Toitu te Land whenua Information New Zealand

Specifications for Post-Earthquake Precise Levelling and GNSS Survey

Version 1.0
National Geodetic Office

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Contents

SPECIFICATION FOR PRECISE LEVELLING

1 Scope

This specification covers the precise levelling and GNSS survey requirements for the re-establishment of reliable heights for the National Height Network in the wake of the Canterbury Earthquake of 4 September 2010.

2 Related Standards and Specifications

Standard for tiers, classes and orders of LINZ data – LINZS25006 (21 September 2009)

Standard for the New Zealand survey control system – LINZS25003 (21 September 2009)

Specifications for Geodetic Physical Network v2.6 (24 November 2010)

Specifications for Geodetic Contract Deliverables v1.5 (24 November 2010)

3 General Description of Works

3.1 *Introduction*

This specification describes requirements for precise levelling survey between benchmarks and other geodetic marks in Canterbury as specified in Schedule 1. The works included are limited to the precise levelling survey of the specified marks.

3.2 *Site Access*

Permission to enter private land should be obtained from the landowner/occupier prior to accessing any privately-owned site. If after reasonable attempts, the landowner/occupier is unable to be contacted prior to the work commencing, the contractor is required to leave their contact details so that the landowner/occupier is informed of the site access. Details of the land owner/occupier may be available from the Geodetic Database (see http://www.linz.govt.nz/geodetic/geodetic-database/index.aspx).

Contractors must be fully aware of, and at all times exercise their responsibilities and obligations under, the Health and Safety in Employment Act 1992. Sites, marks, beacons and other protection structures shall be left in a respectable and safe state.

3.3 *Notification of Work Being Undertaken*

The National Geodetic Office shall be notified of any work that is likely to affect users of the site, mark and/or beacon during the course of the survey, such as beacon removal for a period (greater than several hours) while surveys are carried out.

Note: If a beacon is removed from a mark it should be laid on its side to avoid possible confusion if observed to while out of position.

4 Mark and Site Selection

4.1 *Marks to be Used – Precise Levelling Survey*

Existing marks to be surveyed are listed separately to this specification.

Where a new mark is required, it shall be in the same general location as the mark it is replacing. The construction of the new mark and/or any associated protection structures shall comply with the benchmark construction requirements of the Specifications for Geodetic Physical Network.

4.2 *Marks to be Used – GNSS Survey*

LINZ has identified the number of marks to be GNSS surveyed. The final choice of marks to be surveyed must be made using the following criteria. Each mark must:

a) Be one of those identified by LINZ for precise levelling survey

b) Have a current NZGD2000 order of 6-12

In addition, each mark selected should

a) Have good current and future sky visibility

b) Be clear of live traffic lanes

Taking account of the above factors, GNSS surveyed marks should be distributed as evenly as possible amongst the marks in the levelling run.

4.3 *Maintenance of Marks*

Any maintenance of the mark and/or its associated protection structures shall comply with the requirements of the Specifications for Geodetic Physical Network. Such maintenance shall only be carried out for one of the following reasons:

a) It is requested by LINZ

b) It is required to enable the survey to be carried out (for example, clearing a site to allow access)

c) It is required to protect an at-risk mark (for example, where a mark is likely to be destroyed before a maintenance contractor could be sent to maintain it)

d) It is required to avert a Health and Safety hazard (for example, a cast iron box with a missing or broken cover.)

Any maintenance not meeting the above criteria shall be advised to LINZ so that it may be considered for a future work programme.

5 Geodetic Codes and Mark Naming

5.1 *Geodetic Codes*

Each mark is to be assigned a unique four-character geodetic code supplied by the National Geodetic Office.

If a mark has an existing geodetic code, its existing code shall be used.

5.2 *Names for Existing Marks*

Where an existing mark with a geodetic code is selected, its existing identification as shown in the geodetic database shall be used.

5.3 *Names for New Order 2000 Marks*

New marks shall be named as a ‘Number 2’ position of the benchmark they are replacing. For example, if a new mark is replacing UE 72, its name shall be UE 72 NO 2.

6 Precise Levelling Survey Requirements

6.1 *Precise Levelling Observations*

Levelling observations are to be undertaken in accordance with good survey practice using levelling techniques suitable to meet the required standard.

Precise spirit-levelling using invar staves is one technique capable of complying with the accuracy standard. Other methods that can be shown to meet the accuracy standard may be used with the prior approval of LINZ.

Precise levelling observations shall be made between marks in a manner that ensures that all observations are checked and comply with the accuracy requirements (e.g. double-run levelling). Each mark shall be directly connected to at least one other mark, and all marks must form part of a single traverse. The methodology used and the circuit or fore and back misclosures, compared against the allowable misclosures, shall be fully documented in the survey report. Full details of reductions applied in producing the final height differences must also be included.

6.2 *Field Notes*

The Contractor shall supply field notes for all levelling work undertaken. These should *clearly* show as a minimum, the equipment used, personnel involved, all observations, reductions and checks.

6.3 *Accuracy Standard*

The allowable misclose in millimetres for height differences between fore and back levelling runs is defined by the equation:

$$Misclosure = 5\sqrt{k}$$

In this formula, *k* represents the one-way summation of the slope distances between change points along the route between benchmarks in kilometres

For example, levelling of 1.8 kilometres (each way) has an allowable misclose of 6.71mm.

The misclose test shall be applied once any instrumental and atmospheric corrections to height differences have been made.

6.4 *Levelling Data*

The height differences supplied in accordance with section **Error! Reference source not found.** must be unadjusted summations of all intermediate height differences in the forward direction and return direction respectively. They shall be reduced to correct for instrument errors and atmospheric effects, where these are significant. The normal-orthometric correction shall not be applied.

6.5 *Mark/Site Photographs*

Mark/site photos are required for all marks, except where there is already a photo in the Geodetic Database, as noted in the supplied spreadsheet of marks to be precise levelled.

Where mark/site photos are required, the following must be supplied:

a) A Mark Photo. This must clearly show the mark and the material in which it is installed.

b) A Site Photo. This must clearly show the mark in relation to its immediate surroundings, including any protection structures.

c) An Extended Site Photo. This must show a wider view of the site and its surroundings, including features which may help to locate the mark in the future. It must also contain enough information to convey the suitability of the mark for terrestrial or GNSS observations. Where the mark would not otherwise be clearly visible in the photo, an item (such as a road cone) should be placed over the mark to identify its location.

In all photos, care must be taken not to include members of the public, or anything else that could compromise an individual's privacy, bearing in mind that the photograph will be made available over the internet in a public database.

6.6 *Mark and Site Details*

For each site visited, sufficient mark and site details are to be recorded to enable a Report of Maintenance Work Completed and Required to be compiled.

For each mark the Contractor shall supply either an Access Diagram or Finder Diagram.

- Access Diagrams should be provided for all trigs and marks with complex access instructions.
  Access Diagrams should provide enough information to ensure that anyone locating the mark will travel via the safest, most direct route, or that preferred by the landowner/occupier.

- Finder Diagrams should be provided in all other cases.
  Finder diagrams should include street names and ties to nearby physical objects to allow the mark to be located in a timely manner.

7 GNSS Survey Requirements

7.1 *Method of Survey*

The method of survey used must be a Global Navigation Satellite System (GNSS) technique such as GPS or GPS/GLONASS.

Survey observations shall be undertaken in accordance with good survey practice (refer to Appendix 1) and sufficient observations must be made to test for any potential survey errors, such as plumbing errors or, where GNSS is used, multipath errors, and to ensure that the survey accuracy requirements can be tested and proven.

7.2 *Post-earthquake Higher Order Control*

Marks with accurate post-earthquake coordinates are listed separately to this specification.

Only these marks may be used as higher order control.

7.3 *Network Configuration and Connections*

Marks must be connected to a minimum of 2 post-earthquake higher order control marks in a way that absolute coordinate accuracy tests can be applied and proven (refer to Appendix 2). The survey network shall be designed in such a way that **ALL** observations can be checked by a network adjustment and that the relative accuracy to other geodetic control marks is maintained.

Unless specifically stated, LINZ does not require additional connections to neighbouring marks which are the same order as the survey.

7.4 *Connection to Local Higher Order Control*

Where a mark is selected for survey, a connection to at least one post-earthquake higher order control mark must be made, if there is such a mark within 10km.

Where no local marks exist, or accessing a local mark is not reasonable, the Contractor shall explain this in the survey report.

7.5 *Field Notes and Raw GNSS Data*

The Contractor shall retain survey field notes and raw GNSS data for 2 years from the date of survey. This shall be provided to LINZ upon request.

7.6 *Survey Accuracy*

The accuracy requirements for provision of survey control shall meet the following standards for class and order:

Table 2: Standards for Class 2000 Surveys

Order	Horizontal Accuracy and Class			Height Accuracy and Class		
	Class	Constant - e (mm)	Line length error - p (ppm)	Class	Constant - e (mm)	Line length error – p (ppm)
5	VIII	10	50	IX	20	100

Note: Although p is a dimensionless quantity, when it is used in the formula below it has the effect of being a ppm accuracy standard, e.g. when p=1 this represents a distance dependent error of 1:1,000,000 or 1 part per million.

The accuracy for an observed vector is determined by:

$$\text{95\% confidence limit} = \pm \sqrt{e^2 + (\text{distance (km)} \times p)^2} \quad \text{mm}$$

Guidelines for Assessing Data Accuracy are provided in Appendix 2 attached to these specifications.

7.7 *Mark/Site Photographs*

No additional Mark and Site Photographs are required. Note that photos are already supplied by Section 6.5.

7.8 *Mark and Site Details*

No additional Mark and Site Details are required. Note that this information is already supplied by Section 6.6.

8 Contract Deliverables

The format and content of the contract deliverables for Geodetic Control Survey are contained in the Specifications for Geodetic Contract Deliverables.

Appendix 1: Geodetic Good Survey Practice

The following field procedures are to be followed to ensure good survey practice:

- all field equipment shall be calibrated and checked prior to and on completion of the survey
- specific procedures shall be adopted to ensure that instrument centring and heighting errors do not go undetected
- where GNSS is used field procedures shall be adopted to minimise the effects of multipath and sufficient satellites shall be used to ensure a strong geometry
- where a level is used, regular collimation checks shall be carried out
- all field measurements shall be independently checked and recorded
- two independent setups shall be undertaken on each mark
- sufficient time shall be allowed to ensure that GNSS satellite geometry changes to minimise the effects of multipath and other errors
- hanging lines shall be avoided where possible and where used sufficient checks shall be carried out to ensure no errors in the data
- sufficient observations shall be collected to ensure that a free and fixed network adjustment can be performed to check that the required survey accuracy standard has been met
- check to ensure the relative accuracy between new and existing nearby control is achieved

Appendix 2: Assessing GNSS Data Accuracy

1 Introduction

General information about accuracy requirements are contained in the following standards:

LINZS25005: Standard for the geospatial accuracy framework

LINZS25006: Standard for tiers, classes and orders of LINZ data

The accuracy requirements for specific control networks are contained in the following standard:

LINZS25003: Standard for the New Zealand survey control system

This appendix provides information on how to assess data accuracy, based on the requirements of these standards.

1.1 Accuracy, Tiers, Classes and Orders

Two types of accuracy are defined: network accuracy and local accuracy.

Network accuracy is a measure of the uncertainty of a coordinate relative to the NZGD2000 datum. It is conceptually similar to absolute accuracy.

Local accuracy is a measure of the uncertainty of a coordinate relative to other nearby coordinates. It is conceptually similar to relative accuracy.

Coordinates are assigned to various classifications based on their accuracy. Three classifications are used for LINZ data: tier, class and order.

Tier is a categorisation of a coordinate's network accuracy.

Class is a categorisation of a coordinate's local accuracy.

Order is a categorisation incorporating the requirements of both tier and class. It describes a coordinate's network and local accuracy.

Note that a coordinate must achieve both the class and tier standards to be assigned to an order. Therefore the assigned order will be limited by the least accurate of either the class or tier that is achieved by the coordinate.

1.2 Network Accuracy

A coordinate can be assigned to a tier based on the network accuracy that it achieves. Table A1 shows that multiple orders have the same tier requirements (e.g. both order 0 and 1 need to meet tier A horizontally). These levels have been set in LINZS25006 based on the purpose of the control networks for which these orders were specified.

To enable these orders to be implemented operationally it is necessary for successive orders to have increasing network accuracy tolerances. The numerical uncertainty values required to achieve the tier for each order (and which satisfy the need to have increasing values between orders) are listed in Table A2.

Horizontal network accuracy at the 95% confidence level is computed using the formula:

$HE_{95} = \frac{2.45}{\sqrt{2}}\sqrt{\sigma_X^2 + \sigma_Y^2}$ where σ_X and σ_Y are the two orthogonal horizontal standard deviations.

The horizontal network accuracy formula averages orthogonal error components to determine a circular accuracy. These orthogonal components could be the standard deviations of the northing and easting, or the semi-major and semi-minor axes of the absolute error ellipse of the coordinate.

Vertical network accuracy at the 95% confidence level is computed using the formula:

$VE_{95} = 1.96\sigma_X$ where σ_X is the vertical standard deviation.

Network accuracy can be tested in a "classical" adjustment, where the coordinates of higher order marks are held fixed. For example, in an Order 5 adjustment, the coordinates of Order 4 and higher marks are held fixed. This ensures that these high order mark coordinates are not changed by the adjustment of the lower order network.

We need to consider that the fixed control in our adjustment will itself contain errors. Table A3 provides network accuracy values which account for this, based on the order to be generated in the adjustment and the order of the fixed control. The columns represent the Order of the fixed marks. The rows represent the Order of the marks being adjusted. For a classical adjustment using Order 4 control to generate Order 5 coordinates, the 95% network accuracy of the Order 5 coordinates must be better than 70mm. The 95% vertical network accuracy must be better than 150mm. It would not be correct to test using the values of 132mm and 350mm for horizontal and vertical network accuracy given in Table A2, as these values assume no error in the fixed coordinates.

1.3 Local Accuracy

Least squares adjustment allows the local accuracy of adjusted coordinates to be derived from the inverse of the normal matrix. This can be calculated regardless of whether the line between the marks was directly observed or not.

Horizontal local accuracy at the 95% confidence level is computed using the formula:

$HE_{95} = \frac{2.45}{\sqrt{2}}\sqrt{\sigma_{\Delta X}^2 + \sigma_{\Delta Y}^2}$ where $\sigma_{\Delta X}$ and $\sigma_{\Delta Y}$ are the two orthogonal horizontal standard deviations between two coordinates.

Once again, this formula averages orthogonal error components to determine a circular accuracy. These orthogonal components could be the standard deviations of the change in northing and change in easting, or the semi-major and semi-minor axes of the relative error ellipse between the two coordinates.

Vertical local accuracy at the 95% confidence level is computed using the formula:

$VE_{95} = 1.96\sigma_{\Delta X}$ where $\sigma_{\Delta X}$ is the vertical standard deviation between two coordinates

The classes which categorise local accuracy for coordinate order are listed in Table A1. The numerical uncertainty values required to achieve the class for a given order are listed in Table A2.

For lines between coordinates of different classes, the local accuracy standard of the lower class shall apply. For example, a line between a Class V and a Class VIII coordinate shall have a horizontal uncertainty no greater than that given by the Class VIII standard of 10mm + 50ppm at 95% confidence, not the Class V standard of 3mm + 1ppm at 95% confidence.

The accuracy threshold in millimetres between coordinates in a class is calculated from the constant (c) and proportional (p) values in Table A2 using the formula $\sqrt{c^2 + \left(Dp \times 10^{-3}\right)^2}$ where D is the distance in metres between the two coordinates being evaluated.

◆ Table A1. Tier and Class for Order Categories

Order	Control Network	95% Confidence Limit			
		Horizontal		Vertical	
		Class	Tier	Class	Tier
0	National Reference Frame	II	A	II	A
1	National Deformation Monitoring Network	III	A	IV	B
2	Regional Deformation Monitoring Network	V	B	VI	E
3	-	VI	B	VII	F
4	Local Deformation Monitoring Network	VII	C	VIII	F
5	Cadastral Horizontal Control Network	VIII	C	IX	F
	Cadastral Horizontal Control Network				
	Basic Geospatial Network				

◆ Table A2. Accuracy Standards for Order Categories

Order	95% Confidence Limit					
	Maximum Horizontal Coordinate Accuracy			Maximum Vertical Coordinate Accuracy		
	Local		Network (mm)	Class		Network (mm)
	c (mm)	p (ppm)		c (mm)	p (ppm)	
0	3	0.03	35	3	0.03	50
1	3	0.1	50	3	0.3	100
2	3	1	87	10	3	250
3	10	3	100	10	10	285
4	10	10	112	10	50	315
5	10	50	132[1]	20	100	350

[1] This value is tighter than that required for Tier C, since Order 6 coordinates also need to be Tier C and we need to allow for error in the Order 6 survey.

◆ **Table A3. Standard for Network Accuracy in Terms of Fixed Control**

		Horizontal Network Accuracy in Terms of Fixed Control (mm)						Vertical Network Accuracy in Terms of Fixed Control (mm)					
		Lowest Order of Fixed Control											
		0	1	2	3	4	5	0	1	2	3	4	5
Adjustment Order	0	-						-					
	1	35	-					87	-				
	2	78	70	-				246	230	-			
	3	93	86	50	-			281	267	135	-		
	4	105	99	71	50	-		311	299	191	135	-	
	5	127	122	99	86	70	-	346	334	243	202	150	-

2 Checking for Compliance with these Standards

The LINZ adjustment software package SNAP (Version 2.3.28 dated 14 October 2009 or greater) is to be used to check for compliance with the standards in the Tables above. A copy of SNAP and its associated utilities may be obtained from the LINZ website at http://www.linz.govt.nz/software-downloads/snap/index.aspx.

Reasonable and justifiable observational errors in terms of the methodology used should be assigned to the data. These should be no greater than the values in Table A4 according to the order of coordinates to be defined from the survey.

Different error models may be used for different subsets of the data, however the use of these different error models must be justified.

Assigning observational errors is often an iterative process. The initial observational errors may be amended based on adjustment statistics such as the RMS, SEUW or some other form of variance component analysis. However the rationale for any such re-weighting must be explained in the report and must not result in clearly inappropriate errors being estimated.

◆ **Table A4: Maximum Observational Errors**

		Constant (e)				Line Length Error (p)		
Order		**E mm**	**N mm**	**U mm**		**E ppm**	**N ppm**	**U ppm**
0		1.2	1.2	1.5		0.012	0.012	0.015
1		1.2	1.2	1.5		0.04	0.04	0.15
2		1.2	1.2	5		0.4	0.4	1.5
3		4	4	5		1.2	1.2	5
4		4	4	5		4	4	25
5		4	4	10		20	20	50

2.1 Accuracy Tests

The survey data, both observations and assigned observational errors, shall be tested by a series of adjustments as follows:

1. Observation Accuracy Test: this tests that the observations are as accurate or better than the assigned observational errors.
2. Local Accuracy Test: this tests the local (relative) accuracy of coordinates derived from the survey.
3. Network Accuracy Test: this tests the network (absolute) accuracy of coordinates derived from the survey, in terms of the higher order marks controlling the survey.

2.2 Observation Accuracy Test

The accuracy of the observations shall be tested by a minimally constrained adjustment. The observational accuracy requirements are achieved if the following conditions are met:

1. the standard error of unit weight is no more than 1; and

2. all *a priori*[2] standardised residuals are less than a limit R_{max} which depends upon the degrees of freedom in the adjustment. R_{max} is calculated from the degrees of freedom n as

$$R_{max} = P^{-1}((1 + 0.95^{1/n})/2)$$

where P^{-1} is the inverse cumulative standard normal probability distribution function. R_{max} is evaluated in Table A5.

[2] This means that adjustment outputs such as standardised residuals and error ellipses are not scaled by the SEUW. In SNAP, this is achieved with the command `error_type apriori` in the command or configuration file.

◆ **Table A5: Allowance for Degrees of Freedom**

n	R_{max}
10	2.80
20	3.02
50	3.28
100	3.47
200	3.66
500	3.88
1000	4.05

Note: Values calculated from the degrees of freedom in the minimally constrained adjustment. For degrees of freedom not listed, either calculate using the formula, or take the smaller of the nearest R_{max} values.

2.3 Local Accuracy Test

The local accuracy of the coordinates is tested in a minimally constrained adjustment. The local accuracy test uses the calculated *a priori* relative horizontal error ellipse and the *a priori* relative vertical error from every coordinate to every other coordinate within a specified distance (the evaluation radius).

Evaluation radii are listed in Table A7. Where an adjustment incorporates marks in both urban and rural areas, the rural evaluation radius shall be used.

The test values to be used in SNAP are specified in the Local Accuracy columns of Table A6. SNAP outputs the results of local accuracy tests as a ratio of actual local accuracy to maximum permitted local accuracy. If the ratio between all pairs of coordinates is less than 1.0, then the local accuracy tests are passed.

Table A6: Test for the Accuracy of Coordinates in a Classical Adjustment

Order	Horizontal Accuracy				Vertical Accuracy		
	Local (mm)	Local (ppm)	Network * (mm)		Local (mm)	Local (ppm)	Network * (mm)
1	3	0.1	35		3	0.3	87
2	3	1	70		10	3	230
3	10	3	50		10	10	135
4	10	10	50		10	50	135
5	10	50	70		20	100	150

* in terms of higher order control

Table A7: Evaluation Radius for Local Accuracy Tests

Order	Evaluation Radius (km)
1	300
2	50
3	50
4	6 – urban areas 20 – rural areas
5	0.3 – urban areas 1 – rural areas

2.4 Network Accuracy Test

The network accuracy of the coordinates is defined by the *a priori* error ellipses in a constrained adjustment in which the coordinates of the control marks are held fixed.

The test values to be used in SNAP are specified in the Network Accuracy columns of Table A6. SNAP outputs the results of network accuracy tests as a ratio of actual network accuracy to maximum permitted network accuracy. If the ratio for all coordinates is less than 1.0, then the network accuracy tests are passed.

3 Compliance Checking Procedure Using SNAP

This section outlines one way that SNAP can be used to demonstrate that accuracy specifications can be met. There are many other approaches, particularly with regards to observation weighting, that produce an acceptable result, so there is no need to be constrained by what is outlined here. However, any approach taken needs to be justifiable.

The following assumes that SNAP data, coordinate and command files have already been created.

1. Assign observational errors to the observations. It is convenient if these match one of the sets of values listed in Table A4. We therefore select the observational errors that most closely reflect our equipment and methodology. For example, we may have used fast static GNSS, which the manufacturer advises has a precision (RMS) of 5mm + 1ppm horizontally and 5mm + 2ppm vertically. This is closest to Order 3 observational errors in Table A4, so we enter the following command in the SNAP data file: `#gps_enu_error 4 4 5 mm 1.2 1.2 5 ppm`

2. Run SNAP and confirm in the SNAP report that the observational errors generated are reasonable. For example, 2cm for a 10km line might be considered reasonable. 10cm probably would not. Make any amendments to the observational errors until you are satisfied that they are consistent with your knowledge and experience of the equipment and methodology used.

3. In a minimally constrained adjustment, check for outliers. As well as using the standardised residual to identify potential errors, look at the size of the residuals and confirm that they are reasonable in terms of the expected accuracy of the survey. Correct or reject any outliers.

4. Having removed any outliers, consider using the value of the SEUW to reweight the data files. This should only be done if the adjustment is large and has high levels of redundancy. The final SEUW must be less than 1.0 in a minimally constrained adjustment.

5. In a minimally constrained adjustment, check that the observation accuracy tests are passed.

6. In a minimally constrained adjustment, check that the local accuracy tests are passed.

7. In a constrained adjustment, check that the network accuracy tests are passed.