



# **Guideline for Control Surveys by Differential Levelling**

## **Special Publication 1**

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Intergovernmental Committee on Surveying and Mapping (ICSM)

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## Table of contents

<b>Document History</b> .....	<b>2</b>
<b>Table of contents</b> .....	<b>3</b>
<b>List of figures</b> .....	<b>3</b>
<b>Terms and definitions</b> .....	<b>4</b>
<b>1 About this Guideline</b> .....	<b>4</b>
1.1 Introduction .....	4
1.2 Normative references.....	4
<b>2 Connection to datum</b> .....	<b>5</b>
<b>3 Levelling Guidelines</b> .....	<b>5</b>
3.1 Differential levelling .....	5
3.1.1 Differential levelling equipment.....	5
3.1.2 Differential levelling observation techniques .....	7
3.2 Total station differential levelling .....	8
3.2.1 Total station differential levelling equipment.....	8
3.2.2 Total station differential levelling observation .....	9
<b>4 Differential levelling quality</b> .....	<b>10</b>
<b>5 Example evaluation procedure</b> .....	<b>10</b>

## List of figures

Figure 1: Differential levelling survey example .....	10
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## List of tables

Table 1: Differential levelling equipment recommendations, where $k$ = distance in kilometres .....	6
Table 2: Differential levelling observation techniques, where $k$ = distance in kilometres.....	7
Table 3: Total station levelling equipment recommendations, where $k$ = distance in kilometres .....	8
Table 4: Total station differential levelling observation techniques, where $k$ = distance in kilometres .....	9
Table 5: Evaluating the forward and backward miscloses .....	11
Table 6: Evaluating and adjusting the traverse misclose.....	11

## Terms and definitions

For the purpose of this Guideline, the terms and definitions are those listed in the *Standard for the Australian Survey Control Network – Special Publication 1, Version 2.2*.

# 1 About this Guideline

## 1.1 Introduction

The availability of accurate and reliable information relating to the position and uncertainty of Australia’s survey control marks is critical to the integrity of the Australian Geospatial Reference System (AGRS). The purpose of this Guideline is to promote the adoption of uniform differential levelling procedures to achieve the highest level of rigour and integrity in Australia’s survey control mark network.

There are two commonly accepted forms of differential levelling – differential levelling using a level and level staff, and differential levelling using a total station and fixed height prism. These terrestrial techniques are regarded as the most reliable and precise techniques for determining differences in height between survey control marks. Where accuracy requirements are less stringent, GNSS techniques may be used. For information about GNSS heighting procedures, please refer to the *Guideline for Control Surveys by GNSS*.

This Guideline outlines ICSM’s recommended equipment and procedures for differential levelling and provides examples for evaluating the uncertainty of estimated height differences between survey control marks.

## 1.2 Normative references

This Guideline should be read in conjunction with the *Standard for the Australian Survey Control Network – Special Publication 1, Version 2.2* herein referred to as the Standard.

The following documents may have relevance to the application of this Guideline.

### International Guidelines

JCGM 100:2008, *Evaluation of Measurement Data – Guide to the Expression of Uncertainty in Measurement*, Joint Committee for Guides in Metrology – Bureau International des Poids et Mesures, Paris, France.

### SP1 Standard

ICSM (2020), *Standard for the Australian Survey Control Network – Special Publication 1, Version 2.2*, Intergovernmental Committee on Surveying and Mapping, Canberra, Australia.

### SP1 Guidelines

ICSM (2020), *Guideline for the Adjustment and Evaluation of Survey Control*, Version 2.2, Intergovernmental Committee on Surveying and Mapping, Canberra, Australia.

ICSM (2020), *Guideline for Control Surveys by GNSS*, Version 2.2, Intergovernmental Committee on Surveying and Mapping, Canberra, Australia.

ICSM (2020), *Guideline for the Installation and Documentation of Survey Control Marks*, Version 2.2, Intergovernmental Committee on Surveying and Mapping, Canberra, Australia.

### **ICSM Technical Manuals**

ICSM (2020), *Geocentric Datum of Australia 2020 Technical Manual*, Intergovernmental Committee on Surveying and Mapping, Canberra, Australia.

ICSM (2007), *Australian Tides Manual – Special Publication 9*, Intergovernmental Committee on Surveying and Mapping, Wollongong, Australia.

## **2 Connection to datum**

Survey control marks for the AGRS shall be coordinated relative to the height datums set out in Section 2 of the SP1 Standard.

## **3 Levelling Guidelines**

The following Guidelines for the observation of differences in height between survey control marks are in three generalised groupings of survey quality based on allowable survey misclose. Survey specifications may adopt any value for an allowable survey misclose depending on the requirements of the project, however when connecting to datum, the quality of the heights that are to be used as constraints will dictate the quality of the resultant heights (i.e. no better than the quality of the constrained heights).

### **3.1 Differential levelling**

Differential levelling with an optical or digital level instrument to a graduated level staff is the conventional method of determining the differences in height between survey control marks.

#### **3.1.1 Differential levelling equipment**

Table 1 lists the recommended equipment requirements to achieve various levels of survey misclose.

**Table 1: Differential levelling equipment recommendations, where k = distance in kilometres**

<b>Quality - Maximum allowable misclose (between forward and back)</b>		
$2 \text{ mm} * \sqrt{k} \text{ (km)}$	$6 \text{ mm} * \sqrt{k} \text{ (km)}$	$12 \text{ mm} * \sqrt{k} \text{ (km)}$
<b>Instrument:</b>		
0.4 mm/km digital level	1 mm/km digital level	2 mm/km optical or digital level
<b>Vertical collimation test:</b>		
daily	daily	start of project
<b>Graduated (or coded) staff:</b>		
Calibrated, rigid invar staff, (+ bi-pole support)	Wood or fibreglass staff, calibrated within 5 years	Wood or fibreglass staff, calibrated within 5 years
Staff bubble attached and accurate to 10' verticality		
<b>Tripod:</b>		
Rigid		Telescopic
<b>Change plates:</b>		
Heavy duty change plates	Standard change plates	Standard change plates
<b>Thermometer accurate to:</b>		
1°C		

### 3.1.2 Differential levelling observation techniques

The differential levelling observation techniques employed have a direct impact on the quality of the survey results. Table 2 lists the recommended survey practices to achieve various levels of height difference survey misclose.

**Table 2: Differential levelling observation techniques, where k = distance in kilometres**

Quality - Maximum allowable misclose (between forward and back)		
2 mm * $\sqrt{k}$ (km)	6 mm * $\sqrt{k}$ (km)	12 mm * $\sqrt{k}$ (km)
Survey specific:		
Two-way levelling <sup>1</sup>		
Avoid staff index error – observe same staff for first back-sight and last fore-sight		
Back-sight/fore-sight lengths (total between survey control marks):		
Individual sights approximately equal Total difference within 1 metre	Total difference approximately equal	
Staff readings to nearest:		
0.1 mm. Mean of five readings with a standard deviation of $\leq 0.0002$ m/20 m	0.1 mm. Mean of three readings with a standard deviation of $\leq 0.001$ m/20 m	1 mm
Temperature recorded:		
Start and at 1 hour intervals or pronounced changes in conditions		
Maximum sight length:		
30 m	50 m	80 m
Minimum ground clearance:		
0.5 m	0.3 m	0.3 m

<sup>1</sup> Two-way levelling means two independent levelling surveys between two or more permanent marks in each direction. For example, survey one is from Point A to Point B to Point C and a survey two is from Point C to Point B to Point A.

## 3.2 Total station differential levelling

Total station differential levelling is a variant of conventional differential levelling. Differences in height can be determined by making a series of zenith angle and slope distance observations to prisms mounted on fixed height poles. This technique is conducted in the same fashion as conventional two-way differential levelling.

### 3.2.1 Total station differential levelling equipment

Table 3 lists the recommended equipment requirements to achieve various levels of survey misclose.

**Table 3: Total station levelling equipment recommendations, where k = distance in kilometres**

Quality - Maximum allowable misclose (between forward and back)		
2 mm * $\sqrt{k}$ (km)	6 mm * $\sqrt{k}$ (km)	12 mm * $\sqrt{k}$ (km)
Total station instrument standard deviation:		
Distance: $\pm 1$ mm + 1 ppm Zenith angle: 1"	Distance: $\pm 2$ mm + 2 ppm Zenith angle: 3"	Distance: $\pm 3$ mm + 2 ppm Zenith angle: 5"
Daily calibration of index errors of vertical circle and level sensor		
Accuracy of level sensor or compensator:		
0.5"	1.5"	2.5"
Atmospheric measurement device (accurate to):		
Temperature =1°C, Pressure =1 mb, Relative Humidity=2%		N/A
Tripod:		
Rigid		Telescopic
Fixed height reflector rod with bi-pole support:		
Staff bubble attached and accurate to 10' verticality		
Solid fixed height rod (e.g. stainless steel)		Fixed height ensured
Permanently mounted, balanced and tilting prism:		
Precision prism		General prism
Change plates:		
Heavy duty change plates	Standard change plates	Standard change plates

### 3.2.2 Total station differential levelling observation techniques

The total station differential levelling observation techniques employed have a direct impact on the quality of the survey results. Two fixed height poles and prism sets should be used to perform simultaneous observations and suitable change plates should be used on the base of the prism poles. Table 4 lists the recommended survey practices to achieve various levels of height difference survey misclose.

**Table 4: Total station differential levelling observation techniques, where k = distance in kilometres**

<b>Quality - Maximum allowable misclose (between forward and back)</b>		
$2 \text{ mm} * \sqrt{k} \text{ (km)}$	$6 \text{ mm} * \sqrt{k} \text{ (km)}$	$12 \text{ mm} * \sqrt{k} \text{ (km)}$
Survey specific:		
Two-way levelling		
Avoid fixed rod index error - observe same rod for first back-sight / last fore-sight		
Atmospherics recorded and applied:		
Start and at 1 hour intervals or pronounced changes in conditions		N/A
Back-sight and fore-sight lengths (total between survey control marks):		
Approximately equal and measured to 1 metre	Total difference approximately equal	
Number of rounds face left/face right:		
5	4	3
Height difference readings to nearest:		
0.1 mm	0.5 mm	1 mm
Maximum sight length:		
50 m	80 m	120 m
Minimum ground clearance:		
1.0 m	0.5 m	

## 4 Differential levelling quality

When conducting differential levelling or total station differential levelling, errors propagate in proportion to the square root of the travelled distance.

A misclose assessment should be undertaken to verify that forward and backward runs of a levelling traverse, including any individual bays, are within the maximum allowable misclose. The allowable misclose is calculated using the formula:

$$r = n\sqrt{k}$$

Where:

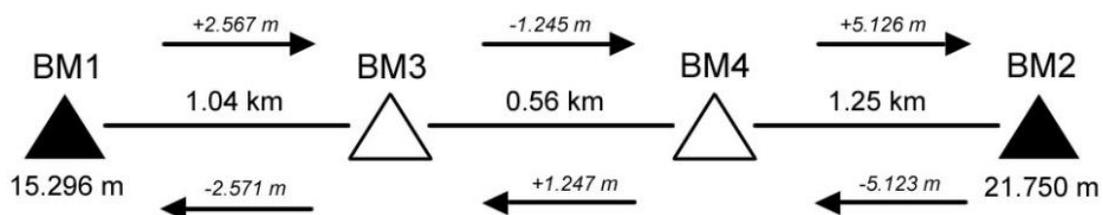
- $r$  = maximum allowable misclose in mm
- $n$  = an empirical value describing the outcome
- $k$  = distance in km

To determine the quality of datum aligned heights and validate connection to a datum for a differential levelling control survey, observations should be made to at least two survey control marks with datum aligned heights.

Refer to the SP1 Standard and the *Guideline for the Adjustment and Evaluation of Survey Control* for deriving uncertainty, the adjustment of survey control and evaluating survey measurements.

## 5 Example evaluation procedure

Figure 1 depicts a typical example of the establishment of two new survey control marks. Two way differential levelling is conducted from existing survey control marks BM 1 and BM 2 to the new survey control marks BM 3 and BM 4.



**Figure 1: Differential levelling survey example**

The survey misclose is calculated by comparing the forward and backward height differences of the individual bays of levelling. The total survey misclose is also calculated on the accumulated total of the forward and backward height difference miscloses. These miscloses are compared to the specified allowable misclose to determine if the survey (independent of datum) meets the recommended outcome.

Using the value of  $6\sqrt{k}$  which was determined under the project specifications as an example, Table 5 shows the evaluation of the forward and backward miscloses, based on the example in Figure 1.

**Table 5: Evaluating the forward and backward miscloses**

Dist km	From BM	To BM	Total Dist	Difference in Elevation		Forward/Backward Misclose Evaluation			
				Fwd	Bwd	Misclose Per Bay	Allowable $6\sqrt{k}$	Misclose Acc	Allowable $6\sqrt{k}$
1.04	BM 1	BM 3	1.04	2.567	-2.571	-0.004	<b>0.006</b>	-0.004	<b>0.006</b>
0.56	BM 3	BM 4	1.60	-1.245	1.247	0.002	<b>0.004</b>	-0.002	<b>0.008</b>
1.25	BM 4	BM 2	2.85	5.126	-5.123	0.003	<b>0.007</b>	0.001	<b>0.010</b>

When connecting to datum, consideration needs to be given to the quality of the existing heights that will be used as constraints in determining heights of the new marks. The heights of the new marks cannot be assigned a quality that is better than the quality of the constrained heights. The traverse misclose between the known survey control marks is distributed proportionally, based on the distance levelled, to the unknown survey control marks. Table 6 shows the evaluation and adjustment of the traverse misclose, based on the example in Figure 1.

**Table 6: Evaluating and adjusting the traverse misclose**

Distance km	From Mark	To Mark	Total Dist	Calibrated Mean Ht Diff	Adjustment Closure	Datum aligned height		
						Observed	Mark	Adjusted
							BM 1	<b>15.296<sup>#</sup></b>
1.04	BM 1	BM 3	1.04	2.569	0.003	17.865	BM 3	17.868
0.56	BM 3	BM 4	1.60	-1.246	0.004	16.619	BM 4	16.623
1.25	BM 4	BM 2	2.85	5.124	0.007	21.743	BM 2	<b>21.750<sup>#</sup></b>
							misclose	-0.007
							$12\sqrt{k}$ allowable	0.020

<sup>#</sup> Existing  $12\sqrt{k}$  Mark

Least square adjustments should be used for more complex differential levelling networks, to ensure that any misclose is appropriately apportioned within the network. When using least square adjustment, the residuals on the observed height differences and the accumulated residuals between known survey control marks need to be evaluated to determine if the survey has achieved the recommended outcome of  $n\sqrt{k}$ .