Made To Measure: Constructing Modern EDM Baseline Infrastructure in NSW

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The NSW Surveyor General is a Verifying Authority under the National Measurement Act 1960 and responsible for ensuring that surveyors use verified measuring equipment for all boundary definitions and control surveys within the State. This is achieved through both a hierarchy of regulatory requirements and the provision and maintenance of Electronic Distance Measurement (EDM) baselines by Land and Property Information (LPI).

The NSW Surveying and Spatial Information Regulation 2012 requires surveyors to verify their measuring equipment in relation to an Australian standard of measurement of length at least once a year. On behalf of the Surveyor General, LPI is the sole organisation responsible for constructing, maintaining, monitoring and verifying these baselines within NSW. Local organisations (e.g. councils and mines) often support this function by hosting the physical baseline infrastructure.

LPI is currently rationalising, improving and future-proofing its EDM baseline infrastructure. This involves upgrading existing baselines to include a larger number of pillars, building completely new baselines, expanding some to contribute to GNSS validation networks, evaluating new national calibration software and completing succession training for tomorrow's metrology staff. This article, however, focuses on the issues that need to be considered in the construction of a new state-of-the-art EDM baseline.

EDM CALIBRATIONS

The EDM instrument correction is dependent on many variables, including distance, temperature and atmospheric pressure. It is made up of at least two terms, i.e. the additive constant (a constant term expressed in mm) and the scale correction (a linear distance-dependent term expressed in ppm). Additional terms can be added to describe the instrument correction in more detail, e.g. non-linear distance-dependent terms and cyclic error terms.

This correction is valid for a specific instrument-prism combination only. The field procedures prescribed for EDM calibrations in NSW are documented in Surveyor General's Direction No. 5: Verification of Distance Measuring Equipment (see http://www.lpi.nsw.gov.au/surveying/publications/surveyor_generals_directions).

EDM calibrations require the measurement of distances over highly precise baseline infrastructure. Initially, EDM baselines constructed in NSW consisted of four concrete pillars. However, current best practice has established that EDM baselines should include at least five (and preferably six or seven) pillars. This increases the number of observed inter-pillar distance combinations and therefore allows a more reliable determination of the instrument correction.

In order to improve its survey infrastructure, LPI is now upgrading existing baselines to include more pillars where possible. However, baseline expansions are often extremely difficult in practice. So, a number of new 7-pillar baselines are being built to replace existing ones that cannot be upgraded. Here we focus on the Eglinton EDM baseline in Bathurst (released in April this year) to outline the issues that need to be considered in the construction of a modern EDM baseline.

SITE SELECTION

The existing 4-pillar EDM baseline in Bathurst had been in use since its construction in 1979. However, a combination of slope and soil type meant that following each period of either drought or heavy rain the pillars appeared to move slowly downhill, at different and unpredictable rates. The problem was worsened by the construction of a contour bank immediately below the second pillar (pooling water after heavy rain) and a council gravel stockpile constructed on line with the baseline.

In the early 2000s, it was decided that this baseline could not be maintained into the future. Investigations into an alternative site around Bathurst commenced in 2007. In order to provide high-quality survey infrastructure far into the future, LPI elected to build a 7-pillar baseline.

The search for candidate sites involved the following constraints:

- Public land.
- Easy access, preferably without the need for keys and close to a major population centre.
- Safety for those using the baseline and the general public passing by (human and vehicle traffic).
- The right shape, i.e. up to 1,000 m long, ideally dipping in the middle, with intervisibility and minimal change of height between proposed pillars.
- Stable and consistent soil and geology, preferably on flat ground.
- Free from current or future development changes, road widening and drainage works.
- Easy construction and subsequent clearing/maintenance.
- Clear of overhead obstructions and surrounding vegetation, and suitable for GNSS.

LPI investigated several road reserves, public reserves and parks, but future clearing and access issues generally limited the suitability of these sites. A number of locations were discarded due to high vehicle volumes and high speed on adjacent roads. It quickly became clear that finding a suitable site would be a difficult, time-consuming and long-term task.

Finally, the road reserve of a quiet rural road at Eglinton was selected because it complied with almost all requirements. In 2011, funding became available to proceed with the design and construction of the new EDM baseline.

BASELINE DESIGN

Baseline designs generally aim to achieve an equal distribution of all measured distances between the shortest and longest line on the baseline, with no or minimal repetitions. Some designs require each length to be a multiple of a basic unit length. The unit length is the scale on which the EDM instrument measures the distance. It is derived from the fine measuring frequency and equals half the EDM's modulation wavelength.

All baselines in NSW follow the Heerbrugg design, which allows the detection of all distance-dependent errors (including cyclic errors). It is based on four input parameters to determine the spacing between the pillars: unit length of the EDM(s) to be calibrated, shortest distance on the baseline (a multiple of the unit length), desired total length of the baseline, and the number of pillars. Obviously, a larger number of pillars results in an increased number of observations (over various combinations of distances), translating into a higher precision of the resulting additive constant.

An optimal balance between cost and precision is generally obtained with six to seven pillars. Applying this procedure for the design of the 7-pillar Eglinton baseline resulted in a total baseline length of 849 m with the shortest section being 21 m. LPI also ensured that the design delivered an equal distribution of the distances measured in all combinations over the unit lengths for a wide range of current EDM instruments.

The vertical design profile of the Eglinton baseline was equally important. It shows a slightly concave shape with minimal height undulation, allowing intervisibility between all pillars while minimising the average height differences between pillars. This also avoids the use of extremely tall and/or low pillars, supporting Work Health and Safety considerations by providing maximum comfort to the observer (See Figure 1 below).

APPROVAL TO BUILD

Bathurst Regional Council supported the construction of a new local EDM baseline from the beginning. Fortunately, a Development Application was not required. In this case, a proposal outlining the purpose of the baseline and what it would look like when completed was accepted by Council.

Prior to the formal proposal being submitted, LPI performed the following work:

- Cadastral and detail survey.
- Modelling the shape for a baseline design.
- Generating a baseline design proposal.
- Confirming the location of underground utilities.
- Pegging out the proposed pillar locations and creating digital images.

The submission was approved by Council subject to a number of conditions deemed to be within the design guidelines and projected budget. Core sampling investigated the underlying geology and confirmed that a stable baseline could be constructed economically. LPI modified the original pillar design (very similar to that used for Tier 2 GNSS CORS) by increasing the size of reinforcing steel and requiring a depth of 6.5 m (!) for all base piles to reach stable sandy strata.

BASELINE CONSTRUCTION

In June 2012, construction officially commenced with the set-out survey, which included placement of two 3 m offset pegs for each pillar. All pegs were levelled to second order specifications to confirm that heights agreed with the design and to provide additional height checks at each pillar.

Physical construction was awarded to a local engineering firm. Pre-made steel formwork was placed on site and the boring machine was used to lower the steel into the boreholes. This allowed the boring of holes, placing of base steel formwork and pouring of concrete bases

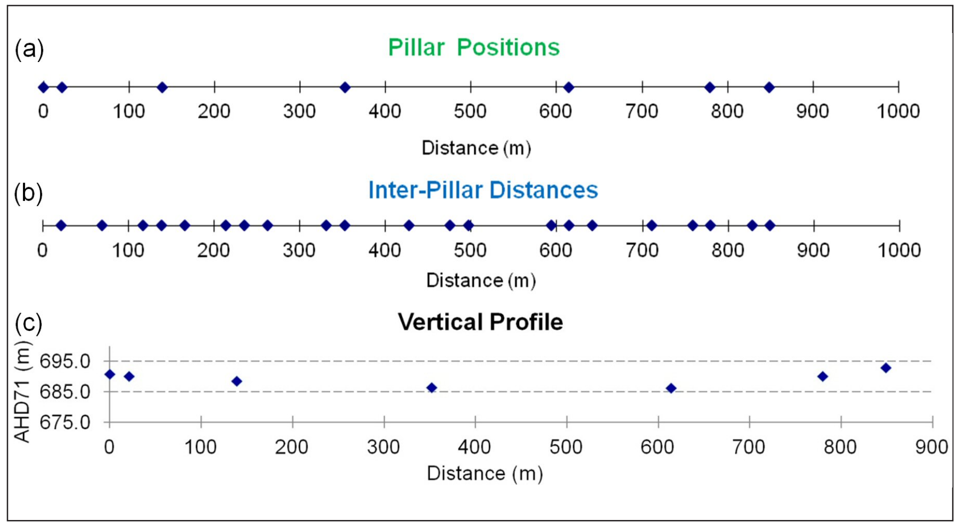

Figure 1: (a) Design positions for the seven pillars, (b) distribution of the 21 inter-pillar distance combinations, and (c) vertical profile design for the Eglinton EDM baseline.

to be performed on the same day. The use of a concrete pumping machine allowed the filling of the boreholes with concrete with very little disturbance to the sides of the holes.

Once the bases were poured, boxing was set up for the pillar section pour. As PVC pipe was used to form the outside of the pillars, it only had to be set up vertical, on line and at the correct height. This was easily carried out with stringline offsets and the top of the PVC pillar accurately located by total station. Before and after the second concrete pouring, a bracket and prism were used to confirm that no movement had occurred (See Figure 2 below).

Figure 2: Pre-pour check of line and height (top), and post-pour marking for pillar plate alignment (above).

Once all pillar pours were completed, the pillars were allowed to cure for one week before the pillar plates were grouted into place. During this period, the bases around the pillars were formed and poured, and final landscaping and clearing occurred. In addition, the safety barrier construction commenced.

The pillar plates were installed using a low-shrinkage grouting mix. The two end pillar plates were installed first and each plate was accurately levelled. Each subsequent pillar plate was then grouted and levelled, and its position confirmed accurately from either end of the baseline.

Brass number plates were placed in the exposed grout to avoid confusion with pillar numbering. All seven pillars were then sanded, undercoated and painted to protect the PVC pipe. Finally, a stainless steel etched plaque was affixed to each pillar.

The erection of the safety barriers would complete construction. A statement in Council's approval stated that "even though a low risk has been determined, it is recommended that an appropriate safety barrier be installed at your cost, as per the RTA's Road Design Guide".

As this dead-end rural road has no posted speed limit, the contractor's traffic engineer deemed that it defaults to 100 km/h, thus requiring highway-specification safety fencing. In total, the construction was completed within one month (Figure 3 below).

Baseline verification

Following a pillar-settling period of four months, the Eglinton EDM baseline was verified by LPI legal metrology staff in November 2012. During verification, all 21 inter-pillar distances were observed under careful consideration of accurately measured temperature and atmospheric pressure using precise calibrated instruments.

The relative height differences between the pillar plates were determined to second order specifications in December 2012. Initially, absolute Reduced Levels (RLs) were obtained via static GNSS using CORSnet-NSW and applying AUSGeoid09. A levelling connection to surrounding AHD71 marks was then carried out to provide final RLs for the pillar plates. In April 2013, LPI released the Eglinton EDM baseline as its first new 7-pillar installation.

Conclusion

LPI is currently in the process of improving its survey infrastructure for the calibration of EDM instruments in a variety of ways. This includes upgrading some existing baselines to include more pillars and building new 7-pillar baselines in key urban locations. This article has outlined the issues that need to be considered in the construction of a modern, state-of-the-art EDM baseline, using the newly constructed Eglinton EDM baseline in Bathurst as an example.

This process is not straightforward, takes considerable time and effort, and requires careful consideration of various issues faced during the planning, site selection, baseline design and pillar construction stages. The Eglinton EDM baseline is a fundamental piece of survey infrastructure and is now available to the profession. LPI encourages its immediate use (see http://www.lpi.nsw.gov.au/surveying/surveying_services/edm_baseline_certificates for more details). ∎

Figure 3: Eglinton EDM baseline after completion.

A new Australian Standard: Classification of Subsurface Utility Information

A new Australian Standard, AS5488 *Classification of Subsurface Utility Information,* was published on 14 May 2013 and officially launched on 12 June 2013.

Unlike previously published international utility Standards and Guidelines, the Australian Standard AS5488-2013, Classification of Subsurface Utility Information (SUI), is not an *engineering* Standard but is unashamedly a *surveying and spatial information* standard due to its attention to absolute spatial position, metadata and attributes.

Utility services have been placed underground since the early years of the colony: for example, the construction of Busby's Bore commenced in 1827. The advent of gas, water and electricity services in the latter part of the nineteenth century inevitably led to conflicts between the increasing number of subsurface utility services. Notwithstanding that such conflicts were costly to rectify, location technologies were immature and maps of unknown origin and accuracy were the accepted means of location prior to the 1970s. However, as society progressed and utility strikes and conflicts became more prevalent, often resulting in injury or death, society looked for means to reduce the financial and personal cost associated with subsurface utility strikes.

On 23 March 1977, the Institution of Surveyors NSW Inc held a seminar on *"The Need for Common Standards in the Recording and Charting of Underground Services"*. The report of this seminar was provided to me by Gary Fuller FIS. John Naughton FIS, a member of the Institution's INSURE (Information Needs for Surveyors in the Eighties) Committee that was responsible for the seminar, recently (6 June 2013) wrote to me stating *"Unfortunately our efforts prior to 1980 achieved little except to leave a spark of frustration at the reluctance of government to recognise the vulnerability of underground assets"*. Two of the seminar's key recommendations recognised the need for all mapping to be on a coordinated grid system and common symbology.

In the USA, recognition of the same problem resulted in the introduction of Subsurface Utility Engineering (SUE) in Virginia in 1982. At the same time, progress in Australia continued to be non-existent.

More urgent action was taken following a "wake-up call" in New York City on September 11, 2001. Asset owners then began to talk more about infrastructure protection, their vulnerabilities & risk and the value in accurate mapping and recording of their assets. In 2002 the American Society of Civil Engineers published ASCE 38-02, the *Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data.*

In 2006, the Surveying & Mapping Industry Council of New South Wales (SMIC) released an issues paper on *'Underground Services Detection & Data'*, recommending common accuracy standards for data capture of new or replaced underground utilities and as-built drawings to be lodged for new or replaced services. Also in 2006, RailCorp NSW published a *Specification for the Collection of Services Data,* specifying survey accurate 3D location for underground utilities.

In the following year, a GITA Workshop in Brisbane inspired by the SMIC Issues Paper concluded that *"a national standard for recording the location of underground services is urgently required"* and *"critical infrastructure protection is a prime driver for recording the location of underground services"*.

In 2009, Main Roads Western Australia published Underground Utility Standard 67-08-121, based on the USA Standard ASCE 38-02. In the same year, the NSW Board of Surveying & Spatial Information (BOSSI) published its "Roadmap", which investigated current standards for recording underground services and made key recommendations concerning accuracy, absolute positioning, data capture methods, data quality, symbology and a common data exchange format.

At 9.30 pm on 15 September 2009, a contractor in the Sydney CBD accidentally cut through 10 Telstra fibre optic and capper cables. The final cost of the repair was $800 million and this directly resulted in important changes in NSW State legislation. The cost of not knowing "where" was significant, and this was a catalyst for initiating work towards the development of an Australian Standard in the mapping and location of underground utility services.

After lobbying by Cardno, BOSSI and NSW Roads & Traffic Authority (now Roads & Maritime Services - RMS), an industry meeting was hosted by Standards Australia on 10 May 2010, involving presentations by locally and internationally respected experts. This meeting demonstrated industry commitment to the development of an Australian Standard. The Project Proposal was consequently submitted by RMS and SMIC successfully lobbied for sufficient funding. Standards Australia then asked for nominations from specific national industry groups for membership on the Committee. The Committee first met on 17 August 2011, with Mark Gordon representing Austroads accepting the nomination for Chair of the Committee. Also joining me from our profession on the 22 member Committee were Norm Bruhn, Bruce Douglas, Paul Harcombe, Bill Kearsley, John Minehan and Tom Williams. Only twelve months later, the draft Standard was released for public comment.

The new published Standard recommends the absolute spatial positioning of subsurface utilities in three dimensional coordinates as an improvement upon the widely adopted method of relative spatial positioning that involves measuring offsets from physical structures and depth below ground level, both of which can change over time. In countries prone to natural disasters, such as Australia and New Zealand, or terrorist attacks, such as the USA, absolute spatial positioning appears to be a logical and necessary improvement when called upon to locate critical subsurface utility assets after the event.