New South Wales Government

Surveyor General's Directions

No. 5

Verification of Distance Measuring Equipment

DOCUMENT CONTROL SHEET

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Approved By:

Paul r Harcombe

Paul Harcombe
Surveyor General of NSW
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Introduction

The Surveyor General, as a verifying authority under the provisions of the National Measurement Act 1960, is responsible for ensuring that surveyors use appropriately verified measuring equipment when carrying out cadastral surveys. Consequently surveyors are required by the Surveying and Spatial Information Regulation 2012 to verify their measuring equipment in relation to an Australian or State Primary Standard of measurement of length.

To achieve Legal Traceability of length measurement the verification should be carried out in a manner and at a frequency which is approved by the Surveyor General. In addition to the legislative requirements, verification of distance measuring equipment ensures that the compatibility of measurement is maintained for all surveys.

It should be noted that Legal Traceability of length measurement is not confined to cadastral surveys, as any length measurement stated by a surveyor could be subject to dispute and subsequent litigation.

This document outlines the facilities in New South Wales, maintained by the Surveyor General, for the verification of survey measuring bands and Electronic Distance Measuring (EDM) equipment. It has been produced to assist surveyors in verifying their distance measuring equipment in order to comply with the requirements of the Surveying and Spatial Information Regulation 2012, and in particular to describe the verification methods approved by the Surveyor General of New South Wales.

Background - Verification and Legal Traceability of Length Measurement

The National Measurement Act, 1960 establishes the legislative framework for a national system of standards and prescribes the legal measurement units for all physical quantities. Length measurement, while being a basic element of all survey work, is only one of more than thirty physical quantities covered by the Act which also refers to area, mass, volume, density and other physical quantities relating to the measurement of electrical and electromagnetic properties.

The National Measurement Act is administered by the National Measurement Institute which may in turn appoint organisations as verifying authorities under the provisions of Clause 73 of the National Measurement Regulations 1999. The Office of the Surveyor General of NSW within Spatial Services – Department of Finance, Services & Innovation has been so appointed. The National Standards Commission (now the National Measurement Institute) produced the Verifying Authorities Handbook which specifies how Verifying Authorities are to perform verifications of measuring equipment. This system of verification is necessary in order to maintain Legal Traceability for the measurement of all physical quantities.

The Quality Assurance system implemented by the Surveyor General for the Verifying Authority function is used by the National Measurement Institute when re-assessing the Surveyor General as a Verifying Authority at three yearly intervals.

Legal Traceability of length measurement refers to the legal hierarchy of measurement standards traceable through an unbroken chain of verifications from the most precise Standard (e.g. National Standard) down through the subsidiary standards to the working standard being the surveyor's steel band or EDM instrument. In particular the National Measurement Act requires "all measurements for legal purposes to be made in terms of the Australian standards of physical quantities."

Consequently, the requirements of the National Measurement Act which are relevant to Surveyors are incorporated in the Surveying and Spatial Information Regulation 2012 to ensure that length measurements, made using Surveying equipment, have legal traceability.

The Surveying and Spatial Information Regulation 2012 requires surveyors to verify their measuring equipment in relation to a National or State Primary Standard of measurement of length. Survey bands are to be verified at least once every two years and Electronic Distance Measuring (EDM) instruments at least once every 12 months and immediately after service or repair (see Appendix A).

Precision is generally defined as the repeatability of readings as displayed by measuring equipment, or the internal consistency of a measuring procedure, and would usually be quantified in terms of the standard deviation or uncertainty of a set of observations.

Accuracy is a measure of how closely the mean value of a set of observations conforms to the `true' value.

The Surveying and Spatial Information Regulation 2012 requires that both the accuracy of the calibration and the field measuring technique is to be such that any length measurement made with the equipment will achieve *an accuracy of 10mm + 50ppm or better at a confidence interval of 95%* in relation to the State Primary Standard of measurement (see Appendix A).

Surveyors have generally used the traverse closure as an indicator of survey accuracy, however this is only a measure of internal consistency or precision.

Verification - is a test to confirm that the accuracy attained by a measuring instrument is within allowable accuracy limits as defined in a specification or as required by legislation.

Calibration - is the determination of instrument errors by comparing the value indicated by the measuring equipment with the known or true value. Consequently corrections must be applied to all measurements made with the equipment in order to obtain `true' measurements.

PART I - SURVEY MEASURING BANDS

This section outlines the procedure to be adopted to verify survey bands in a manner approved by the Surveyor General.

The Surveying and Spatial Information Regulation 2012 requires steel and invar bands to be verified at least once every 2 years and immediately after repair (see Appendix A). This is to ensure that the survey band maintains legal traceability of measurement throughout its working life.

Survey bands may be verified in one of two ways:

(a) By submitting the band to the Office of the Surveyor General, who have been delegated the Verifying Authority function by the Surveyor General. A fee is charged for this service (see Appendix B).

(b) By the owner of the survey band carrying out the verification in a manner approved by the Surveyor General as detailed in Section 5.

1. Description of Baseline Facilities

Two band verification baselines are located on the ground floor, east wing of the former Lands Department building, 23-33 Bridge Street, Sydney. See Appendix C for Locality Diagram.

The first baseline was established in the then Department of Lands building by Henry Alexander in 1890. The facility now contains one Departmental and one Public baseline, each consisting of a zero terminal and successive terminals at:

20 metres,
100 links (66 feet),
25 metres,
100 feet.

Currently only the two 20 metre baseline intervals are verified by the Surveyor General.

Baseline terminals consist of finely scribed lines on the top face of stainless steel rods which are grouted into bedrock. Both the Departmental and Public baselines have provision at each terminal for the attachment of microscopes with horizontal micrometer adjustment for direct reading of the offset (band graduation to baseline graduation) to an accuracy of 0.01 millimetres. Each of the five Departmental baseline terminals is protected by a screwed brass cap whereas the Public baseline has open terminals for easy access.

2. Access to the Baselines

2.1 Public Baseline

The exposed terminals of the public baseline provide unrestricted access during business hours, subject to the use of the adjacent Department baseline. The use of this facility is free of charge, however any surveyor wishing to use the public baseline should first obtain permission and an instruction sheet from Metrology & Governance, Office of the Surveyor General, Spatial Services, Department of Finance, Services & Innovation, Sydney.

2.2 Department's Baseline

The Department's baseline and ancillary equipment is restricted to suitably qualified officers engaged in official verification work.

3. Verification of the Baselines by the Surveyor General

Regular verification of the two 20 metre baselines is carried out by Metrology & Governance in accordance with the National Measurement Institute (NMI) requirements using a State Primary Standard. The primary standard currently used is a 6mm wide stainless steel tape, which is verified in relation to the Australian Primary Standard of length every two years by the National Measurement Laboratory, Lindfield.

4. Verification of Survey Bands by the Surveyor General

4.1 Procedure

All verifications are carried out in accordance with National Measurement Institute requirements as specified in the Verifying Authorities Handbook and are subject to a Quality Assurance system.

Surveyors may have their survey bands verified by the Surveyor General by forwarding them to the Manager, Metrology & Governance, Office of the Surveyor General. The verification is carried out for a fee and provides the surveyor with a Measurement Report, including sag and temperature correction tables for each individual band. See Appendix B for the Scale of Fees and Appendix D for an example of a Measurement Report.

4.2 Analysis of the Measurement Report

The information issued on verification of the band includes a Measurement Report and a computer printout providing a Test Summary and Sag and Temperature Correction Tables.

The information in the Measurement Report will be explained using the example in Appendix D – Measurement Report No 9904, and the attached computer printout.

The Measurement Report lists the actual length of the band for each of the five 20 metre intervals, fully supported on a horizontal surface, at a temperature of 20°C and subject to applied tensions of 50 and 70 Newtons. The uncertainty of the stated lengths is ± 0.5mm at the 95% confidence level.

In the example, the actual length of band No. 5214 between the inside face of the terminal loop at 0 metres and the 20 metre graduation mark is 20.0001 metres, when fully supported at a temperature of 20°C and an applied tension of 70 Newtons. The National Measurement Institute requires all verification statements to show the lengths of the band in this format in order to maintain uniformity of verification reports.

The computer generated Test Summary also refers to the `Test Temperature' (16.3°C), being the temperature at which the verification was performed. The final lengths displayed in the Measurement Report have then been computed for a temperature of 20°C.

The surveyor may refer to the Sag and Temperature Correction Tables to obtain the Standard Temperature for the band at either 50 or 70 Newtons tension. Referring to the example, the Standard Temperature for the band when fully supported and at 70 Newtons tension is 22.8°C, that is, at 22.8°C the actual length of the band would be 100.000 metres.

5. Verification of the Survey Band by the Surveyor

The following information is provided to give surveyors guidance when carrying out their own verification of a survey band. It is strongly recommended however that every survey band in use be verified at least once by a Verifying Authority at which time it would be allocated a unique Band Number and verified to a higher accuracy in accordance with the National Measurement Institute requirements.

The two-yearly verification required by the Surveying and Spatial Information Regulation 2012 may be carried out by the individual surveyor in relation to the Bridge Street public baseline or a band which has a current Measurement Report. In each case the surveyor is to precisely determine the length of each successive twenty metre band interval by measuring the offset between the graduation marks on the band under test and those on the certified Standard. Field notes and calculations relating to the verification are to be retained by the surveyor in order to maintain legal traceability of distance measurements.

The thermometer and spring balance used in the verification and in subsequent field work should also be verified in relation to a certified standard in order to achieve legal traceability of distance measurements.

The spring balance may be verified in relation to a certified spring balance or set of certified weights. When verifying in relation to certified weights the conversion factor of 9.8 Newtons = 1kgf should be used to convert a mass to an equivalent force or tension.

The total weight of the survey band should be known to the nearest five grams so that a weight per unit length may be determined for the calculation of sag correction in field measurements.

5.1 Recommended Verification Procedure

5.1.1 Verification using the Bridge St Public Baseline

The surveyor should first obtain the current certified length of the Public baseline from Metrology & Governance, Office of the Surveyor General before carrying out the verification.

The temperature should be measured at each end of the band to an accuracy of 0.2°C and the band should be subject to a tension of 50 or 70 Newtons.

When performing the verification the surveyor must precisely measure the offset between the graduation marks of the Public baseline and the band under test to an accuracy of 0.5 millimetres.

5.1.2 Verification using a Standard Band

The Standard Band used for verifying field bands should not be used for field work. It should be kept free of kinks and distortions and verified every two years by the Surveyor General.

When verifying in relation to a Standard Band both the Standard and field bands should be composed of the same material. This will eliminate the need to measure the ambient temperature because the coefficient of thermal expansion for both bands may be considered equal. Thus errors otherwise introduced by the uncertainty of temperature measurement will be avoided.

Similarly the verification should be carried out at the same tension at which the Standard Band was certified (ie. 50 or 70 newtons) so as to minimise errors arising from any uncertainty of Young's modulus of elasticity for the subject bands.

The verification should be performed on a flat, horizontal, low-friction surface, free of direct sunlight and so that a uniform temperature is maintained for both bands over the length being verified.

When performing the verification the surveyor must precisely measure the offset between the graduation marks of the certified Standard band and the band under test to an accuracy of 0.5 millimetres.

5.2 Processing Observations

The following is a brief explanation of the results required on completion of the verification. A more detailed description can be found in most surveying reference books.

On processing the observations, it is suggested that the surveyor determine the Standard Temperature of the field band subject to an applied tension of 50 and/or 70 newtons. To achieve this, the surveyor must calculate the temperature differential, based on the coefficient of thermal expansion of the material, which would produce the measured offsets observed between the graduations on the certified Standard and the field band under test. The following coefficients of expansion are to be used for that purpose:

Steel .... 11 x 10^{-6} / °C
Invar .... 1 x 10^{-6} / °C

6. Field use of the Verified Survey Band

In the field, the band should be used at the Standard tension of 50 or 70 Newtons and the temperature correction applied based on the difference between Standard and ambient temperature.

Sag corrections, based on the weight per unit length of the band, should be applied in the usual manner. Note that Sag and Temperature Correction Tables are supplied with the Measurement Report for bands verified by the Surveyor General to assist surveyors in applying these corrections, (see Appendix D).

As stated previously, surveyors should regularly verify their thermometer and spring balance against a certified Standard in order to maintain Legal Traceability of their measurements.

The Reader-to-band swivel coupling should be checked regularly to confirm that the distance between the survey band sleeves and the Reader graduations is equal to the nominal value. This connection is not checked during the verification of the band, as Readers may be changed during the life of the band and as most new bands are submitted to the Surveyor General without a Reader.

Similarly only the five 20 metre intervals as shown on the Measurement Report are verified by the Surveyor General. Surveyors should carry out their own tests to prove that the intervening metre graduations are equal to the nominal value.

PART II - ELECTRONIC DISTANCE MEASURING EQUIPMENT

The Surveying and Spatial Information Regulation 2012 requires surveyors to verify their Electronic Distance Measuring (EDM) equipment in relation to the State Primary Standard of measurement, in the form of pillared testlines, at least once each year and immediately after service or repair (see Appendix A.)

This section outlines the procedure to be adopted to verify EDM equipment in a manner approved by the Surveyor General.

7. Description of EDM Testline Facilities

The Surveyor General has established sixteen concrete pillared EDM Testlines throughout NSW, two in Sydney and the remainder located in regional centres throughout the State (see Appendix E).

All eighteen testlines are based on the Heerbrugg design. Each pillar contains a stainless steel base plate with a 5/8" Whitworth screwed spigot to receive the tribrach. The spigot is protected by an acorn nut and PVC cap secured by three bolts which require the use of a 3/8inch or 10mm Allen key for their removal.

Surveyors are asked to replace the PVC caps and bolts securely to minimise damage caused by vandalism. Damaged or missing caps and bolts should be reported immediately to the Manager Metrology & Governance, Office of the Surveyor General, so repairs can be undertaken promptly.

8. Access to EDM Testlines

Use of all testlines is provided free of charge to the owners of EDM equipment for the calibration of their instruments. Access is unrestricted at all testlines except where specific access details are shown on the Measurement Report, e.g. Bathurst, Goulburn and Ulan baselines.

9. Verification of EDM Testlines by the Surveyor General

The National Measurement Institute recommends that EDM baselines be capable of calibration at an uncertainty of ±(1.5mm + 20ppm) at a 99% confidence interval. This uncertainty is equivalent to a standard deviation (67% confidence interval) of ± (0.6mm + 8ppm).

The EDM Testlines are currently verified using a Leica TCA2003 precise EDM instrument. This instrument has an accuracy specification of ±(1mm + 1ppm) and is verified annually by the National Measurement Institute, Lindfield as a Reference Standard of measurement.

Each of the eighteen EDM testlines is visited in rotation such that every testline is re-verified within a two-year period in accordance with National Measurement Institute recommendations.

10. Verification of EDM Equipment by the Surveyor

EDM instruments have three inherent systematic errors. These are Additive constant, Scale factor and Cyclic error. The surveyor must solve for all three systematic errors to achieve legal traceability of distance measurements.

Verification of EDM equipment in NSW. is to be carried out in relation to the State Primary Standard in the form of pillared EDM Testlines. By using these Testlines the surveyor will be able to determine the additive constant and scale factor of the EDM instrument. The cyclic error should be determined independently of the Testlines as detailed in section 10.4.2.

The following is a summary of the steps required to verify EDM equipment. For a complete description of EDM instrument verification refer to the following publications:

> 'Instructions on the verification of electro-optical short-range distance meters on Subsidiary Standards of length in the form of EDM calibration baselines', (1984), J.M. Rüeger, School of Surveying, UNSW.
>
> 'Electronic Distance Measurement', (1990), J.M. Rüeger, Springer-Verlag, Berlin.

10.1 Preparation of the Equipment

1. Obtain the latest EDM Testline Measurement Report detailing the current distances, reduced levels and access details from Metrology & Governance, Office of the Surveyor General, Sydney. (See Appendix F for an example of an EDM Testline Measurement Report.)

2. Check the levelling bubbles on all tribrachs and adjust if necessary before observing the distances. Levelling of the instrument and reflectors is critical during verification.

3. Check and adjust theodolite mounted EDM equipment for correct alignment.

4. Verify the thermometers and barometer against a certified Standard.

5. All reflectors should be marked with a unique identification number. Only **one** of these reflectors is to be used for the verification observations.

6. The field recording sheet `EDM Testline Observations', (see Appendix G) is recommended for the recording of baseline observations.

7. The EDM battery should be fully charged prior to carrying out the verification.

10.2 Observation Procedure

The following procedures are to be adopted for the eighteen baselines established by the Surveyor General.

1. Before commencing measurement the EDM instrument should be carefully levelled and allowed a `warm up' period if recommended by the instrument manufacturer.

2. 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 summers day can exceed this temperature range.

3. Set the atmospheric correction (ppm) and instrument / reflector constant to **zero**. Some EDM instruments will 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.

4. The height of the instrument and the height of the 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. In the case of a telescope-mounted instrument the height is measured to the theodolite, not the EDM. See section 10.4.1(b) for an explanation of the reduction of measured slope distances.

5. 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.

6. Point the instrument as prescribed by the manufacturer in order to maximise the return signal strength. For long range instruments an attenuator should be fitted where appropriate.

7. The observation sequence should be chosen so that the shorter lines are measured first and last. e.g. 1-2, 1-3, 1-4 ; 2-4, 2-3, 2-1 ; 3-1, 3-2, 3-4 ; 4-1, 4-2, 4-3, where `1-2' is the observation from pillar No.1 to pillar No.2, etc. This procedure allows the instrument to `warm up' if necessary and also facilitates the comparison of the remaining reflectors on the shorter line where the uncertainty of the distance measurement due to atmospheric conditions is minimised.

   In general the verification should not be carried out in the early morning or late afternoon when the air temperature may be unstable or changing more rapidly along the measuring path than can be monitored accurately with the thermometers.

8. 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 onboard 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 EDM instrument

9. The temperature and pressure at both the instrument and the reflector should be measured to an accuracy of 0.5°C and 1 millibar (or millimetre Hg) respectively. 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 and the pressure at the reflector calculated from the height difference between pillars where the difference is considered significant. For example, at 1025mb and 30°C, a height difference of 30 metres would result in a pressure difference of 3.5mb, (see Appendix H).

   Note that an error in measurement of 1°C in temperature or 3 millibars in pressure will make a corresponding error in the reduced distance of approximately 1 part per million (ppm).

10. When transporting the instrument between pillars, ensure that it is kept shaded from direct sunlight.

11. Once all interpillar 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, eg 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 verifications of the EDM instrument should be performed using the same uniquely numbered reflector where possible in order to compile a verification history for the instrument/reflector combination.

10.3 Data Recording

All field notes and calculations relating to the verification are to be retained by the surveyor in order to maintain legal traceability of distance measurements.

10.3.1 Manual Recording

The field recording sheet supplied by the Department is recommended for the recording of observations (see Appendix G) or http://www.lpi.nsw.gov.au/__data/assets/pdf_file/0007/25756/EDM_Calibration_For m_Ver141.pdf . 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:

(a) The make, model and serial number of the instrument and the reflector used in the verification.

(b) Enter the mounting details for telescope-mounted or standards-mounted EDM equipment where applicable.

(c) The make, serial number and correction to the thermometers and barometer used.

(d) `Weather' - record the weather as it applies to the Testline, noting the cloud cover, wind speed and direction and the presence of heat shimmer, fog or rain if applicable.

(e) Enter Pillar numbers in the `From' and `To' columns. Each pillar has a unique PM number fixed to the front of the pillar.

(f) 'H.I.' and `H.R.' are the instrument and reflector heights above the pillar plate, read to an accuracy of 1 millimetre. See section 10.2(4) for an explanation of the procedure to be adopted for telescope-mounted EDM's.

(g) The recorded temperature and pressure as read. The correction to each reading is to be applied when reducing observations.

(h) `Slope Distance' measurements - the first column is for the whole distance and the other four columns are for the millimetres only.

(i) Observations should be dated and signed by the observer.

10.3.2 Electronic Recording

It is quite acceptable to use an electronic data recorder to record observations. However slope distances should be recorded in preference to the horizontal distances automatically reduced by the EDM. All other observations made including heights of the instrument and the reflector as well as temperature and pressure readings should be recorded.

10.4 Data Processing

The following information is included for those wishing to process the observations manually. There are several calculator and computer programs available that will determine the additive constant, scale factor and cyclic error. Note that the order in which the corrections are presented is generally the order in which they should be applied.

10.4.1 Initial Processing

(a) **First Velocity Correction**: The First Velocity correction (ppm correction) is applied because the ppm factor was set to zero at the time of verification. The formula is generally in the form:

$$d_1 = d_{meas} + K_a$$

$$K_a = \left[C - \frac{D * p}{273.15+t} + \frac{11.27\, e}{273.15+t} \right] 10^{-6}\, d_{meas}$$

Where `p'= pressure in millibars ; `t'= temperature in EC ; `e'=partial water vapour pressure (mb) ; ($p_{millimetres} = 0.75006\, p_{millibars}$)

`C' and `D' are parameters specific to the modulation frequency and the carrier wavelength respectively of the EDM instrument. Refer to the instrument manual for the relevant parameters.

For example, with the Topcon GTS series of instruments the following parameters are applicable: C = 279.6 D = 79.51

Note that in all but precise EDM calibrations the second term, relating to partial water vapour pressure in the above equation, may be omitted or an approximate value of e = 15mb may be adopted.

(b) **Slope Correction**: The measured distances are then reduced to the horizontal at the mean elevation of the two pillars using the following formula:

$$d_{hor} = d_1 - S_{cor}$$

$$S_{cor} = \frac{\Delta h^2}{2d_1} + \frac{\Delta h^4}{8d_1^3} + \frac{\Delta h^6}{16d_1^5}$$

Where Δh = Height difference between the instrument and the reflector. For interpillar distances with a gradient of less than 4% the third term may be ignored. That is:

$$S_{cor} = \frac{\Delta h^2}{2d_1} + \frac{\Delta h^4}{8d_1^3}$$

The distances are reduced to the horizontal using published pillar heights and the height of the instrument and reflector.

Note that in the case of a telescope-mounted EDM instrument the slope distance measured from EDM does not differ from the slope distance computed at the height of the theodolite by more than 1mm for distances in excess of 10 metres irrespective of the slope of the line. Therefore reducing the measured distance using the height of the theodolite rather than the height of the EDM avoids the necessity to calculate a tilt correction for the EDM slope distance.

An estimate of the additive constant should be applied to the observed distances before applying the slope correction if the magnitude of the additive constant or the grade of the testline makes the correction significant.

(c) **Height Correction**: The horizontal distances at mean elevation are reduced to the height of the lowest pillar. The magnitude of this correction becomes significant on the steeper Testlines. The effect of not applying this correction to the mean elevation distance is an error of 1 ppm for each 6.37 metre height difference between the height at the mean elevation of a pair of pillars and the height of the lowest pillar.

$$d = d_{hor} * \frac{R + h_o}{R + h_m}$$

Where R = 6 370 100m (Radius of Earth);

h_o = height of lowest pillar;

h_m = height at mean elevation;

d_{hor} = horizontal distance at mean elevation.

10.4.2 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. Using the New South Wales testlines it is possible to solve for the additive constant and the scale factor, however the cyclic error should be determined independently as detailed below.

Additive Constant

The additive constant is generally computed using the `parts to the whole' method. As an example, a four pillar Testline would give the following combinations for additive constant (C):

$$2C_1 = -(d_{12} + d_{23} + d_{34} - d_{14})$$

$$C_2 = -(d_{12} + d_{23} - d_{13})$$

$$C_3 = -(d_{23} + d_{34} - d_{24})$$

$$C_4 = -(d_{13} + d_{34} - d_{14})$$

$$C_5 = -(d_{12} + d_{24} - d_{14})$$

Where ` d_{12} ' is the mean of the two reduced horizontal distances measured between pillar one and pillar two, etc.

The additive constant should be computed using the closed least square solution as detailed for various configurations of baseline in Rüeger, `Electronic Distance Measurement' section 13.2.4.4.

In the case of a four-pillar baseline the additive constant is given by:

Additive Constant: $C = -0.5\,(d_{12} + d_{23} + d_{34} - d_{14})$

To confirm that the constant has been determined correctly, re-compute the parts to the whole, using the corrected distances.

Scale Factor

The Scale Factor for the instrument is determined by computing the ratio of each of the interpillar 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 Testline certificate.

On a four pillar testline the scale factor is determined using the weighted mean of the six interpillar distances. However an estimate of the scale factor can be determined by comparing the unweighted mean of three interpillar distances with the published values, for example:

Scale factor	=	known distance / observed distance
	=	650.500 / 650.502
	=	0.999 9969
	=	-3.1 ppm.

Cyclic Error

Although Cyclic error may be significant in older instruments, modern instruments generally have a Cyclic error of a magnitude of one millimetre or less. Despite the small magnitude, Cyclic error must be determined through verification in order to achieve legal traceability of distance measurements.

Note that Cyclic error, if found to be significant, must be applied to the original measured distances before the other instrument corrections are determined.

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, (usually ten metres) at 50 to 70 metres distant from the EDM instrument.

A reflector, mounted in a tribrach, is moved to each successive one 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. For example:

EDM	50.125;51.126	59.124;	60.123
TAPE	2.000; 3.000	11.000;	12.000
Cyclic Error	+0.000;+0.001	-0.001;	-0.002

For a detailed description of the procedure for determining cyclic error refer to ‘Electronic Distance Measurement’, (1990), J.M. Rüeger, Springer-Verlag, Berlin.

10.5 Analysis of the Verification Results & Application of Instrument Corrections

On completion of the EDM calibration the three instrument corrections of Additive constant, Scale factor and Cyclic error should be known to sufficient accuracy such that the total instrument calibration has an uncertainty not exceeding ±(5.0mm + 30ppm) at the 99% confidence level as recommended by the National Measurement Institute.

10.5.1 Cyclic error

Cyclic error is generally insignificant in modern instruments and consequently not applied to the measured field distances. However its magnitude must be determined in order to achieve legal traceability of distance measurements.

Although the Heerbrugg/Schwendener baselines of six pillars or more are intended to solve for cyclic error, most designs are based on an instrument unit length of 5 or 10 metres. Modern instruments are tending toward the shorter unit lengths of two or three metres in order to improve instrument accuracy. Consequently the Surveyor General advocates the determination of cyclic error by using an independent cyclic error testline rather than modifying existing baselines to cater for the various unit lengths of the newer instruments.

Note that cyclic error if found to be significant, 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.

10.5.2 Additive constant

Because the additive constant is determined without reference to the published interpillar distances it will not be influenced by changes in the true distances caused by pillar movements occurring since the testline 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 scale factor should not be influenced by a change in the ambient temperature. Consequently the additive constant should not vary significantly in subsequent verifications given the same reflector and EDM combination.

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

10.5.3 Scale factor

The scale factor will generally vary for subsequent verifications within the accuracy specification of the instrument (e.g. ±3ppm or ±5ppm). This is because the scale factor is dependent on the 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 aging 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 verification under different climatic conditions both to confirm the result and to observe if the scale factor changes with different ambient temperatures. The thermometers and barometer used in the calibration should also be re-verified against a certified standard as an error in temperature and pressure readings will contribute to the scale error of measured distances.

10.5.4 Uncertainty of the Instrument Correction

The former National Standards Commission recommended in 1983 that the minimum standard for the uncertainty of calibration of an EDM instrument should be ±(5mm+30ppm) at a 99% confidence interval. This uncertainty is equivalent to ±(4mm + 24ppm) at a 95% confidence interval.

The uncertainty of the instrument correction (in relation to the National Standard) includes the uncertainty of the verified baseline distances as shown in the Baseline

Measurement Report, currently stated as ± (2mm+10ppm) at a 95% confidence interval.

Note that all statements of uncertainty are now required to be shown at the 95% confidence interval to achieve international uniformity in accordance with the International Organisation for Standardisation (ISO).

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 document.

10.5.5 Error analysis of the field measurement technique

The Surveying and Spatial Information Regulation 2012 requires surveyors to make distance measurements to an accuracy (uncertainty) of ±(10mm + 50 ppm) or better at a confidence level of 95%.

Following is an example of an `error budget' for measurements made using an EDM instrument given the required uncertainties for the instrument calibration and the measurement accuracy. For a detailed explanation refer to Rüeger, ` Legal Calibration of Electronic Distance Meters in Australia', 1991.

11. Conclusion

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 ±(10mm + 50ppm). The required accuracy or uncertainty is to include the uncertainty of the length measurement arising from all possible sources.

Length measurements made with a survey band have a total uncertainty which includes not only the uncertainty of calibration of the band but those errors associated with the corrections applied for temperature, tension and sag, slope reduction and the plumbing technique used.

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.

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.

For further information, contact:

Manager Metrology & Governance
Spatial Services
Department of Finance, Services & Innovation
Queens Square Building
1 Prince Albert Rd
SYDNEY NSW 2000
Telephone: (02) 8258 7503

Glossary of Acronyms

AGAL	-	Australian Government Analytical Laboratories
CI&SO	-	Cadastral Integrity & Sydney Operations
EDM	-	Electronic (Electromagnetic or Electro-Optical) Distance Measurement
ISO	-	International Organisation for Standardisation
NATA	-	National Association of Testing Authorities
NMI	-	National Measurement Institute (comprising the former AGAL, NML and NSC)
NML	-	National Measurement Laboratory
NSC	-	National Standards Commission
ppm	-	Parts Per Million

Appendix A - Applicable Clauses of the Surveying and Spatial Information Regulation 2012

14 Equipment for measurement of surveys

(1) A survey must be made using appropriate equipment.

(2) A surveyor must not use any equipment in making a survey unless the surveyor knows the accuracy obtained by its use. That accuracy must be determined by reference to:

(a) the Australian primary standard of measurement of length, within the meaning of the *National Measurement Act 1960* of the Commonwealth, or
(b) the State primary standard of measurement of length, within the meaning of that Act, that is under the control of the Surveyor-General, or
(c) in the case of GNSS equipment, at least 3 established survey marks with accurate AHD values.

(3) A surveyor must not use any steel or invar band in making a survey unless it is verified at least once every 2 years and immediately after any repair.

(4) A surveyor must not use any electronic distance measuring equipment in making a survey unless it is verified against the State primary standard of measurement of length (as referred to above), by using pillared testlines, at least once every year and immediately after any service or repair.

(5) A surveyor must not use any GNSS equipment in making a survey unless it is verified against the State control survey:

(a) at least once every year, and
(b) immediately after any service or repair, and
(c) immediately after any change or upgrade of software.

(6) The accuracy and method of any verification under this clause must be as approved.*
*see the definition of "approved" in Clause 5 of the Surveying and Spatial Information Regulation 2012.

25 Accuracy of length measurements

(1) A length measurement must be verified, either directly by means of a second measurement of that length or indirectly by calculation of that length from the measurements of other lengths and angles.

(2) In making a survey, a surveyor must measure all lengths to an accuracy of 10 mm + 50 parts per million or better at a confidence interval of 95%.

Appendix B - Contact details & Scale of Fees

For further information or advice, contact:

Manager Metrology & Governance
Spatial Services
Department of Finance, Services & Innovation
Queens Square Building
1 Prince Albert Rd
SYDNEY NSW 2000

or

GPO Box 15
SYDNEY NSW 2001

Telephone: 02 8258 7503
Email: EDMcal@lpi.nsw.gov.au

The following list outlines the fees for service performed by the Office of the Surveyor General

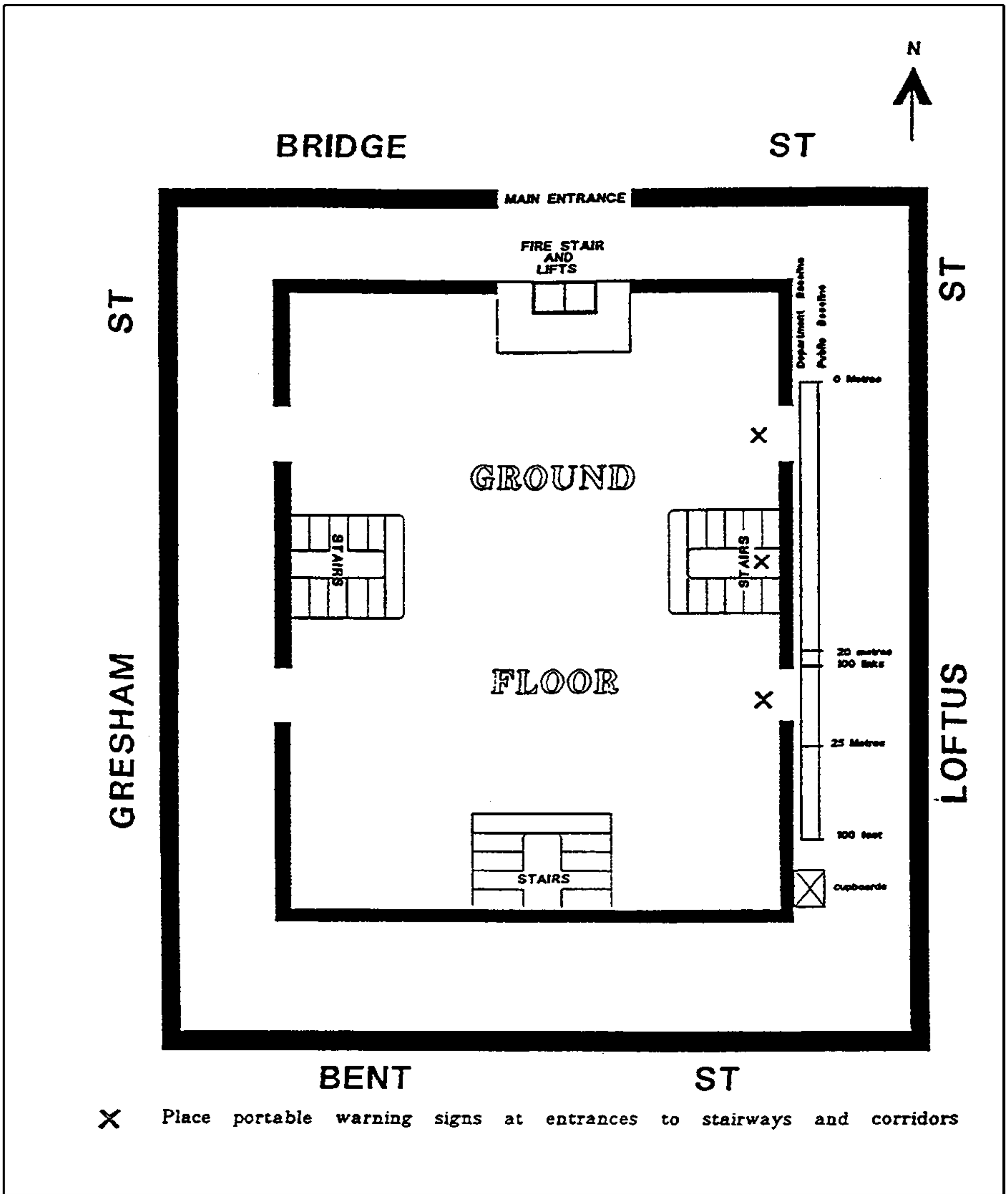
1. Verification of 100 metre steel or invar survey band with "Measurement Report" certificate for bands up to 100 metres in length. Five 20 metre intervals of the band are verified at 50 and 70 Newtons.

   $90.20 (incl. GST)

2. EDM Test Line Measurement Reports

   No Charge.

Appendix C - Survey Band Baseline Locality Diagram



Appendix D - Measurement Report

MEASUREMENT REPORT

SURVEY MEASURING BAND

REPORT No. 9904
CLIENT: Energy Australia

BAND No. 5214

Length (nominal): 100 metres
Material: Steel

Width: 1.6 millimetres
Weight: 638 grams

Marking by brass sleeves at 2 metre intervals

Terminal points: Inner face of terminal loop at 0 metres and at 100 metres

Interval Measured (metres)	Length of interval Fully Supported at 20 degrees Celsius		Associated Uncertainty (metres)
	50 N	70 N	
0 to 20	19.9976	20.0001	± 0.000 5
20 to 40	19.9970	19.9994	± 0.000 5
40 to 60	19.9972	19.9996	± 0.000 5
60 to 80	19.9968	19.9992	± 0.000 5
80 to 100	19.9962	19.9986	± 0.000 5

Measurements were conducted on 28 July 1999 at the tape calibration baseline located in the Department of Lands building, Bridge Street, Sydney, and have been determined in relation to the State primary standard tape No. H302407.

The lengths of the intervals have been determined from measurements taken at a mean tape temperature of 16.3° C and at tensions of 50N and 70N. Corrections have been applied to the measured lengths so that they refer to a temperature of 20° C as shown in the table above.

Uncertainty of the stated measurements: ±0.0005 metres

This uncertainty is calculated in accordance with the principles of the ISO Guide to the Expression of Uncertainty in Measurement (1995), with an interval estimated to have a confidence level of 95% at the time of verification and a coverage factor (k) of 2.

The tests, calibrations or measurements covered by this document have been performed in accordance with NATA requirements which include the requirements of ISO/IEC 17025 and are traceable to Australian national standards of measurement. This document shall not be reproduced, except in full.

NATA Accredited Laboratory Number: 14965

....
R K Lock
Surveyor
Legal Metrology Officer
For the Surveyor-General
Date: 18 December 2003

Department of Lands
1 Prince Albert Road, Queens Square, GPO Box15, Sydney NSW 2001
Phone (02) 8258 7500 Fax (02) 8258 7555

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Land and Property Information, NSW

PROGRAM: BAND PC-1.0

T E S T   S U M M A R Y

Tape number	5214
Test number	9904
Date of Test	28-07-99
Test Temperature (C)	16.3
Nominal length (m)	100
Number of intervals	5
Precise Base Length (m)	20.000 03
Weight of Band (grams):	638
Remarks	ENERGY AUST
Input Data filename	TEST9904.dat

INTERVAL	Measured Length of Interval Tested at TEST TEMPERATURE		
TESTED	50 Newtons	60 Newtons	70 Newtons
0 TO 20	19.99678 ± 0.00013		19.99926 ± 0.00006
20 TO 40	19.99612 ± 0.00003		19.99855 ± 0.00006
40 TO 60	19.99633 ±0.00007		19.99875 ± 0.00013
60 TO 80	19.99596 ±0.00011		19.99838 ± 0.00007
80 TO 100	19.99536 ±0.00010		19.99774 ± 0.00006

INTERVAL	Measured Length of Interval Tested at TEMPERATURE of 20EC		
TESTED	50 Newtons	60 Newtons	70 Newtons
0 TO 20	19.99761 ±0.00013		20.00010 ± 0.00006
20 TO 40	19.99695 ±0.00003		19.99938 ± 0.00006
40 TO 60	19.99717 ±0.00007		19.99958 ± 0.00013
60 TO 80	19.99679 ±0.00011		19.99921 ± 0.00007
80 TO 100	19.99619 ±0.00010		19.99857 ± 0.00006

** UNCERTAINTY VALUES ARE CALCULATED USING A CONFIDENCE INTERVAL OF 99%**

Appendix D - .... cont'd

Land and Property Information, NSW

PROGRAM: BAND PC-1.0

SAG AND TEMPERATURE CORRECTION TABLE

Tape Number	=	5214	Tape Unit=	METRES
Standard Temp	=	33.6	Tension =	50 Newtons

DIST	SAG	DIST	SAG	DIST	SAG	DIST	SAG
2	0	28	1	54	10	80	33
4	0	30	2	56	11	82	36
6	0	32	2	58	13	84	39
8	0	34	3	60	14	86	41
10	0	36	3	62	16	88	44
12	0	38	4	64	17	90	48
14	0	40	4	66	19	92	51
16	0	42	5	68	21	94	54
18	0	44	6	70	22	96	58
20	1	46	6	72	24	98	61
22	1	48	7	74	26	100	65
24	1	50	8	76	29		
26	1	52	9	78	31		

***** TEMPERATURE DIFFERENCE *****

DIST	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**	**22**	**24**	**26**	**28**
10	0	0	1	1	1	1	2	2	2	2	2	3	3	3
20	0	1	1	2	2	3	3	4	4	5	5	5	6	6
30	1	1	2	3	3	4	5	5	6	7	7	8	9	9
40	1	2	3	4	5	5	6	7	8	9	10	11	12	13
50	1	2	3	5	6	7	8	9	10	11	12	14	15	16
60	1	3	4	5	7	8	9	11	12	14	15	16	18	19
70	2	3	5	6	8	9	11	13	14	16	17	19	20	22
80	2	4	5	7	9	11	13	14	16	18	20	22	23	25
90	2	4	6	8	10	12	14	16	18	20	22	24	26	28
100	2	5	7	9	11	14	16	18	20	23	25	27	29	32

(NOTE : All corrections are in mm)

Appendix D - .... cont'd

Land and Property Information, NSW

PROGRAM: BAND PC-1.0

SAG AND TEMPERATURE CORRECTION TABLE

Tape Number = 5214 Tape Unit = METRES

Standard Temp = 22.8 Tension = 70 Newtons

DIST	SAG	DIST	SAG	DIST	SAG	DIST	SAG
2	0	28	1	54	5	80	17
4	0	30	1	56	6	82	18
6	0	32	1	58	6	84	20
8	0	34	1	60	7	86	21
10	0	36	2	62	8	88	23
12	0	38	2	64	9	90	24
14	0	40	2	66	10	92	26
16	0	42	2	68	10	94	28
18	0	44	3	70	11	96	29
20	0	46	3	72	12	98	31
22	0	48	4	74	13	100	33
24	0	50	4	76	15		
26	1	52	5	78	16		

***** TEMPERATURE DIFFERENCE *****

DIST	2	4	6	8	10	12	14	16	18	20	22	24	26	28
10	0	0	1	1	1	1	2	2	2	2	2	3	3	3
20	0	1	1	2	2	3	3	4	4	5	5	5	6	6
30	1	1	2	3	3	4	5	5	6	7	7	8	9	9
40	1	2	3	4	5	5	6	7	8	9	10	11	12	13
50	1	2	3	5	6	7	8	9	10	11	12	14	15	16
60	1	3	4	5	7	8	9	11	12	14	15	16	18	19
70	2	3	5	6	8	9	11	13	14	16	17	19	20	22
80	2	4	5	7	9	11	13	14	16	18	20	22	23	25
90	2	4	6	8	10	12	14	16	18	20	22	24	26	28
100	2	5	7	9	11	14	16	18	20	23	25	27	29	32

(NOTE : All corrections are in mm)

Appendix E - Location of EDM Testlines

The location and configuration of pillared Test Lines throughout New South Wales are as follows:

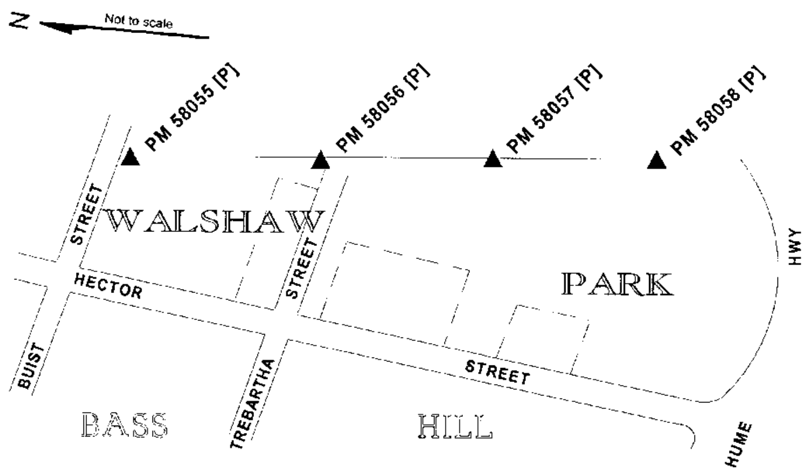
BASELINE	LOCALITY	TOTAL DIST (m)	No. of PILLARS
Armidale	Grafton Road	600	4
Bankstown	Walshaw Park, Hector St, Bass Hill	605	4
Bega	Bega Rifle range, adj. to Golf Course	503	4
Coffs Harbour	Dowsett Drive, Coffs Harbour Airport	921	7
Dubbo	Dunedoo Road	765	6
Eglinton	Thomas Drive	849	7
Goulburn	Goulburn Police Academy	497	4
Grafton	Old Glen Innes Road	610	4
Kingscliff	Marine Parade	721	7
Lethbridge Park	Bougainville Road	984	7
Nowra	Flinders Road	581	4
Seaham	Croft Road	867	7
Taree	Omaru Park, Muldoon Street	515	4
Ulan Coal	Ulan Rd, Ulan	650	6
Wagga Wagga	Stanley Street, Kooringal	535	5
Wollongong	Sir Thomas Dalton Park, Elliots Rd	600	4

Appendix F - Example of EDM Testline Measurement Report

Report No. Bankst04

MEASUREMENT REPORT

BANKSTOWN EDM TESTLINE



ACCESS : Unrestricted (10mm Allen key required to remove pillar caps)

HORIZONTAL DISTANCES (metres) AT DATUM 47.484 m AHD

From	To	Distance	Mark	RL (AHD) *
PM 58055	PM 58056	202.077	PM 58055	47.484
PM 58055	PM 58057	458.732	PM 58056	48.445
PM 58055	PM 58058	605.006	PM 58057	50.739
			PM 58058	57.634

* The Reduced Levels (in metres AHD) were re-verified at this date.

Method of verification: VA-QM-01 and NMI's Verifying Authorities Handbook, 2nd Ed. November 1988

Distances by the Surveyor-General of NSW, in accordance with the verification of a Reference standard of length as prescribed by the National Measurement Act, 1960.

Instrument used : Leica TCA2003, Serial No. 438583
Verified in accordance with Regulation 13 of the National Measurement Regulations, 1999

Uncertainty of distances: +/- (2mm + 5ppm)

This uncertainty is calculated in accordance with the principles of the ISO Guide to the Expression of Uncertainty in Measurement (1995), with an interval estimated to have a confidence level of 95% at the time of verification and a coverage factor (k) of 2.

The tests, calibrations or measurements covered by this document have been performed in accordance with NATA requirements which include the requirements of ISO/IEC 17025 and are traceable to Australian national standards of measurement. This document shall not be reproduced, except in full.

NATA Accredited Laboratory Number: 14965

C. W. Jeremy
Surveyor
for the Surveyor-General of NSW

DATE: 23 September 2004

Department of Lands
1 Prince Albert Road, Queens Square, GPO Box 15, Sydney NSW 2001
Phone (02) 8258 7500 Fax (02) 8258 7555

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Appendix G - EDM Testline Observations

EDM CALIBRATION

BASELINE NAME	DATE	OBSERVER	ASSISTANT	INST. MAKE	MODEL	SERIAL No.	REFL. MAKE	SERIAL No.	± CONST.
	/ /								0·

THERMOMETERS

	MAKE	SERIAL No	±	CORR^n
I				°C
R				°C

BAROMETERS

	MAKE	SERIAL No.	±	CORR^n
I				
R				

WEATHER

☐ Instrument shaded
☐ Reflector shaded
☐ P.P.M. set to ZERO
☐ Inst. / Refl. const. set to ZERO

FROM	TO	H.I.	H.R.	TEMP °C I	TEMP °C R	PRESSURE I	PRESSURE R	HUMIDITY	SLOPE	DISTANCES				MEAN SLOPE DIST STD DEV	REMARKS
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SIGNED ______________________

DESIGNATION ____________________ DATE ___/___/_____

page ___ of ___

Version 1.3 EDM Calibration Recording Sheet 9/02/2004

CHANGE IN PRESSURE (Millibars) CORRESPONDING TO A CHANGE IN HEIGHT OF 10 GEOPOTENTIAL METRES

Temp °C	Pressure in Millibars								
	1050	1000	950	900	850	800	750	700	600
-10	1.3622	1.2974	1.2325	1.1676	1.1028	1.0379	0.9730	0.9082	0.7784
0	1.3124	1.2499	1.1874	1.1249	1.0624	0.9999	0.9374	0.8749	0.7499
10	1.2660	1.2057	1.1454	1.0852	1.0249	0.9646	0.9043	0.8440	0.7234
20	1.2228	1.1646	1.1064	1.0481	0.9899	0.9317	0.8735	0.8152	0.6988
30	1.1825	1.1262	1.0699	1.0136	0.9573	0.9010	0.8446	0.7883	0.6757
40	1.1447	1.0902	1.0357	0.9812	0.9267	0.8722	0.8177	0.7632	0.6541
50	1.1093	1.0565	1.0037	0.9508	0.8980	0.8452	0.7924	0.7395	-

Reproduced from Smithsonian Meteorological Tables,(1971) R.J. List

List, R.J. (1971) `*Smithsonian Meteorological Tables'*, Smithsonian Institute

National Standards Commission (1988) `*Verifying Authorities Handbook'*

Rüeger, J.M. (1984) `*Instructions on the verification of electro-optical short-range distance meters on Subsidiary Standards of length in the form of EDM calibration baselines'*, School of Surveying, UNSW.

Rüeger, J.M. (1990) `*Electronic Distance Measurement'*, 3rd ed. Springer Verlag, Berlin.

Rüeger, J.M. (1991) `Legal Calibration of Electronic Distance Meters in Australia', *The Australian Surveyor*, Vol 36, Sept 1991, pp195-212

End of Direction