"Errors? Surveyors are 100% correct - aren't they?"

Error analysis and localised deformation monitoring - a local example

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Errors. As experts in the science of measurement, errors (in the statistical sense) are inherent in everything we do, whether we like to admit it or not. This issue was on the forefront of our minds two years ago as we planned and implemented a system to monitor a localised area of land for deformation along a new roadway. The survey provided an exciting opportunity to use a number of modern and innovative surveying techniques to deal with the challenges of the site and present the results in the context of their error estimates.

Introduction

In planning this survey three key questions were raised:

1. How do we reduce potential errors to a level that would fit the client's precision requirements?
2. How do we then demonstrate that those requirements are met?
3. How do we effectively communicate with our clients that apparent movement of the marks may actually be within the estimated error of that position?

As Surveyors, most clients and contractors assume that a measured position is an exact position (without error). The distinction often needs to be made between an *error*, simply being a "mistake" and the term as used in the context of surveying where physical measurements are correct within statistical confidence limits i.e. the estimation of measurement precision or accuracy (precision can be defined as the closeness of a set of repeated observations, accuracy is the closeness of a set of measurements to their true values). While random measurement error cannot be completely eliminated, systematic and periodic errors may be corrected through instrument calibration and mistakes are normally detected through good survey practice.

This article will outline the background and constraints of this localised deformation survey, the combination of survey techniques used to meet those constraints and how we analysed and presented both the results and estimated errors to the client.

Background

In late 2010 Staig & Smith Ltd were approached by a geotechnical engineer consulting to the Nelson City Council to provide a proposal for carrying

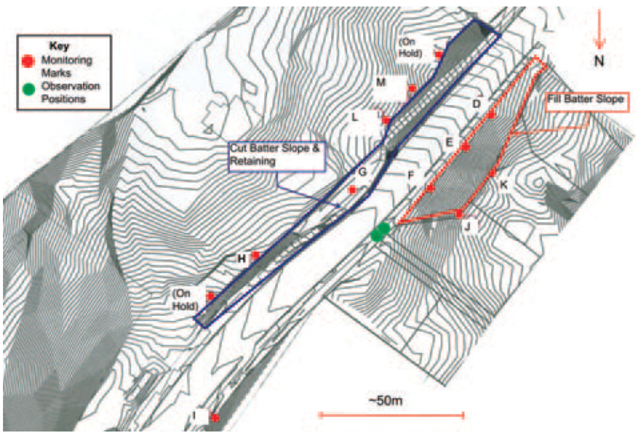

Figure 1: Survey area showing monitoring mark locations

Figure2: Monitoring site at the start of the project, with positions to be monitored above and below the road

out a monthly deformation monitoring survey. The monitored positions were adjacent to a newly constructed road extension located within a broader area known to contain areas of ground instability. The area to be monitored was approximately 110m long by 35m wide.

The purpose of the survey was to determine if ground movement was occurring on land adjacent to the carriageway and by inference whether the carriageway or other land may be subject to movement. The final survey requirements were:

Survey Requirements	
Monitoring horizontal & vertical accuracy requirements (1 Standard Deviation)	Initially 2-3mm revised to 6mm
Frequency	2 monthly
Period	24 months
Marks monitored	8 to 10

Survey Methodology

General Survey Design

The survey design aimed to use a number of survey techniques to both establish survey control and automate the survey observations and analysis to create both efficiency and consistency.

The site constraints lead to three levels of marks being used:

- **Control Survey Marks:** These marks were established well outside the area of interest at locations that were considered stable.
- **Monitoring Marks:** These marks were located within the broader area of the road construction in consultation with the client.
- **Observation Positions:** Feasible locations for survey observation positions from which all monitoring marks and control marks could be seen were constrained by features, such as trees, fences, and topography. Furthermore, due to the extent of land movement, the observation positions would need to be located within the area of potential land movement. Clearly, if the observation positions are subject to ground movement and also held fixed as control marks then the monitoring marks would be observed within a dynamic system. Potentially erroneous deformation or no deformation may be observed.

The key features of the general survey design were:

- A total station was to be used to carry out the *monitoring observations* from the primary observation position, at a central location within a limited area, from which all the monitoring marks could be observed. An independent set of observations were also to be carried out from a second observation position within close proximity, as a check on the first monitoring mark positions calculated.
- The horizontal and vertical position of the *observation position and orientation were to be derived independently* each time using observations to surrounding control marks, essentially a "free-station" or resection technique.
- *Multiple rounds* of angles and distances were to be observed automatically by the instrument to both the survey control and monitoring mark targets using automated target recognition.
- A *monitoring target system* was to be trialled that consisted of concreted tubes to which a fixed pole was inserted. This forced centring system reduces

target setup time and would also eliminate target setup error (both horizontal and vertical).

As with the majority of deformation monitoring surveys two key aspects were, firstly, establishing control that is both physically reliable and accurate relative to the project survey and secondly, implementing ways to reduce errors to ensure results will be within the specifications.

Monitoring Mark Design

It was fortunate, that while the client had made decisions on the preferred location of the monitoring marks, their installation formed part of the survey brief. Marks established by non-surveyors often results in the type and position of the marks adversely affecting the time required to establish targets and significantly limiting the number of ways they can be observed.

Our ideal target system would have the following qualities:

- High level of repeatability
- Resistant to disturbance by wind or distortion by heat
- Fast setup time
- Compact to transport

Figure 3: Target system

After considering a range of options, including the traditional tripod/tribrach method, it was decided to design and trial a new system. This system incorporated 500mm long aluminium tubes as the monitoring marks, with an associated target rod and prism that was inserted into this tube. These were generally 500mm high above the top of a concreted tube (with a further 250mm inserted into the concreted tube), except for two locations where topography necessitated 750mm high targets.

It was acknowledged in the design that a potential shortcoming of this system was shallow surface movement causing the concrete monitoring mark encasement to tilt. This effect could be magnified through the height of the target above the tube. However, it was considered that this was a low risk on the relatively gentle slopes of the site and was outweighed by the overall repeatability gained. Pole verticality was therefore monitored throughout the project, with no significant effect noted.

Establishing Survey Control

Four key survey control marks were established well outside the survey area. Three of these marks were established using the same system as the monitoring marks and housed under lids for protection. Because of poor visibility to the uphill side of the site due to trees, the fourth mark was mounted low down on a pylon. An eccentric mark was therefore established to survey its position.

Horizontal Positioning

The control marks were positioned horizontally using post-processed fast static GPS with a leap-frog system of measurement. Each of the marks were occupied for at least 30 minutes and post processed against the NLSN LINZ PositioNZ [PositioNZ is an active control network of continuously operating GNSS reference stations operated by Land Information New Zealand (LINZ) (http://apps.linz.govt.nz/positionz/)] GNSS station. Because of nearby features within the residential area a number of marks had reduced sky visibility, thus necessitating longer occupation times.

Following processing of the GPS baselines, final horizontal positions using the GPS and total station observations were determined using a least squares adjustment within the LINZ SNAP software. The error ellipses for the horizontal portion of the control ranged between 2 to 3mm at 1SD (4 to 8mm at the 95% confidence interval (2.45SD)).

Vertical Coordination

Two of the closer control marks to the monitoring site were used as the primary height control, with the height difference determined by levelling. This approach was used instead of utilising the GPS observed ellipsoidal heights because the vertical component is less precise (up to 6mm 1SD).

Error Reduction & Consistency

Atmospheric conditions, equipment and survey techniques were designed to maximise consistency and reduce potential errors in the survey. These are outlined below:

- *Pressure, temperature and humidity corrections:* Values were entered into the instrument for automatic corrections to be applied.
  (5°C temperature change = 5ppm or 3mm affect to the distance measurement over the longest control line (600m))
- *Timing of the Survey:* Programmed for the early morning in order to minimise the effects of shimmer for the horizontal observations, and effects of the sun directly shining on the instrument.
- *Prisms and poles:* Both were labelled and used for the same marks, with the poles orientated consistently towards the instrument.
- *Automatic target recognition (ATR)*: All observations were performed using automatic target recognition of the prisms, thus reducing the need to touch the instrument, decreased observation time by improving speed and decreasing the potential effects of different operators.
- *Rounds of observations:* The instrument used had a nominal angular precision of 5". It was therefore decided to observe at least six sets on both instrument faces to both the control and monitored stations to increase the estimated precision of the resulting coordinates.

Error Analysis

Processing the Observations

Two of the key processing aims we had for this project were to develop an efficient and semi-automated system to both calculate positions for the monitored marks and estimate their associated precision. With the time and information available, a combination of SNAP and Microsoft Excel spreadsheet software were used. The key steps to the data processing were:

1. Outlier detection and creation of SNAP data file: A template was created in Excel that allowed for easy detection and removal of any outlier observations and creation of a SNAP data file from the mean control observations.
2. Observation position: The coordinates and precision were calculated using the observations to the fixed control marks.
3. Calculate the final coordinates and error budget: Adjusted control coordinates were used in Excel to calculate the final coordinates of the monitored marks and the total precision estimate, as shown in the error budget in Table 1.
4. Independent check: A further automated comparison from a second independent observation position provided an additional check on the final results.

Table 1 - Error Budget	**Range of error estimates from surveys (1SD)**	
	Position (+/-)	Height (+/-)
Observation position maximum error ellipse axis (from SNAP)	1-3mm	1-2mm
Monitored mark position (maximum SD of coordinates calculated in Excel from 6 rounds of observations)	0-1mm	0-1mm
Total precision estimate	**1-4mm**	**2-4mm**

Presentation of Results and Error Estimates

Within Excel a combination of a summary spreadsheet and graphics were produced that demonstrated the movement of the monitored marks and also showed the simple error ellipses (horizontal positions) or error bars (heights) estimated. It quickly became obvious which marks were moving well outside those estimates (for example Mark J) and those that demonstrated little movement, with any apparent movement tracking around within those error ellipses, such as Mark D.

Three of the 10 marks monitored displayed movements less than 6mm in position over the 24 months surveyed, with five showing movements less than 6mm in height. This helped provide confidence in the reliability and repeatability of the results being generated. These marks were generally towards the extents of the project site and located at the top of the cut or fill batters.

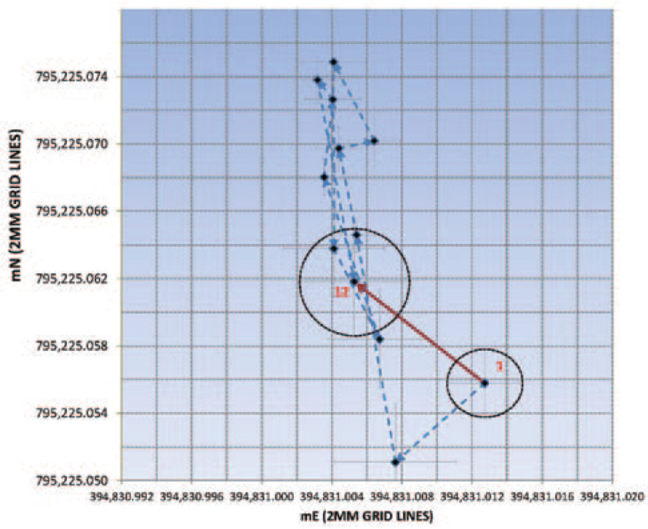

Figure 4 – Mark J horizontal movement and error ellipses

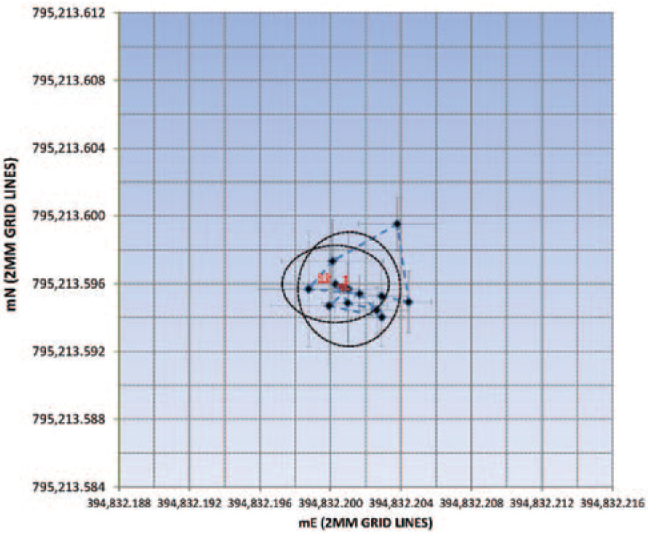

Figure 5 – Mark D horizontal movement and error ellipses

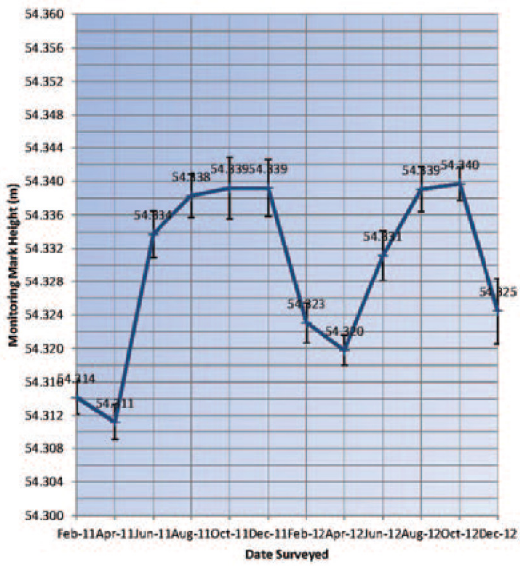

Figure 6 – Mark J changes in height and error bars

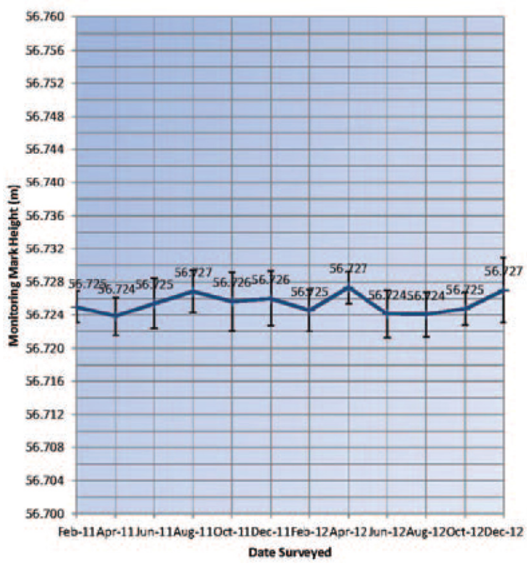

Figure 7 – Mark D changes in height and error bars

Key Features of 24 Month's Results	Horizontal Position	Height
Total number of observations made to calculate monitoring mark positions	*~1,800*	
Maximum movement observed from the first monitoring survey (Mark J)	*28mm (±2mm @ 1SD)*	*25mm (± 3mm @ 1SD)*
Number of marks showing <6mm movement from first monitoring survey	*3*	*6*
Number of marks showing >12mm movement from first monitoring survey	*2*	*3*

Only two of the marks showed movements greater than 12mm in both height and position, including Mark J, as shown. Both these marks were located at the bottom of a fill batter slope. They reflected a cyclical trend, moving upwards in height over the winter months and downwards during summer, also being reflected was an up-slope and down-slope horizontal movement. When soil moisture levels were graphed against the height movements a clear correlation could be seen.

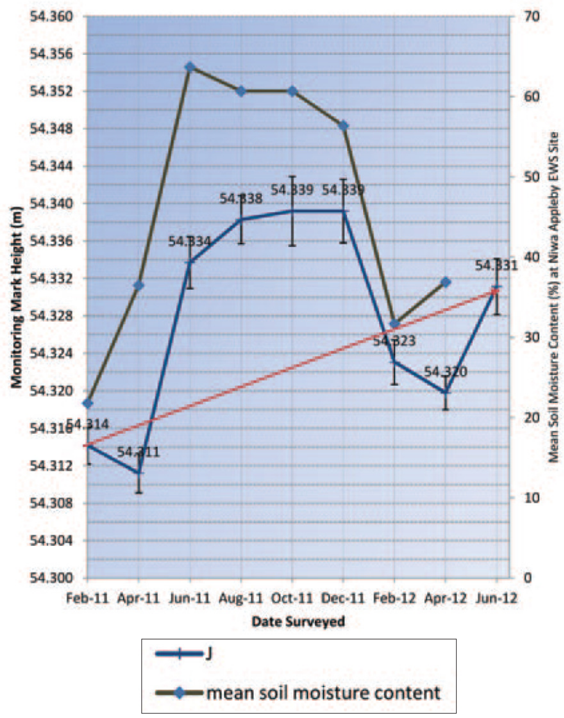

Figure 8: Mark H – Relationship between soil moisture content and mark heights

Conclusion and Discussion

This survey provided an exciting opportunity to use a range of survey techniques to both establish site control and survey the monitored marks over the two years. These ranged from levelling to eccentric setups and fast-static GNSS observations to automated rounds of observations. A system was also successfully developed that was relatively automated in calculating and displaying the movement of the monitored marks from the 1,800 observations made. Furthermore it provided a level of confidence that the monitoring mark positions lay within the range shown.

We endeavoured to find an effective and efficient means of presenting the land movement that would enable a more informed interpretation of the results and confidence in the data accuracy. However, the solution described here is one possibility among many. **Have you found novel approaches to doing this well?**

Have you considered any of these issues? We hope this article has stimulated some ideas or practical applications for survey situations you will encounter. We encourage you to **continue the conversation** by emailing the authors with any thoughts or posting on the NZIS forum.

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