflectors should be marked with a unique identification number. Only one of these reflectors is to be used for the EDM calibration observations.
7. It is recommended to use the EDM calibration recording sheet available from LPI (2015a) for the recording of baseline observations in the field.

5.2 Observation Procedure

1. Standard Work Health and Safety (WHS) principles must be observed. For example, this includes obeying road rules, not obstructing traffic near the baseline and wearing personal protective equipment.
2. Any general and baseline specific conditions of use must be obeyed. These conditions are detailed in the booking confirmation email, a printout of which must be carried on site.
3. Upon arrival at the baseline, each pillar must be checked for damage, disturbance or obstruction. Remove any protective pillar caps (and replace these after completion of the field work). If minor clearing of vegetation is required, do so in the appropriate manner and adhere to any restrictions and/or process that may be applicable.
4. The instrument and meteorological equipment should be shaded by an umbrella. Note that most EDM instrument specifications refer to a temperature range of -20°C to +50°C. However, the temperature inside an EDM instrument in direct sunlight on a hot summer's day can exceed this temperature range.
5. Before commencing measurement, the EDM instrument should be carefully levelled and allowed a 'warm up' period if recommended by the instrument manufacturer.
6. Set the additive constant and the atmospheric correction (ppm) to zero. Some EDM instruments only accept the input of ambient temperature and pressure readings in lieu of a ppm setting. When calibrating these instruments, the operator should refer to the instrument manual and input a temperature and pressure which corresponds to the reference refractive index for that particular instrument. This is the temperature and pressure at which the instrument applies a zero ppm correction to measured distances.
7. If possible, set the instrument to display distances to four decimal places of a metre rather than three.
8. The height of instrument and the height of reflector above the pillar plate are to be measured to an accuracy of one millimetre. These heights are combined with the height of the pillar plate to reduce distances to the horizontal.

9. All measurements should be made to one, uniquely numbered reflector. Note that a separate tribrach may be fixed to each of the pillars and the single reflector located in each tribrach in turn. Centring errors caused by the tribrach are very small in relation to the magnitude of other instrument/reflector errors and may be ignored.
10. Point the instrument and reflector as prescribed by the manufacturer in order to maximise the return signal strength.
11. The observation sequence should be chosen so that the shorter lines are measured first and last. For baselines consisting of 6 or 7 pillars, it is sufficient to observe the baseline in one direction only (generally in the forward direction). On a 7-pillar baseline, this translates into the following sequence of 21 distances (Figure 3): 1-2, 1-3, 1-4, 1-5, 1-6, 1-7; 2-7, 2-6, 2-5, 2-4, 2-3; 3-4, 3-5, 3-6, 3-7; 4-7, 4-6, 4-5; 5-6, 5-7; 6-7, where '1-2' represents the observation from pillar 1 to pillar 2, etc. For baselines consisting of 4 or 5 pillars, it is necessary to observe all inter-pillar distances in both the forward and reverse direction in order to achieve reasonable redundancy. On a 4-pillar baseline, this translates into the following sequence of 12 distances (Figure 4): 1-2, 1-3, 1-4; 2-4, 2-3, 2-1; 3-1, 3-2, 3-4; 4-1, 4-2, 4-3.
12. A minimum of five individual slope distances should be measured to the same single reflector, re-pointing after each measurement. This will allow the instrument to go through the initialisation procedure and reset the signal strength for each measurement. The instrument should not be set to display the mean of a set of five measurements in lieu of five individual readings unless this procedure is repeated five times independently. Horizontal distances are computed more accurately using the known pillar heights. Recording of the horizontal distance displayed by the instrument or reducing the slope distances to the horizontal using the zenith angle should only be used for a check on field procedure or on-board computation. The following sources of error may occur if horizontal distances are calculated from zenith angles either manually or by automatic reduction in the EDM instrument: pointing error, vertical circle index error, variation in reduction formula used in different instruments, round-off errors after automatic computation in the EDM instrument.
13. The temperature and atmospheric pressure at both the instrument and the reflector should be measured to an accuracy of at least 0.5°C and 1 millibar (mb) respectively, using calibrated thermometers and barometers. Temperatures should be measured at the height of instrument and reflector to minimise the effect of radiated heat from the ground. Note that pressure may be measured at the instrument only, provided the baseline is not located in steep terrain.
14. When transporting the instrument between pillars, ensure that it is kept shaded from direct sunlight.
15. Once all inter-pillar distances have been measured to the one uniquely numbered reflector, compare this reflector with the remaining reflectors by measuring to each in turn. This should be carried out on the shortest line and by comparing the slope distances. However, if the reflectors vary in height, measurements should be reduced to the horizontal before the comparison is made. This comparison is important when using different makes of reflector but can also be significant when different reflector holders of the same make are used, e.g. single reflector holders compared with triple reflector holders. Where found to be significant, variations should be applied as corrections to the additive constant for each reflector concerned. It is for this reason that all reflectors should be uniquely numbered. Subsequent calibrations of the EDM instrument should be performed using the same uniquely numbered reflector where possible in order to compile a calibration history for the instrument/reflector combination.

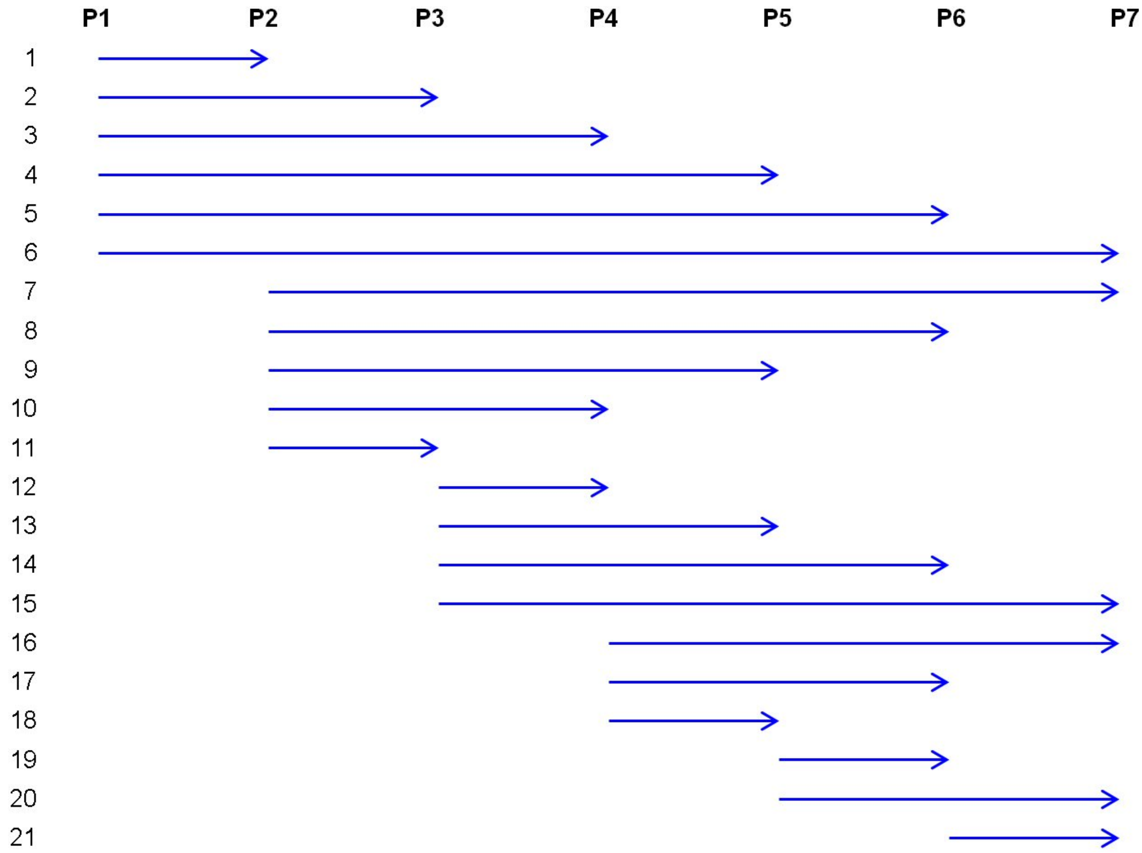

Figure 3: Observation sequence for 7-pillar baselines.

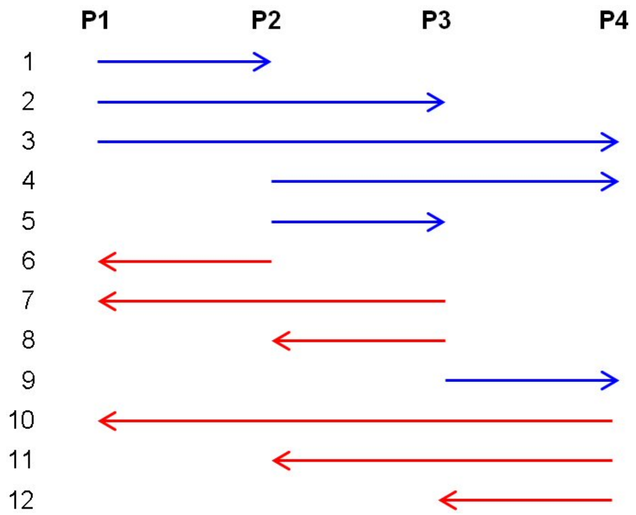

Figure 4: Observation sequence for 4-pillar baselines.

It is important to note that the accurate observation of meteorological data is essential for a reliable EDM calibration. An error in the measurement of 1ºC in temperature or 3 mb in atmospheric pressure will cause a corresponding error in the reduced distance of approximately 1 ppm. If possible, relative humidity (%) should also be observed (once for each inter-pillar distance), although it is recognised that its effect on EDM calibration results is minimal. Handheld met sensors currently available on the market are affordable and can provide temperature, atmospheric pressure and relative humidity in the one compact unit.

Upon completion of the field work, surveyors are required to restore any baseline security measures to their original state, e.g. replacing any protective caps and bolts securely to minimise damage to pillars caused by vandalism. Damaged or missing caps and bolts should be reported immediately to LPI, so repairs can be undertaken promptly.

5.3 Data Recording

All field notes and calculations relating to the EDM calibration are to be retained by the surveyor in order to maintain legal traceability of distance measurements. Records should be kept indefinitely because measurements made by any instrument (and at any point in time) may be questioned.

5.3.1 Manual Recording

It is strongly recommended to use the EDM calibration recording sheet available from LPI (2015a) for the recording of baseline observations in the field. All data entry fields should be completed. Although the recording sheet is self-explanatory, the following is a brief explanation of what details to record:

- Make, model and serial number of the instrument and the reflector used in the calibration.
- Make, serial number and correction to the thermometers and barometers used.
- Weather as it applies to the baseline, noting cloud cover, wind speed and direction, and the presence of heat shimmer, fog or rain if applicable.
- Pillar numbers in the ‘From’ and ‘To’ columns. Each pillar has a unique PM number fixed to the front of the pillar.
- Instrument height (H.I.) and reflector heights (H.R.) above the pillar plate, read to an accuracy of 1 mm.
- Temperature and atmospheric pressure as read. The correction to each reading is to be applied when reducing observations. It is advised to also record relative humidity.
- Slope distance measurements – the first column is for the entire distance and the following four columns are for the last two decimals only.
- Observations should be dated and signed by the observer.

In the event of booking errors, each mistake should be crossed out (not erased or made illegible) and the correct value entered alongside. All such alterations should be dated and signed or initialled by the person making the correction.

5.3.2 Electronic Recording

Although it is strongly recommended to use manual booking, it is acceptable to electronically record observations onto the instrument’s memory card. However, slope distances should be recorded in preference to the horizontal distances automatically reduced by the instrument. All other observations made including heights of the instrument and the reflector as well as meteorological data readings must be recorded as well – on the instrument’s memory card or elsewhere.

5.4 Data Processing

The data processing procedures should be commenced as soon as possible once field work has been completed. Firstly, the field observations must be checked against any electronic data recorded in the field. Booking sheets must be complete and include all mean calculations.

Once the raw EDM calibration data has been checked, it can be processed to determine the additive constant, scale factor and cyclic error (if required) using various software tools, e.g. EDMCAL (Janssen and Watson, 2014a; 2014b), the spreadsheet developed at the University of New South Wales (Harvey, 2014) or Baseline (Klinge, 2007). This section is included for those wishing to process the observations manually. It should be noted that the order in which the corrections are presented is generally the order in which they should be applied. The equations stated are based on those found in Rüeger (1996). For a detailed description of least squares adjustments and statistics related to surveying applications, the reader is referred to Harvey (2009).

5.4.1 Initial Processing

The following corrections are applied to the observed slope distances (d) in order to reduce these to 'horizontal' distances (d_{hz}) at the height of the lowest pillar:

$$d_{hz} = d + c_{atm} + c_{slope} + c_{height} \tag{1}$$

where c_{atm} = atmospheric correction
c_{slope} = slope correction
c_{height} = height (or datum) correction

The basic principle of EDM instruments is the indirect determination of the travel time of a wave of light from the instrument to the reflector and back. While the speed of light in a vacuum is well known, in practice measurements are (of course) not carried out in a vacuum. The EDM measurements must therefore be corrected for the ambient atmospheric conditions because the velocity of visible and infrared waves changes with temperature, atmospheric pressure and relative humidity (for light waves, humidity is often ignored). The atmospheric correction (also known as first velocity correction) c_{atm} is calculated as follows:

$$c_{atm} = \left[VC1 - \frac{VC2\,p}{(273.15+t)} + \frac{11.27\,PWVP}{(273.15+t)}\right] 10^{-6}\, d \tag{2}$$

where $VC1$ = reference refractive index specific to EDM instrument (also known as C)
$VC2$ = instrument pressure factor specific to EDM instrument (also known as D)
t = temperature (ºC)
p = atmospheric pressure (mb)
$PWVP$ = partial water vapour pressure (mb)
d = observed slope distance (m)

It should be noted that it is generally sufficient to adopt an approximate value of 15 mb for the partial water vapour pressure. The second velocity correction (accounting for the fact that the light wave does not follow a circular path between the two pillars) is more important for microwaves than for light waves and ignored for EDM calibrations because it is insignificant over such distances. Also insignificant over such distances is the reduction from observed wave path arc distance to wave path chord distance.

The slope correction reduces the slope distance to a horizontal distance at the mean elevation of the two pillars involved:

$$c_{slope} = -\frac{\Delta H^2}{2\,d} - \frac{\Delta H^4}{8\,d^3} - \frac{\Delta H^6}{16\,d^5} \tag{3}$$

where ΔH = height difference between instrument and reflector (m)

The height (or datum) correction (also known as sea level correction) reduces the horizontal distance at the mean elevation of the two pillars to the horizontal distance at the lowest pillar elevation:

$$c_{height} = -\frac{H_M}{R}\, d + \frac{H_M \Delta H^2}{2\, d\, R} + \frac{H_M \Delta H^4}{8\, d^3 R} + \frac{H_M \Delta H^6}{16\, d^5 R} \tag{4}$$

where H_M = mean height of instrument and reflector above the lowest pillar (m)
R = radius of curvature of the ellipsoid along the line (m), here assuming R = 6,370,100 m for New South Wales

Strictly speaking, this would be followed by the chord-to-arc correction, which converts the chord distance at the lowest pillar elevation to the datum arc distance. However, this correction is generally zero over distances used for EDM calibrations.

5.4.2 Solving for the Instrument Corrections

As stated previously, in order to achieve legal traceability of distance measurements all three instrument corrections (additive constant, scale factor and cyclic error) must be determined. However, for modern instruments the magnitude of the cyclic error is generally negligible.

The additive constant for a particular instrument/reflector pair is generally computed using the 'parts to the whole' method. As an example, a 4-pillar baseline would give the following combinations for the additive constant (AC):

$$\begin{aligned} 2\,AC_1 &= -(d_{12} + d_{23} + d_{34} - d_{14}) \\ AC_2 &= -(d_{12} + d_{23} - d_{13}) \\ AC_3 &= -(d_{23} + d_{34} - d_{24}) \\ AC_4 &= -(d_{13} + d_{34} - d_{14}) \\ AC_5 &= -(d_{12} + d_{24} - d_{14}) \end{aligned} \tag{5}$$

where d_{12} is the mean of the two reduced horizontal distances (forward and reverse) measured between pillar 1 and pillar 2, etc. The additive constant should be computed using a standard least squares adjustment as detailed in Rüeger (1996). In order to confirm that the additive constant has been determined correctly, the parts to the whole should be re-computed, using the corrected distances.

The scale factor is determined by computing the ratio of each of the inter-pillar distances (reduced to the horizontal at the height of the lowest pillar and corrected for additive constant) with the corresponding known distances shown on the baseline certificate. On a 4-pillar baseline, the scale factor is determined using the weighted mean of the six inter-pillar distances. However, an estimate of the scale factor can be determined by comparing the unweighted mean of three inter-pillar distances with the published values, e.g.:

$$\begin{aligned} \textit{scale factor} &= \textit{known distance} \,/\, \textit{observed distance} \\ &= 650.500 \text{ m} / 650.502 \text{ m} \\ &= 0.999\,9969 \\ &= -3.1 \text{ ppm} \end{aligned} \tag{6}$$

The cyclic error in modern EDM instruments is usually less than 2 mm in magnitude and can therefore generally be ignored. However, strictly speaking, it must be determined in order to achieve legal traceability of distance measurements. It should be noted that, if found to be significant, the cyclic error should be applied to the measured slope distances before the other instrument corrections are determined. All EDM baselines in NSW are designed to allow the cyclic error to be determined, and available EDM baseline software can generally be used in this regard.

The principle of determining the cyclic error can be explained using an example that does not require a baseline to be observed. In its simplest form, the test consists of laying out a calibrated tape horizontally along the top of a low wall for a distance corresponding to the unit length of the instrument (e.g. 10 m) at a distance of about 50-70 m from the EDM instrument. A reflector, mounted in a tribrach, is moved to each successive 1-metre (or ½-metre) graduation along the tape and both the EDM distance and the tape distance is recorded. The two sets of measurements are then compared (see Table 1 for an example). More details can be found in Rüeger (1996).

Table 1: Example of cyclic error determination using a calibrated tape measure.

Measurement	1	2	...	10	11
Calibrated Tape	2.000	3.000	...	11.000	12.000
EDM	50.125	51.126	...	59.124	60.123
Cyclic Error	**0.000**	**+0.001**	...	**-0.001**	**-0.002**

5.5 Analysis of the Calibration Results and Application of Instrument Corrections

The EDM calibration result should be checked to ensure that it reflects the quality of the instrument tested. As a general rule, the instrument correction should approximate the precision to which the instrument is capable of measuring distances, as stated by the manufacturer.

If the calibration result significantly exceeds the manufacturer's specifications, the following may have occurred and appropriate action should be considered:

- The instrument may not be in good working order and in need to be serviced and then re-tested.
- The observation procedures may not have been followed to a satisfactory standard, commonly caused by poor meteorological observations and/or low precision instruments, and taking shortcuts to save time.
- The verified baseline values may no longer be accurate. This is unlikely to occur if the baseline has recently been verified, but can occur if the baseline has been confirmed to be subject to pillar movement.

5.5.1 Cyclic Error

The cyclic error is generally insignificant in modern instruments and consequently not applied to the measured field distances. However, strictly speaking, its magnitude must be determined in order to achieve legal traceability of distance measurements. If the cyclic error is found to be significant, it should be applied as a correction to the measured slope distances prior to reduction of the distances to the horizontal and the determination of additive constant and scale factor.

5.5.2 Additive Constant

Because the additive constant is determined without reference to the published inter-pillar distances, it is not influenced by changes in the true distances caused by pillar movements occurring since the baseline was last verified. The additive constant is primarily a correction for the combined physical offset of the reflector and the offset of the electrical centre of the instrument and, unlike the scale factor, should not be influenced by a change in the ambient temperature. Consequently, the additive constant should not vary significantly in subsequent calibrations, provided the same instrument/reflector combination is used.

The additive constant should be applied to all measured field distances either manually or by setting the constant in the instrument after the calibration. Once set in the instrument, a known distance should be re-measured to ensure the sign (positive or negative) of the constant has been correctly applied or set.

5.5.3 Scale Factor

The scale factor will generally vary for subsequent calibrations within the accuracy specification of the instrument because it is dependent on the instrument's modulation frequency, which may change with variations in the ambient temperature. To a lesser extent, the scale factor can also change as a result of frequency drift and ageing of the frequency oscillator. Consequently, if the scale factor falls within the instrument's specification, it should not be applied as a correction to measured field distances.

If the scale factor falls outside the instrument's specification, the instrument should be returned to the manufacturer for service. However, it is advisable to repeat the calibration under different climatic conditions both to confirm the result and to observe if the scale factor changes with different ambient temperatures. The thermometers and barometers used in the calibration should also be re-calibrated against a certified standard as an error in temperature and pressure readings will contribute to the scale error of measured distances.

5.5.4 Uncertainty of the Instrument Correction

The former National Standards Commission (now incorporated into NMI) recommended in 1983 that the minimum standard for the uncertainty of calibration of an EDM instrument should be 5 mm + 30 ppm at the 99% confidence interval (revised value from 1986 stated). This uncertainty is equivalent to 4 mm + 20 ppm at the 95% confidence interval and easily achieved with modern total stations. The uncertainty of the instrument correction (in relation to the national standard) includes the uncertainty of the verified baseline distances as shown in the measurement report for each baseline – currently the least uncertainty quoted for the verified inter-pillar distances is 0.5 mm + 1.3 ppm at the 95% confidence interval. The reader is referred to Rüeger (1984) for details on the calculation of the uncertainty of the instrument correction. The computation of this uncertainty, which varies with the distance range measured, is quite complex and therefore beyond the scope of this paper.

6 CONCLUDING REMARKS

The Surveying and Spatial Information Regulation 2012 requires that the length stated by a surveyor should not differ from the true value in terms of the State Primary Standard of measurement by more than 10 mm + 50 ppm at a confidence interval of 95% (NSW Legislation, 2014b). The required accuracy or uncertainty is to include the uncertainty of the length measurement arising from all possible sources. In addition to the uncertainty of calibration, length measurements made with an EDM instrument are subject to errors arising from the centring of the instrument and reflector, measurement of the atmospheric conditions and those associated with the reduction of the slope distance to the horizontal. A more detailed list of errors occurring in distance measurements with EDM instruments can be found in Rüeger (1996). It is therefore essential that all ancillary equipment is calibrated and in good adjustment and that an appropriate measuring technique be adopted in order to achieve the required result.

This paper has proposed updated best practice guidelines for EDM calibrations in NSW, which are expected to flow on into the next update of Surveyor General's Direction No. 5. It is important to note that calibrating an EDM instrument in prism mode does not calibrate the reflectorless EDM laser. These two modes generally have different additive constants and scale factors within any one instrument, i.e. testing in reflectorless mode must be performed separately – see Evans (2014) for more details. It should also be noted that if surveyors measure any distances that are longer than the longest line on their EDM calibration baseline, they should consider the reliability of the extrapolation of their calibration parameters.

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