



mainroads
WESTERN AUSTRALIA

Settlement Monitoring

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1 PURPOSE

The purpose of this standard is to define the survey requirements for monitoring settlement and displacement of road pavements and structures (e.g. Bridges, large Culverts) for Main Roads Western Australia.

All work shall be performed and presented in accordance with the following standard to ensure that Main Roads has continuity in survey quality and procedure.

2 SCOPE

This standard shall apply to all work related to:

- The monitoring of vertical displacement or subsidence of road pavements for Main Roads Western Australia.
- The monitoring of horizontal and vertical displacement of structures (e.g. bridges and large culverts) for Main Roads Western Australia.
- Monitoring which relates to tunnel construction has been removed from this Standard as it is a specialised activity not intended to be covered by this Standard.

Advice and further information can be obtained by contacting the Senior Geodetic Surveyor.

3 DEFINITIONS

The following terms used in this procedure have the specific meanings indicated:

Term	Definition
AHD	Australian Height Datum
LANDGATE	Western Australian Land Information Authority
NATA	National Association of Testing Authorities
GDA	Geocentric Datum of Australia
GNSS	Global Navigation Satellite Systems
AHD	Australian Height Datum
ICSM	Intergovernmental Committee on Surveying & Mapping
SSM	Standard Survey Mark
RRM	Road Reference Mark
RL	Reduced Level
PCN	Primary Control Network
SCN	Secondary Control Network
MCN	Major Control Network

4 REFERENCES AND RELATED DOCUMENTS

Document Number	Description
	ICSM – Standard for the Australian Survey Control Network (SP1 ver. 2.1)
	ICSM - GDA Technical Manuals for both GDA94 v2.4 and GDA2020 v1.3
	ICSM – Guideline for Control Surveys by GNSS v2.1
	ICSM – Guideline for Control Surveys by Differential Levelling
	Landgate Requirements for GNSS Geodetic Surveys
	Landgate Requirements for Vertical Control by Differential Levelling
67/08/100	Metadata Guideline
67/08/36	Road Reference Mark Standard
67/08/37	Minor Control Point Standard
67/08/38	Differential Levelling Standard

5 MONITORING OF SETTLEMENT FOR ROAD PAVEMENTS

5.1 GENERAL

Road embankments usually experience settlements when they are built on soft compressible foundation soils.

The total settlement is the sum of three components:

- Immediate Settlement
- Consolidation Settlement
- Secondary Compression

The immediate component is that portion of the settlement that occurs essentially with load application. The other two components of settlement result from the gradual expulsion of water from the voids and the concurrent compression of the soil skeleton.

Settlements that occur very slowly, over decades or more, may be tolerable by pavements. These same settlements, if they occurred within a period of a few months or years, would result in severe pavement damage. It is therefore important to be able to accurately measure and monitor the amount of displacement at set locations over a period of time.

For pavement works differential settlement is generally much more critical criteria than total settlement. Deterioration in pavement riding quality with time is broadly proportional to differential settlement (i.e. larger settlements generally lead to poorer ride with time). This effect is typically caused by inherent natural variability in soil deposits.

Differential settlement effects are usually of too long a wavelength to be measured by Road Roughness and have normally been controlled by specifying a “Maximum Post-Construction Residual Settlement”. Typical total settlement limits ranging between 50mm to 100mm.

All survey work associated and undertaken for the monitoring of settlement for road pavements must be sufficiently accurate to detect vertical movements of + or – 3mm.

5.2 SURVEY DATUM

All co-ordinates used shall be in their respective Main Roads WA approved project grid, which are based either on the GDA 94 or the GDA 2020 as required in the survey scope. Vertical datum shall be AHD 71 or another vertical datum if so specified.

Any additional control points established shall be connected to the existing SSMs or RRM network for that road section. Before adopting any SSM or RRM they must first be validated from Reference Marks (RMs) or nearby Geodetic control if no RMs exist. These validations must be done before each monitoring survey and documented.

Monitoring points would normally, but not necessarily, be directly related to chainage and offset as per design drawings supplied. The location, interval and extent will normally be determined by the Main Roads WA Project Manager.

5.3 SURVEY CONTROL

At least two RRMs shall be established at each end and outside of the section of road pavement to be monitored. Each of these RRMs shall be located on stable ground and shall be a maximum of 200 metres apart. New RRMs should then be established along the route of the subject road pavement such that the intervals between RRMs are not greater than 250 metres (existing RRMs may be utilised if available). Refer to Appendix A.

Such RRMs established along the route may well be subject to movement and thus require re-measurement at each survey epoch. It is preferable to use the brass plaque form of RRM for better level transfers. Brass plaques are available from the Senior Geodetic Surveyor.

5.4 METHOD OF SURVEY

The two RRMs on stable ground at each end of the section of pavement to be monitored together with intermediate RRMs shall initially be levelled to in both directions, with connections to existing control of known RL. Levelling should be carried out to Second Order Standards as per ICSM guidelines (i.e. $r = 4\sqrt{d}$ where r = the maximum error in millimetres and d = the distance traversed in kilometres), which will invariably be of a higher order than that of the existing road control. Fixed levels shall be assigned to the two RRMs on stable ground at each end of the road section, such that the accuracy of the new level traverse is maintained and any differences with existing control are distributed equally. Refer to Appendix A.

Survey Monitor Points will be Hilti, Ramset or other approved nails with washers and at least 50mm in length driven until slightly proud of the road pavement so that a staff base plate placed on the mark can rotate and not touch the surface of the road and marked with spray paint. They shall be set out adjacent to kerb lines or near both edges of the bituminous surfacing within the section of road to be monitored, at a maximum spacing of 20 metres unless otherwise directed and initial horizontal and vertical measurements taken.

All set out and horizontal measurement of Survey Monitor Points shall be done using a Total Station from the RRMs established. If horizontal movement is to be monitored, the survey methodology must be developed to ensure the accuracies required are met.

Survey Monitor Points shall be related to the road chainage and offset. Maximum distances from the total station to set out or measurement points shall be 130 metres.

Subsequent surveys of the Survey Monitor Points shall be carried out at specified durations. The Monitoring Control Points and RRMs shall be relevelled in two directions (Second Order) for each new survey. Relative RLs for the two RRMs on stable ground at each end of the project area shall be verified and RLs of other RRMs shall be adjusted if necessary. New intermediate RRMs shall be established if required (due to loss or inaccessibility of previously used control points).

Total station measurements shall again be carried out over all monitor points only if requested by the Main Roads Project Manager. Typically the original coordination of the monitoring marks is to enable each mark to be found at subsequent dates and so that they can be related to a chainage and offset from a design. However, differences in position from the original survey and the previous survey may need to be recorded. If this is the case, then accurate re-survey using Total Station will be necessary using the same observing methodology as the initial survey where possible. All monitor points are to be spirit levelled in a separate traverse to the control verification level traverse.

This procedure shall be repeated for each subsequent survey and the results added to the master spreadsheet.

Times of extreme weather should be avoided. Care should be taken to avoid monitoring during periods of high traffic volumes as this may affect the survey results.

5.5 RECORDING AND PRESENTATION OF DATA

The initial values of the Survey Monitor Points shall be recorded in an Excel spreadsheet and graphical format. Point identifiers, easting, northing, chainage, offset, elevation, time of observation and a description of the point shall be recorded as a minimum. Changes in elevation (and horizontal position if requested) shall be recorded in subsequent surveys and included in the spreadsheet.

Digital copies of survey data shall be provided to Main Roads following the initial and subsequent surveys.

An example of the required format for recording of monitoring data for road pavements is included in Appendix C & E.

6 MONITORING OF SETTLEMENT FOR STRUCTURES

6.1 GENERAL

Structures such as bridges may be required to be monitored for horizontal and vertical displacement. It is important to be able to accurately measure the amount of displacement at predetermined locations over a period of time.

All survey work associated and undertaken for the monitoring of structures must be sufficiently accurate to detect horizontal and vertical movements of + or – 2mm.

Most structural monitoring is for vertical movement only so references to horizontal displacement herein may not apply. The choice of monitoring is Structure dependent and is governed by its length, footing depths and traffic loads.

6.2 SURVEY DATUM

All co-ordinates supplied shall be in a Main Roads WA approved project zone which is based on either the GDA 94 or the GDA 2020 as required in the survey scope. Vertical datum shall be AHD 71 or another vertical datum if so specified.

6.3 SURVEY CONTROL

Survey control for the monitoring of structures should be established so that the integrity of the monitoring data can be guaranteed. A three tiered system, consisting of a Major Control Network (MCN), Secondary Control Network (SCN) and Monitor Points will be established. Refer to Appendix B.

a) Major Control Network (MCN)

- I. Ideally MCN Points will be a maximum of 500 metres apart and not more than 250 metres from the Secondary Control Network.
- II. The MCN is used as a point of reference and should be established on stable ground away from the immediate vicinity of the structure to be monitored. Reclaimed land and areas of seasonal flooding are not suitable for such a network.
- III. MCN marks should be local validated SSM's or marks established to at least RRM standard of construction (brass plaques).
- IV. The MCN should be verified every twelve months unless directed otherwise.
- V. If the MCN is not on stable ground then it must be verified prior to a monitor cycle using a combination of terrestrial and static GNSS observations from the outlying Geodetic Network. High order Geodetic Control – better than SU of 15mm as per ICSM Guideline for Control Surveys by GNSS (v2.1) must be used and the geometry of the network must be considered along with the removal of trivial baselines within the network observed. The observations must be reduced and adjusted using suitable software (e.g. Geolab) then reprojected the project grid and compared to previous results. When using adjustment software that incorporates transformations within the adjustment ensure the transformation section of the adjustment is disabled. These observations will be used to verify the stability of the MCN. Results showing movement of 3mm or less will be acceptable due to the size of the survey area.
- VI. Where movement is found to be greater than 3mm, additional survey should be undertaken to identify the area of movement and the subsequent mark(s) should be re-established to ensure future movement is eliminated. New coordinate values for the mark should also be issued and adopted.

b) Secondary Control Network (SCN)

The SCN is to be established a maximum of 50 m from the monitor points and each SCN point should be established in positions allowing line of sight to at least two of the MCN's and multiple Monitor Points. The SCN marks can be established to RRM brass plaque standard or as a minimum be substantial marks set in concrete or bitumen.

c) Monitoring Points

The Monitoring Points must be a permanent fixture on the structure to be monitored. Consultation with the Works Superintendent or Construction Manager must be carried out prior to construction to agree on the location, number and type of the Monitor Points to ensure all aspects of possible movement are covered and that they are protected from likely disturbance. Please refer to Appendix F which shows the recommended placement specifications for the monitoring pins for columns, piers and footings. Other examples of marks which could be attached to wing walls or abutments are a standard prism mount to facilitate forced centring of monitoring prisms.

6.4 SURVEY EQUIPMENT

All EDM instrumentation shall be calibrated on a Landgate maintained baseline or other NATA accredited baselines prior to the commencement of work and be checked and adjusted for horizontal and vertical collimation

The instrument will have been serviced by an authorised agent for that make of instrument within the last 12 months

Survey instrumentation requirements:

Total Station:	Direct readout to 1" with angular accuracy for Hz & V of 1.5" or better. EDM 2mm + 2ppm or better
Levelling:	Automatic level with parallel plate micrometer or digilevel with an accuracy rating of better than 0.3mm per km. Rigid invar staff or Landgate calibrated Fibreglass staff for digital levels.
GNSS:	Dual frequency Geodetic Standard with all tribrachs in good adjustment.

6.5 METHOD OF SURVEY

Times of extreme weather (heat and wind) should be avoided. Care should be taken to avoid monitoring during periods of high traffic volumes as this may affect the survey results.

All targets are to be interchangeable and tribrachs must remain fixed during observations (forced centring), thus minimizing setup errors. All results should be recorded electronically in the correct format to allow the reduction of angle sets and distances.

Horizontal Survey

The Major Control Network is used to verify the Secondary Control Network that is in close proximity to the Monitor Points, set in or attached to the monitored structure.

Multiple angles (minimum 4 arcs) and distances (minimum 8) are to be observed between Major and Secondary Control Points. The same procedure is then carried out between the Secondary Control and Monitor Points using Major Control Points as reference points. Angles will not have a standard deviation greater than 3" and distances not greater than 2mm. A minimum of two radiations is required to each monitor point.

It is essential that the Monitor Points are observed with the correct Meteorological Data entered into the instrument as measured at the instrument.

Vertical Survey

All Secondary Control and Monitoring Points are to be levelled using the MCN's as the datum points. The MCN must be checked levelled prior to levelling. The Secondary Control Points and Monitoring Points are then levelled to Second Order standard or better as set out in the ICSM Guideline for Control Surveys by Differential Levelling (i.e. $r = 4\sqrt{d}$; where r = the maximum error in millimetres and d = the distance traversed in kilometres). Each Monitor Point is levelled as either a change point or observed from two independent set-ups as intermediate sights. All level runs are closed and adjusted as required to meet the expected accuracy.

Horizontal Reduction

A reduction process using a least squares adjustment of observed horizontal data should be used. Holding the Major Control Network fixed, all other points are left to float. All preliminary results are to be checked to ensure that expected observation accuracies are obtained.

6.6 RECORDING AND PRESENTATION OF DATA

Survey control point data shall be recorded in spreadsheet and graphical format. Point Identification, easting, northing, elevation, time of observation and a description of the point shall be recorded as a minimum. Any subsequent changes in elevation shall also be recorded. Differences in easting, northing and RL should be compared to the initial observations and tabulated. Any movement of 4mm or greater in horizontal position and 2mm in vertical position should be flagged for further scrutiny. Digital and hard copies of survey control data shall be provided to Main Roads following initial and subsequent surveys.

An example of the required format for recording of monitoring results for structures is included in Appendix D & E.

7. DATA LODGEMENT

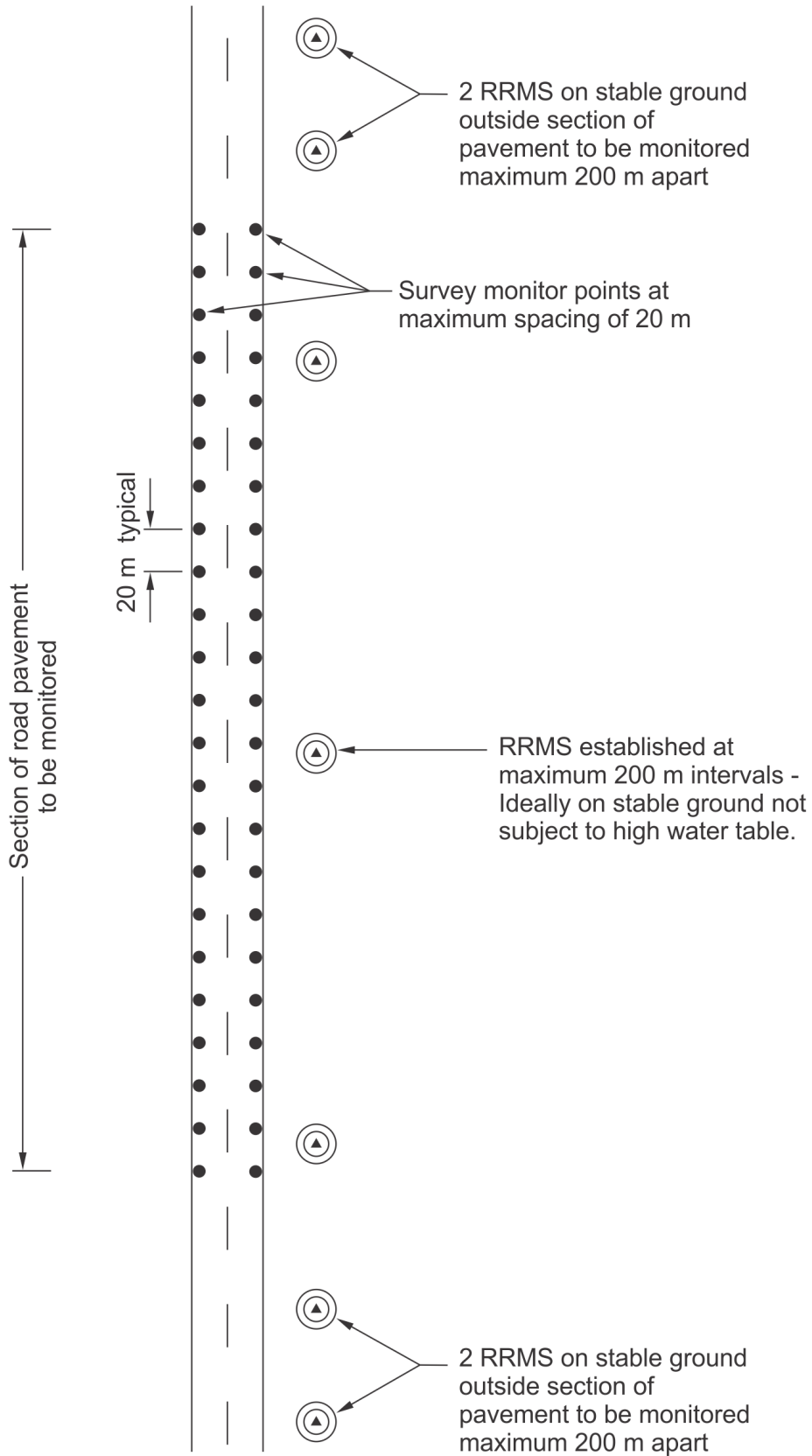
All survey results are to be lodged with the Contract manager who issued the Survey instruction.

The Consultant shall also lodge a copy of all information with Main Roads, Road and Traffic Engineering Branch, Data Manager with a Metadata Statement in accordance with Standard 67/08/100 “Metadata”.

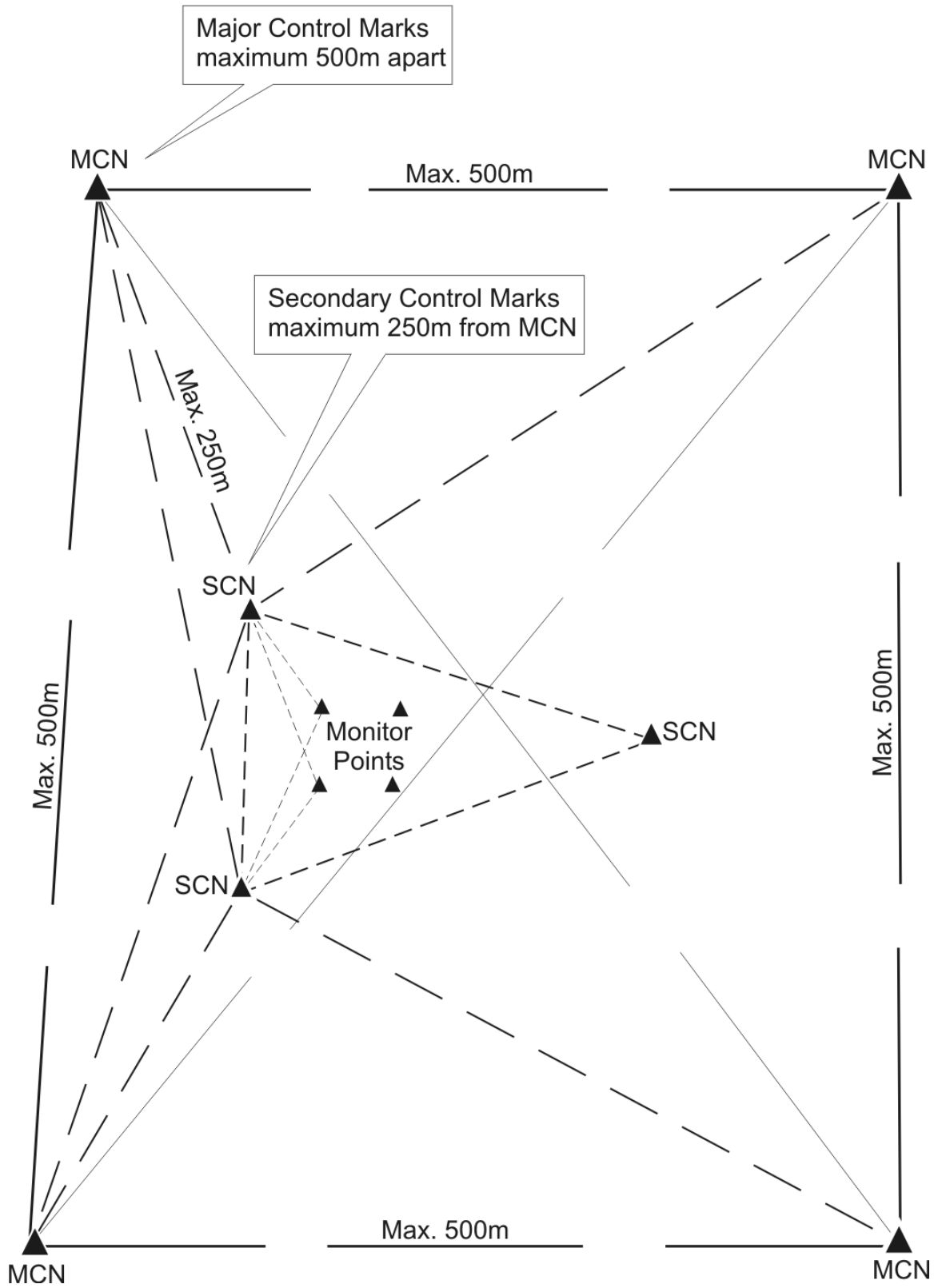
7 APPENDICES

Appendix	Title
Appendix A	Survey Control Network For Road Pavements
Appendix B	Survey Control Network For Structures
Appendix C	Sample Road Pavement Monitoring Output
Appendix D	Sample Structural Monitoring Output
Appendix E	Sample Graphical Monitoring Output
Appendix F	Bridge Abutment/Pier Survey Monitoring Pin

APPENDIX A: SURVEY CONTROL NETWORK FOR ROAD PAVEMENTS



APPENDIX B: SURVEY CONTROL NETWORK FOR STRUCTURES



APPENDIX C: SAMPLE ROAD PAVEMENT MONITORING OUTPUT

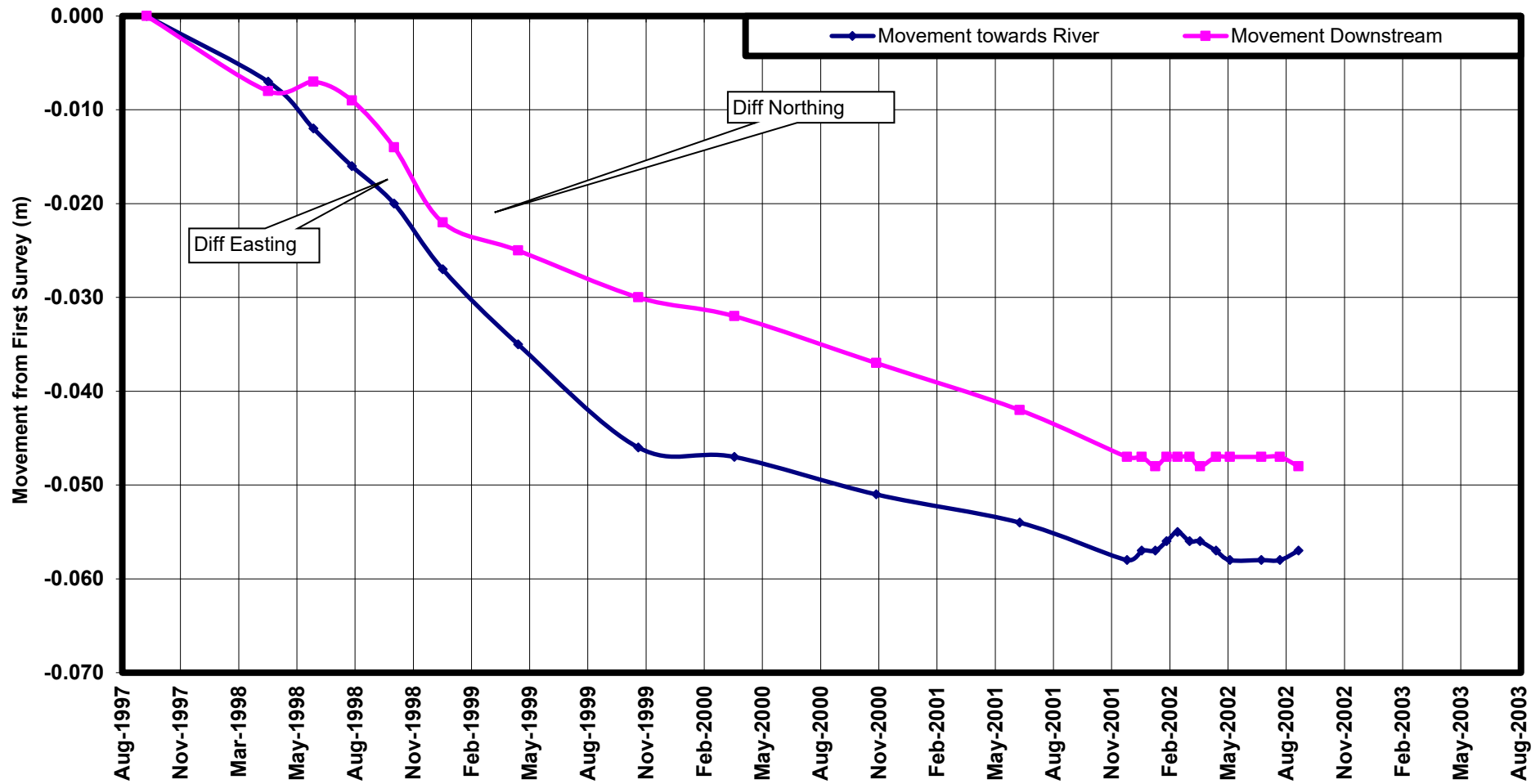
Moss String (Centreline)					June 1999	June 2001		June 2002			June 2003		
	Chainage	Offset	Easting	Northing	Initial RL	Meas RL	Diff from Initial	Meas RL	Diff from Initial	Diff from prev obs	Meas RL	Diff from Initial	Diff from prev obs
1SPK	1820	-4.250			1.186	1.182	-0.004	1.180	-0.006	-0.002	1.180	-0.006	0.000
1SPK	1820	+3.500			1.150	1.150	0.000	1.146	-0.004	-0.004	1.140	-0.010	-0.006
1SPK	1840	-4.250			1.354	1.346	-0.008	1.342	-0.012	-0.004	1.336	-0.018	-0.006
1SPK	1840	+3.500			1.320	1.314	-0.006	1.310	-0.010	-0.004	1.308	-0.012	-0.002
1SPK	1860	-4.250			1.528	1.524	-0.004	1.522	-0.006	-0.002	1.520	-0.008	-0.002
1SPK	1860	+3.500			1.500	1.495	-0.005	1.494	-0.006	-0.001	1.492	-0.008	-0.002
1SPK	1880	-4.250			1.702	1.692	-0.010	1.690	-0.012	-0.002	1.686	-0.016	-0.004
1SPK	1880	+3.500			1.670	1.670	0.000	1.668	-0.002	-0.002	1.666	-0.004	-0.002

APPENDIX D: SAMPLE STRUCTURAL MONITORING OUTPUT

Station	Epoch	Date	PCG94			Last minus Original Epoch			Last minus Previous Epoch			Comments
			Easting	Northing	RL	Diff E	Diff N	Diff RL	Diff E	Diff N	Diff RL	
A	1	2/11/1998	41166.366	262151.177	1.520	*	*	*	*	*	*	
A	2	2/05/1999	41166.368	262151.179	1.521	0.002	0.002	0.001	*	*	*	
A	3	2/11/1999	41166.364	262151.180	1.520	-0.004	0.001	-0.001	-0.004	0.001	-0.001	
A	4	2/05/2000	41166.368	262151.183	1.519	0.004	0.003	-0.001	0.004	0.003	-0.001	
B	1	2/11/1998	41165.977	262148.622	1.535	*	*	*	*	*	*	
B	2	2/05/1999	41165.978	262148.623	1.535	0.001	0.001	0.000	*	*	*	
B	3	2/11/1999	41165.975	262148.622	1.532	-0.003	-0.001	-0.003	-0.003	-0.001	-0.003	
B	4	2/05/2000	41165.978	262148.625	1.532	0.003	0.003	0.000	0.003	0.003	0.000	
C	1	2/11/1998	41192.824	262144.267	1.518	*	*	*	*	*	*	
C	2	2/05/1999	41192.827	262144.272	1.519	0.003	0.005	0.001	*	*	*	
C	3	2/11/1999	41192.828	262144.269	1.518	0.001	-0.003	-0.001	0.001	-0.003	-0.001	
C	4	2/05/2000	41192.830	262144.271	1.518	0.002	0.002	0.000	0.002	0.002	0.000	

APPENDIX E: SAMPLE GRAPHICAL MONITORING OUTPUT

Goongoongup Bridge Monitoring Results for Point 87



APPENDIX F: BRIDGE ABUTMENT/PIER SURVEY MONITORING PIN

