Toitu te whenua
Land Information
New Zealand

Accuracy Standards for Geodetic Surveys

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Office of Surveyor-General

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Contents

Foreword

These standards are prepared for geodetic control surveys for the national survey control system in New Zealand. Geodetic control surveys are carried out under contract from Land Information New Zealand. The standards may also be applied to other high accuracy surveys carried out in New Zealand such as engineering or deformation surveys. The standards relating to mark order are intended to apply only to coordinates generated in terms of the New Zealand Geodetic Datum 2000 (NZGD2000). Due to the inherent accuracy restrictions of the current datum, the standards will not apply to new coordinates generated in terms of New Zealand Geodetic Datum 1949 (NZGD49). However, the standards relating to observation class may be used to classify surveys from which NZGD49 coordinates are derived. This document contains standards set by the Surveyor-General to contribute to achieving this purpose.

Any comments or proposed amendments should be forwarded to the Surveyor-General.

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Document History and Approval

Document History			
Version	**Date**	**Section No.**	**Summary of Changes / Amendments**
1.0	1 March 1998		
1.1	1 March 2003	Formatting Section 3 Table 2 Table 3 and 4 General	This standard has been reformatted to comply with a new LINZ standard format. All explanatory notes are contained in the Guideline to the Standard. Terms and definitions are updated in terms of new legislation. 5th order category added. 5th order category revised. 5th order category added. Miscellaneous other minor corrections and updates.

Approved :

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Surveyor-General

ACCURACY STANDARDS GEODETIC SURVEYS

1 Introduction

These accuracy standards for geodetic surveys follow the general principle that:

> *the accuracy of a mark's coordinates relative to adjacent marks of the next highest order shall be dependent on the distance between them and shall not exceed 0.05m horizontally and 0.15m vertically.*

The accuracy standards have 3 components:

- *a constant term related to plumbing accuracy and other constant and instrumental errors. This is distance independent and is most significant on short lines;*
- *a distance dependent term which is more significant on long lines;*
- *a maximum coordinate accuracy which provides an upper limit to the impact of the distance dependent term (0.05m for one order of mark relative to the next highest order).*

These standards are divided into two sections, Three Dimensional Geodetic Survey Standards and Orthometric Height Standards.

2 Scope

These standards form part of a set of geodetic standards, specifications, and guidelines developed by the Office of Surveyor-General[1]. They have been developed for geodetic control surveys in New Zealand. However they can be extended to many other positioning applications such as for high precision engineering or deformation surveys.

The standards relate to three dimensional and one dimensional geodetic surveys. The standards represent the 95% confidence level and are the minimum geodetic accuracy standards required for each Class of observation or Order of mark.

[1] These standards and specification can be found on the LINZ web site at http://www.linz.govt.nz/rcs/linz/pub/web/root/core/SurveySystem/surveypublications/index.jsp

3 Term(s) and Definition(s)

For the purpose of this Standard the following terms and definitions apply:

absolute coordinate accuracy — The accuracy of a coordinate of a point relative to the coordinate reference frame.

accuracy — Closeness of observations to true values or values accepted to be true in a system as a whole.

class — An attribute of the accuracy of one or more components of a vector between survey marks. Class may be applied to:

- a survey procedure used to observe the vector;
- the *a priori* uncertainty assigned to an observation;
- calculated vectors resulting from a minimally constrained adjustment of observations.

order — An attribute of the official coordinates of a survey mark in a specified reference frame at a specified epoch. It is a measure of how accurately that mark is located with respect to surrounding geodetic survey marks of the same or higher order. This is assessed by an adjustment of data, from one or more surveys in which higher order marks are constrained in a specified manner.

Order 2000 — Newly defined Order of geodetic survey marks to distinguish them from existing *Orders* of mark, ie. NZGD49 1st *Order*.

Zero Order 2000 (Fiducial Network) — National and global fiducial network of continuous tracking stations used to define marks in a nation wide and global framework. Inter-marks spacing in the global network is 1000 - 5000 km and in the nation wide network 100 - 500 km.

1st Order 2000 (National Network) — National network of marks used to monitor dynamics of the datum and provide large-scale network accuracy. Mark spacing is typically up to 200 km.

2nd Order 2000 (Regional Network)	Primary regional survey network of marks across New Zealand with mark spacing up to 70 km.
3rd Order 2000 (Local Network)	Lower precision regional survey network with mark spacing up to 20 km. These network marks will form the basis for cadastral surveys in rural and intensive rural areas.
4th Order 2000 (Urban Control Network)	Densification of the 3rd Order 2000 (Local Network) which will provide control for cadastral surveys in urban and peri-urban areas.
5th Order 2000 (Cadastral Control Network)	Control used for cadastral surveys. Marks that are divided into two categories based on the method used to coordinate the marks: 5a - Marks coordinated by observations captured off existing survey plans. The marks will be existing urban and rural standard traverse marks, or cadastral marks (such as iron tubes and spikes); 5b - Marks coordinated by observations generated from new field surveys.
orthometric height (Ho)	Height of a point above the geoid along the direction of gravity. **NOTE:** *The relationship between ellipsoidal and orthometric (MSL) height is: orthometric height (dho) = ellipsoid height (dhe) - geoid height (dhg)*

4 Symbols (& Abbreviated Terms)

GPS	Global Positioning System
h	ellipsoidal height
Ho	orthometric height
NZGD49	New Zealand Geodetic Datum 1949
NZGD2000	New Zealand Geodetic Datum 2000
NZGS	New Zealand Geodetic System
NZSRS	New Zealand Spatial Reference System
ppm	parts per million
ppb	parts per billion

5 Geodetic Standards of Accuracy for Three Dimensional Geodetic Surveys

5.1 *Class of Observations and Order of Marks*

To prevent confusion between the Order of a mark defined by these standards, and Order of a mark defined by earlier standards, the new Order will be referred to as Order 2000 and similarly the Class of observations as Class 2000.

5.2 *Standards of Accuracy for Class 2000 of Observations*

The Class 2000 of observations will reflect the internal consistency of the survey and this will be measured by the repeatability of observations and the adjustment of the data as shown by the *a priori* 95% confidence limit.

The Class of observations (Table 1) identifies the type of survey and the precision of measurements. Twenty two Classes of observations are established and divided into three broad categories:

- B (10-9) - parts per billion, eg Class B30 is 30 ppb or 0.03 ppm;
- M (10-6) - parts per million, eg Class M10 is 10 ppm;
- C - a constant error, eg C3 is 3 mm across the area of the survey.

To test if a survey meets the Class 2000 observation standard, a minimally constrained adjustment shall be run in which all observations are assigned *a priori* uncertainties at the 95% confidence level which are no greater than that prescribed here by their class.

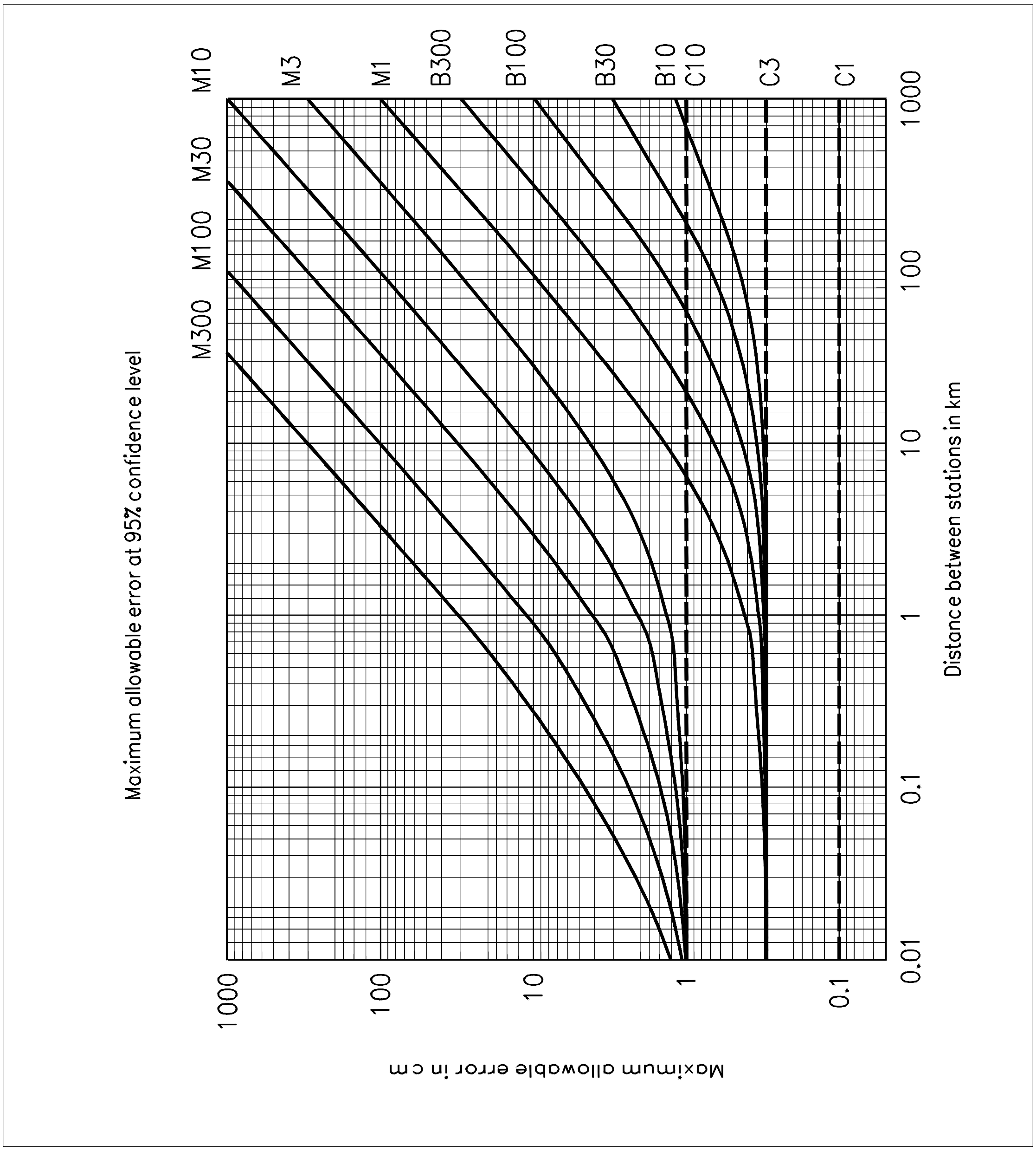
Table 1. Standards of Accuracy for Class 2000 Categories for Three Dimensional Observations

Class	95% Confidence Limit Accuracy Standard	
	Constant e (mm)	Line length error p[1] (ppm)
B10	3	0.01
B30	3	0.03
B100	3	0.1
B300	3	0.3
M1	3	1.0
M3	10	3.0
M10	10	10
M30	10	30
M100	10	100
M300	10	300
C1[2]	1	-
C3[2]	3	-
C10[2]	10	-

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

[2] The allowable constant error is over the extent of the survey area. The specifications may be varied to suit specific project requirements eg. C1 Class observations may be suitable as a short range standard for precise heighting, and C3 and C10 may be suitable on high precision engineering surveys.

◆ **Figure 1. Diagram of Accuracy Standards** (The accuracy standards for the higher Class 2000 of observations, relative to distance between marks).



5.3 *Order 2000 of Marks*

The Order 2000 of marks is a measure of the accuracy of the position or coordinates of a mark which will be dependent on such factors as the Class of observations, and the control network that constrains it. Six Order 2000 categories are defined (Table 2). The mark coordinate accuracy defined in Table 2 is the absolute coordinate accuracy that must be met.

Table 2. Accuracy Standards for Order 2000 Categories for Three Dimensional Control Marks

Order	Control Network	Typical Control Spacing	95% Confidence Limit			
			Horizontal Coordinate Accuracy		Height[1] Coordinate Accuracy	
		km	Class[2]	Max Error mm	Class[2]	Max Error mm
0	National fiducial network and continuous tracking stations.	< 1000	B10H	50	B30V	150
1	National geodetic control network. (Marks tied into the National fiducial network)	< 200	B100H	71	B300V	212
2	Regional geodetic control network. (Marks tied into the National control network)	< 70	M1H	87	M3V	260
3	Local geodetic control network. (Marks tied into the Regional network)	< 20	M3H	100	M10V	300
4	Local geodetic control surveys	< 10	M10H	112	M30V	335
5	Cadastral geodetic control network	< 2	M30H	123	M100V	367

[1] Can be applied to ellipsoidal or orthometric heights.

[2] The relative accuracy (post adjustment) between all marks, whether observed or calculated, must meet this *class of accuracy.*

Note: The accuracy standards in Table 2 are expressed in terms of separate horizontal (H) and ellipsoidal height components (V).

5.4 *Accuracy Required to Connect Between Different Orders*

The accuracy required for the survey connections from lower order to higher order marks are given in Table 3.

Table 3. Standard for Relative Accuracy Between Order 2000 Category Control Marks

	Relative Horizontal Coordinate Accuracy (mm)						Relative Vertical Coordinate Accuracy (mm)					
Order	**0**	**1**	**2**	**3**	**4**	**5**		**0**	**1**	**2**	**3**	**4**
0	-						-					
1	50	-					150	-				
2	71	50	-				212	150	-			
3	87	71	50	-			260	212	150	-		
4	100	87	71	50	-		300	260	212	150	-	
5	112	100	87	71	50	-	335	300	260	212	150	-

For geodetic Orders 0-5 for a mark to be given an Order 2000 classification it must meet a two-way test. Firstly the Class 2000 classification of observations must be met and secondly the coordinate accuracy requirement must be satisfied.

Geodetic Standards of Accuracy for Orthometric Height Determination

6.1 *Orthometric Heights Derived Using Space Surveying Systems*

These standards cover orthometric heights determined using space surveying systems.

6.2 *Standards of Accuracy for Geodetic Orthometric Height Class 2000 of Observations*

The Class 2000 classification as defined in Table 1 will be applied to orthometric heights.

6.3 *Geodetic Orthometric Heights Order 2000 of Marks*

The same Order 2000 categories and height accuracy standards as Three Dimensional Control Marks are adopted for orthometric heights (Table 2).

7 Field Observations for Geodetic Order 0-5

7.1 *Standards for Survey Design*

Survey observations are to be undertaken in accordance with good survey practice. All observations should be independent (eg. when repeating connections between marks, GPS receivers shall be reinitialised). Observation procedures should be adopted to mitigate systematic errors (eg. plumbing errors and GPS multipath).

Table 4. Standards for Survey Design

THREE DIMENSIONAL 'ORDER 2000'	0	1	2	3	4	5
MINIMUM NUMBER OF EXISTING HIGHER ORDER 2000 CONTROL MARKS TO WHICH A NETWORK SHOULD BE CONNECTED (Minimum 3D spheroidal control.)	4	4	3	3	3	2
CONNECTIONS FROM EACH MARK TO OTHER MARKS (Minimum number)	4	4	3	3	2	-
TRAVERSING (2 connections per mark)						
Maximum length of loop (km)	-	-	-	-	10	5[5]
Maximum number of lines in a loop	-	-	-	-	5	5
REPEATED LINES [4]						
Minimum percentage of all lines	100%	100%	50%	25%	-	-
OCCUPATIONS PER MARK [1]						
At least 3 (% of all marks)	100% [2]	100% [3]	50% [3]	25%		
At least 2 (% of all marks)			100% [3]	100%	100%	100%
INDEPENDENT PHYSICAL SETUPS PER MARK PER SURVEY (Minimum number)	1	1	1	2	2	2
ADDITIONAL REQUIREMENTS FOR ORTHOMETRIC HEIGHTING BY GPS						
Minimum orthometric height control	N/A	N/A	5	5	4	3
Network/control overlap [6]			50%	50%	33%	25%

1 An occupation is defined as a single continuous period of observation at a mark. Apart from the exceptions noted below an independent occupation will require a new setup, plumbing and height measurement.
2 Occupations can be back-to-back without new setup check for a continuous tracking mark.
3 Occupations can be back-to-back. Don't require new setup but do require an independent check per occupation.
4 Evenly distributed throughout the network.
5 If there is insufficient 4th order control to enable this requirement to be met approval from LINZ to increase this value is required.
6 Network/Control overlap refers to the percentage of the area of the figure formed by the new network which lies within the figure formed by the orthometric control marks.

Note: A base station set up on a NZGD2000 geodetic mark (new or existing) that is operated continuously during multiple sessions can count as an occupation for each session by splitting the total session. Hence the required number of occupations per mark is easily satisfied, but there still remains the requirement to meet the specified number of independent physical set ups per mark.

7.2 *Field Procedures*

Specific procedures must be adopted and documented so that instrument-centring errors do not go undetected. For example tribrachs should be calibrated before and after the completion of surveys and any errors should be well documented and the tribrachs corrected. The procedures and calibration results should be documented either in the field notes or field report.

For Class 2000 C1 observations instrument centring shall be to ± 0.5 mm, for C3 and M1-B10 to ± 2 mm, and for Class 2000 C10 and M300 - M3 to ± 5 mm (refer Table 5). Centring should take account of any system errors (eg GPS phase center offsets) and plumbing errors.

7.2.1 *Instrument Heighting*

For Class 2000 C1 observations heighting shall be to ± 1 mm, for C3 and M1-B10 to ± 5 mm, and for Class 2000 C10 and M300 - M3 to ± 10 mm (refer Table 5).

Instrument heights must be recorded and checked by an independent means. Such checks may include measurement in inches.

Instrument height measurements must be made to the instrument 'reference point' as recommended by the manufacturer. This reference point must be clearly identified in the survey documentation provided.

7.2.2 *GPS Surveys*

Methods must be adopted to reduce the effect of multipath. Any unavoidable potential sources of multipath within 50 m of the instrument must be documented. Procedures to minimise multipath may include ensuring that vehicles are not parked within 20 m (preferably 50m) of the mark. There is some evidence that very low setups (less than 0.25 m above the ground) cause systematic errors due to multipath. To reduce such errors antennas should be set up higher than 0.3 m. Potential mulitpath sources should be documented either in the field notes or field report.

Where GPS measurements are being made the logging must be either 15 or 30 seconds to ensure compatibility with permanent tracking stations. If a lesser logging interval is required for some reason the interval must form a divisor of 15 seconds eg 1, 3 or 5 seconds and additionally 10 or 15 seconds where 30 seconds is the required standard.

Any potential sources of radio-electrical interference within the vicinity of the instrument shall be documented. This shall be documented either in the field notes or field report.

7.3 *Field Notes*

Detailed clear field notes in digital form or suitable medium for scanning must be maintained for all field observations. Where on paper they should be written in clear black pencil or pen.

The following field notes are required as a minimum:

- **name of mark and Land Information New Zealand geodetic code;**
- **full name of observer;**
- **date and time of observations (stipulate local or UT time);**
- **type and serial number of instrument;**
- **height of instrument in metres with check measurement;**
- **details of height measurement (identify reference point);**
- **any eccentricities (document any eccentricities fully and unambiguously);**
- **any unusual events**

Table 5. Field Observation Standards for Class 2000 Categories for Three Dimensional Observations

Class	95% Confidence Limit Accuracy Standard	
	Instrument Centring (mm)	Instrument Heighting (mm)
B10	2	5
B30	2	5
B100	2	5
B300	2	5
M1	2	5
M3	5	10
M10	5	10
M30	5	10
M100	5	10
M300	5	10
C1[2]	0.5	1
C3[2]	2	5
C10[2]	5	10

Guidelines on Use and Interpretation of These Standards.

1 Introduction

These accuracy standards for geodetic surveys follow the general principle that:

> ***the accuracy of a mark's coordinates relative to adjacent marks of the next highest order shall be dependent on the distance between them and shall not exceed 0.05m horizontally and 0.15m vertically.***

This principle is based on cadastral requirements. The possibility of defining accuracy standards purely in terms of coordinate errors was considered. This would have resulted in the relative accuracy of two marks being independent of the distance between them. This approach would have had some desirable features for large scale applications but most users have requirements for higher relative accuracy over short distances. To require this short range accuracy to be met over long distances would then impose unjustified cost.

The accuracy standards have 3 components:

- **a constant term related to plumbing accuracy and other constant and instrumental errors. This is distance independent and is most significant on short lines;**
- **a distance dependent term which is more significant on long lines;**
- **a maximum coordinate accuracy which provides an upper limit to the impact of the distance dependent term (0.05m for one order of mark relative to the next highest order).**

A mark may be classified differently in the two systems: **Three Dimensional Geodetic Survey Standards; and Orthometric Height Standards**. For example, a precise benchmark may have a high vertical classification in the Orthometric Height Standards but a low classification for its ellipsoidal height in the Three Dimensional Geodetic Survey Standards.

Now that geodetic surveying is dominated by 3 dimensional survey technology such as GPS, a single set of 3 dimensional geodetic standards is an option. If GPS offered the same accuracy in the horizontal and vertical directions for a given quality of observation and processing, and similarly, if users of the geodetic network required the same accuracy for all components, then a single 3 dimensional standard would be desirable. However, neither of these conditions currently applies. GPS surveys are typically 2 to 3 times more accurate in the horizontal components than in the vertical component. Another way of expressing this is that it is more expensive to meet a particular accuracy standard in the vertical direction than to meet it in the horizontal plane. The cadastral survey system, as the major user and funder of the geodetic system, is primarily dependent on horizontal accuracy. Therefore there is good justification for continuing to define and support separate accuracy standards for horizontal and vertical geodetic surveys. A feature of these standards is the development of a common structure for the definition of horizontal and vertical accuracy standards. This will ensure that they can more easily be merged in the future if it becomes appropriate.

The standards have been designed to be technology independent. Each order of mark in the survey network is required to have an accuracy (both in terms of coordinate axes and relative to other marks) defined by the 95% confidence limit. For control network schemes, this requirement can be tested prior to observation by adjustment of simulated observations. In the network adjustment, higher order control marks are constrained in a specified manner. For the above requirement to be satisfied for all adjusted marks, the horizontal error ellipses (at the 95% confidence limit) must have their semi-major axis less than the specified limits. If the above criteria are met then the proposed set of standards will apply.

A new approach has been applied to the orthometric height standards adopted here. Where traditional levelling has been used in the past, it has been the norm to express the accuracy standards in terms of the square root of the distance levelled. While this may be appropriate over short levelling runs such as between bench marks, it is not over longer lines as it makes no account for systematic errors that may accumulate with distance; these errors can amount to 1 ppm [*Reilinger and Brown* 1981]. Systematic errors proportional to the height difference levelled are also not accounted for and in extreme cases these can be as much as 300-400 ppm of the height difference [*Reilinger and Brown* 1981]. The traditional method is also more process rather than outcome based. While it is important for standards to take account of the accuracy achievable using current technology, they should primarily be designed to reflect user needs. The $\sqrt{km}$ formula does not reflect user needs being unnecessarily accurate over long distances. Accordingly, the same method for describing accuracy standards for ellipsoidal heights (constant plus a linear proportional error) have been adopted for orthometric heights.

2 Explanation of Testing Geodetic Standards of Accuracy for Three Dimensional Geodetic Surveys

2.1 *Testing Class 2000 of observations*

Table 1 of the Standard gives the ‘Standards for Class 2000 Categories for Three Dimensional Observations’.

To test if a survey meets the Class 2000 observation standard, a minimally constrained adjustment shall be run in which all observations are assigned *a priori* uncertainties at the 95% confidence level which are no greater than that prescribed here by their class.

For B and M Class observations the difference between successive Classes is about a factor of 3 which means the weighting (inverse square) of precision between successive Classes changes by about an order of magnitude. This provides a simple, logical and technology independent structure for the Class classification. These classes are further divided in horizontal (H) and vertical (V) classifications. The precision of the observations for B, and M Class observations is defined by a constant term (**e**) and a distance proportional term (**p**). For C Class observations only a constant term applies

The accuracy standards detailed here relate to the 95% confidence limit which defines the relative positioning accuracy of a pair of reference marks. From these terms the accuracy for an observed vector can be determined by:

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

The accuracy standards for the higher Class 2000 of observations, relative to distance between marks, is plotted in Figure 1 of the Standard.

Table 1 of the Standard gives the 'Standards for Class 2000 Categories for Three Dimensional Observations'.

2.2 *Testing Order 2000 of Marks*

Table 2 of the Standard gives the 'Standards for Order 2000 Categories for Three-Dimensional Control Marks.

For geodetic control Order 0-5 the mark coordinate accuracy is based on the general principle that:

> '*the accuracy of a mark's coordinates relative to adjacent marks of the next highest order shall be dependent on the distance between them and shall not exceed 0.05m horizontally and 0.15m vertically'*.

Based on this principle, and an assumed accuracy for the global network (zero Order 2000 network) of 50 mm, the accuracy of the 1st Order 2000 marks is 71 mm, and for 2nd Order 2000 marks 87 mm (eg $\sqrt{50^2 + 50^2 + 50^2}$) etc.

The accuracy required for the survey connections from lower order to higher order marks are given in Table 3 of the Standard. For example the accuracy of 4th Order 2000 marks relative to 1st Order 2000 marks is $\sqrt{50^2 + 50^2 + 50^2} = 87$ mm.

For each Order there is a different Class for the horizontal and vertical component of the vector between marks. The reasons for this are:

- the user need for horizontal accuracy is generally greater than the user need for vertical accuracy for a given Order 2000 mark;

- for a given method of three dimensional survey the horizontal accuracy is greater than the vertical accuracy.

There is a relationship between the Class 2000 of observations and the Order 2000 of mark that it defines. The Order 2000 of a mark is dependent on such factors as the Class 2000 of observations and the network to which it is tied. The Order of a mark cannot be higher than the corresponding Class 2000 of observations that define it.

The 1 standard deviation accuracy for the separate north and east horizontal components is the 95% confidence limit divided by 2.45 [*Greenwalt and Shultz* 1962]. For the vertical component the 1 standard deviation accuracy is the 95% confidence limit divided by 1.96.

For example, the expected 1 standard deviation coordinate accuracy limits on a 2nd Order 2000 mark would be:

north and east components = ± 87/2.45. or 36 mm

vertical component = ± 260/1.96 or 133 mm

The application, during network adjustment, of the accuracies in Tables 2 and 3 of the Standard are explained in the next section.

For geodetic Orders 0-5 a mark to be given an Order 2000 classification it must meet a two-way test. Firstly the Class 2000 classification of observations must be met and secondly the coordinate accuracy requirement must be satisfied.

2.3 *Application of Standards in Network Adjustment*

The Order 2000 standards apply to coordinates generated in terms of a new datum. The existing distortions in NZGD49 are such that these standards cannot be applied to NZGD49 coordinates. However, the Class 2000 standards may be used to classify observations from which NZGD49 coordinates are derived.

Minimally constrained network adjustments should be used to assess the strength of the network, detect outlying observations and determine whether the Class 2000 standards have been achieved. However, the Order 2000 standards will apply to fully constrained networks, ie, they apply to final coordinates.

Note that it is possible for a set of observations to meet a high Class 2000 standards but for the resulting coordinates to not meet the corresponding Order 2000 standards due to errors in the existing control or failure to adequately connect to sufficient high Order marks. For example, a deformation survey may meet Class B10H standards but the connections to the existing network may only permit 3rd Order 2000 coordinates to be generated.

2.3.1 *Absolute Coordinates*

The application and testing of these standards depends on the method of network adjustment. There are 3 fundamental cases for fully constrained adjustments.

1. A weighted least squares or "Bayesian" least squares adjustment in which weights are assigned to the coordinates of higher order marks. For example, a 4th Order 2000 adjustment with no fixed marks where 3rd and higher Order 2000 mark coordinates are assigned weights according to their accuracies. These weights may be derived from earlier adjustment or may be based on the nominal accuracies prescribed by these standards; eg., 100 mm at the 95% confidence limit for 3rd Order 2000 horizontal coordinates. This results in a more correct adjustment than the classical method described below. However, coordinates of higher order marks are changed by the adjustment and this may be undesirable.

2. A "classical" adjustment where the coordinates of higher order marks are held fixed. For example, a 4th Order 2000 adjustment where the coordinates of 3rd and higher Order 2000 marks are held fixed. This ensures that these mark coordinates are not changed by the adjustment of the lower order network. This method incorrectly treats the coordinates of the fixed marks as if they had no error.

3. A hybrid adjustment where a number of different orders are adjusted together with the coordinates of the highest order marks being held fixed. For example, a combined 3rd and 4th Order 2000 adjustment where the coordinates of 2nd Order 2000 marks are held fixed.

For a weighted least squares adjustment, all marks shall have 95% confidence ellipses with semi major axes less that the maximum coordinate accuracy outlined in Table 2 of the Standard. For example, all 4th Order 2000 marks shall have 95% confidence ellipses (horizontal) with semi major axes less than 100 mm. The 95% vertical uncertainties shall be less than 300 mm.

For a classical adjustment, the allowed size of error ellipses can be determined from Table 3 of the Standard. The columns represent the Order 2000 of the fixed marks. The rows represent the Order 2000 of the marks being adjusted. For the classical adjustment, the 95% error ellipses (horizontal) of the 4th Order 2000 marks shall be less than 50 mm. The 95% vertical uncertainties shall be less than 150 mm.

For the hybrid adjustment examples given above, the 95% error ellipses (horizontal) of the 4th Order 2000 marks shall be less than 71 mm while those of the 3rd Order 2000 marks shall be less than 50 mm. The 95% vertical uncertainties of the 4th Order 2000 marks shall be less than 212 mm while those of the 3rd Order 2000 marks shall be less than 150 mm.

2.3.2 *Relative Accuracy*

Least squares adjustment allows the relative accuracy of adjusted marks 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. Many least squares programs, including Land Information New Zealand (LINZ's) SNAP, allow this information to be generated and output.

In order to confirm that the relative accuracy standards have been met, relative 95% error ellipses between all marks shall be generated and compared with the corresponding relative accuracy standard. Table 3 of the Standard gives the relative accuracy standards for each Order 2000, expressed in terms of Class 2000 standards, as detailed in Table 2 of the Standard.

For lines between marks of different order, the relative accuracy standard of the lowest order shall apply. For example, a line between a 2nd and a 4th Order 2000 mark shall have a horizontal uncertainty given by the 4th order 2000 standard (M10 or 30 mm + 10 ppm at 95% confidence), not the 2nd Order 2000 standard of M1.

2.3.3 *Check of Compliance with these Standards*

The following method is suggested to check compliance with these standards.

Data should be subject to three accuracy checks:

- confirmation of the accuracy of observations;
- confirmation of the accuracy of coordinates derivable from the survey;
- confirmation of the absolute accuracy of the derivable coordinates in terms of the higher order stations controlling the survey.

These shall be tested by two types of least squares adjustment - a free-net (minimal constraints) adjustment, and a constrained adjustment in which the higher order stations controlling the survey are held fixed.

2.3.3.1 Observation accuracy test

The accuracy of the observations is tested by a free net adjustment in which the *a priori* errors of the observations (from these standards) are assigned according to the order of the survey. The observational accuracy requirements are achieved if the following conditions are met:

- the standard error of unit weight is no more than 1
- all *a priori* 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.

2.3.3.2 Relative coordinate accuracy test

The relative accuracy of the derivable coordinates are also tested in a free-net adjustment. This may be the same adjustment as used to test the observations. However if the observations are actually significantly more accurate than required by the class then smaller *a priori* errors may be assigned to the data. In this case the observation accuracy tests above must be met using the revised *a priori* errors.

The relative accuracy test uses the *a priori* relative horizontal error ellipse and *a priori* relative vertical error between every pair of stations.

The (1 standard error) error ellipses from the adjustment are multiplied by a factor f to obtain 95% confidence limits. This factor depends upon the number of degrees of freedom in the adjustment, n, and is defined as

$$f = \sqrt{(2.F^{-1}(0.95,2,n))}$$

where F^{-1} is the inverse F cumulative probability function. Tests are based upon the length of the maximum axis of the scaled error ellipse.

The (1 standard error) height errors from the constrained adjustment are multiplied by a factor h to calculate 95% confidence limits, where

$$h = \sqrt{F^{-1}(0.95,1,n)}$$

The coordinate accuracy requirements are met if the relative horizontal and vertical 95% confidence limits between every pair of stations are less than the standards for the order of the survey. The relative accuracy comprises the distant independent component (in mm) and the distant dependent component (in ppm). These are to be combined using a root mean square formula. For example in a 4th order survey of two marks 2 km apart the relative horizontal confidence limit has components 10 mm and 10 ppm x 2 km = 20 mm, so the test value is $\sqrt{(10^2 + 20^2)} = 22$ mm.

2.3.3.3 Absolute coordinate accuracy test

The "absolute" accuracy of the coordinates is defined by the *a priori* error ellipses in a constrained adjustment. The test is based upon *a priori* error ellipses in order to be unaffected by possible errors in the coordinates of the higher order constrained stations. The *a priori* errors of the observations in the constrained adjustment should be the same as those used in the relative coordinate accuracy test.

The horizontal error ellipses and vertical errors are multiplied by the factors f and h defined above to convert them to 95% confidence limits.

The absolute accuracy requirements are met if the horizontal and vertical 95% confidence limits of all stations are less than the standards required for the order of the survey.

3 Explanation of Geodetic Standards of Accuracy for Orthometric Height Determination

3.1 *Orthometric Heights Derived Using Space Surveying Systems*

These standards cover geodetic Orders 0-5 are designed to cover various techniques and the appropriate survey technique must be adopted to give the required results.

Orthometric heights can be determined using space surveying systems if the geoidal height differences are (eg. derived from gravity measurements observed over a wide area), or if adequate ties to an orthometric vertical datum have been made.

The accuracy of orthometric heights derived from space surveying systems is dependent on:

- the accuracy of the ellipsoidal height differences;
- the accuracy of the geoid height difference;
- the geometry and accuracy of the orthometric heights of the network (typically derived by trigonometric or precise levelling) that is used to transform the ellipsoidal heights.

Global geopotential models show that the geoid varies by about 10 metres across New Zealand with respect to NZGD49 and 40 metres with respect to WGS84 and is accurate to about 1-2m in absolute terms or 5-10 ppm in relative terms. This model does not take into account second order effects such as topography. Note also that this model is based on the WGS84 ellipsoid. In order to use it with a different datum, such as NZGD49, the transformation between the datums and the difference in ellipsoid sizes must be taken into account.

3.2 *Geodetic Orthometric Height Class 2000 of Observations*

The Class 2000 classification as defined in Table 1 of the Standard will be applied to orthometric heights.

These standards allow for measurements made using space surveying systems and more conventional survey techniques such as precise or trigonometric levelling. Height dependent errors should be reduced through the use of appropriate survey and processing methods.

3.3 *Geodetic Orthometric Heights Order 2000 of Marks*

The same Order 2000 categories and height accuracy standards as Three Dimensional Control Marks are adopted for orthometric heights (Table 2 of the Standard).

Accuracies define the 95% coordinate accuracy for each category. It should be noted that the proposed Orthometric Height Zero Order 2000 category is not yet established in a global sense, but may be established some time in the future. While the maximum error proposed for this category (150 mm, Table 2 of the Standard) is not yet attainable, this may be possible in the future with more refined geoid modelling.

If ellipsoidal heights are being used to derive orthometric heights, the accuracy of the geoid model or height control network being fixed and used to transform between the two height systems must be considered. For 3rd Order 2000 marks a geoid model accurate to 1 ppm (at the 95% confidence level) is required. At present a model of this accuracy is unavailable in New Zealand. For zero and 1st Order 2000 marks a geoid model to the required accuracy (< 1 ppm) is not likely to be available in the foreseeable future, therefore it is not considered appropriate to use a geoid model to transform between ellipsoidal and orthometric heights for these marks.

4 Field Observations for Geodetic Order 0-5

Table 4 of the Standard gives the 'Standard for Network Design'.

4.1 *Survey Design*

Survey observations are to be undertaken in accordance with good survey practice. All observations should be independent (eg. when repeating connections between marks, GPS receivers shall be reinitialised). Observation procedures should be adopted to mitigate systematic errors (eg. plumbing errors and GPS multipath).

4.2 *Mark Connections by Observations*

The minimum number of independent connections between the proposed network and the existing network of Order 2000 control marks shall be in accordance with the requirements in Table 4 of the Standard. Such connections shall be between a proposed mark and an existing mark provided neither of these marks have already been used for a connection between the proposed network and the existing network of Order 2000 control marks. Proposed marks must be connected directly or indirectly by survey observations to existing marks of the same or a higher accuracy order. The network of marks should be connected to stations of a higher order. If the network consists of only one mark, that mark need only be connected to one mark of a higher order provided the other marks connected to are of the same order.

The survey network shall be designed in such a way that ALL observations can be checked by a network adjustment.

Each control mark shall be connected to a minimum of two independent marks with observations to be separated by a minimum of 15 minutes (ie it is not sufficient to have two base stations observed at the same time from a single rover occupation).

With prior approval from LINZ, survey observations from other surveys may be adopted and used as long as these observations are supplied or are otherwise available to LINZ in digital form. Circumstances where approval may not be given are where the age of the adopted data is such that deformation may have degraded its compatibility with new observations or where it is not of an appropriate Class 2000.

Consideration needs to be given to the number, distribution, and type of control points that are being connected to. This is particularly true for vertical control where differences between the geoid and reference ellipsoid may vary significantly across the area of the network. Table 4 of the Standard lists the minimum number of existing control points that must be connected to for three dimensional surveys and, separately, surveys where orthometric heights are required to be determined from GPS surveys.

For high precision surveys, some agencies employ a GPS base station in the vicinity of the project for the duration of the survey. Where these are employed extra care should be taken to ensure that they are stable, have minimal multi-path effects, and will be free from disturbance. The regular monitoring of base stations is required to ensure the correctness of operation and proof of no disturbance.

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