Pacific Sea Level and Geodetic Monitoring Project: Levelling & GNSS Monitoring Survey Report

Pohnpei, Federated States of Micronesia, October 2018

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Contents

1 Motivation

The Australian Bureau of Meteorology (Bureau), Geoscience Australia (GA) and the Pacific Community (SPC) work together on the Australian Aid funded Pacific Sea Level and Geodetic Monitoring Project (PSLGMP). The project is focused on determining the long-term variation in sea level through observation and analysis of changes in the height of the land (using Global Navigation Satellite System (GNSS) data) and changes in the sea level using tide gauges managed and operated by the Bureau. It is the role of GA and SPC to provide information about ‘absolute’ movement of the tide gauge (managed by Bureau) using GNSS to continuously monitor land motion and using levelling (SPC) to measure the height difference between the tide gauge and GNSS pillar every 18 months.

Land movement caused by earthquakes, subsidence and surface uplift have an important effect on sea level observations at tide gauges. For example, a tide gauge connected to a pier which is subsiding at a rate of 5 mm per year would be observed as a rate of 5 mm per year of sea level rise at the tide gauge. Because of this, it is important to measure, and account for, the movement of land when measuring ‘absolute’ sea level variation - the change in the sea level relative to the centre of the Earth. Relative sea level variation on the other hand is measured relative to local buildings and landmass around the coastline.

Geoscience Australia’s work enables more accurate 'absolute' sea level estimates by providing observations of land motion which can be accounted for by Bureau when analysing the tide gauge data.

2 Introduction

This report provides the results of the GNSS monitoring survey & high precision level survey completed between the Sea Level Fine Resolution Acoustic Measuring Equipment (SEAFRAME) tide gauge and the GNSS Continuously Operation Reference Station (CORS) in Pohnpei, FSM from 16th to 27th October 2018. It also provides an updated ellipsoidal height of the tide gauge derived from GNSS time series analysis and precise levelling observations.

GNSS Monitoring Survey

A high precision geodetic terrestrial survey is undertaken to monitor the stability of the GNSS CORS monument. This survey is used to complement GNSS analysis by determining whether movement detected by GNSS analysis is caused by localised movement of the pillar, or movement of the land across a larger area. Local movement is monitored by examining and comparing the results of repeat surveys to the monument and permanent reference marks approximately 20 m from the GNSS monument.

Levelling Survey

The Total Station differential levelling technique is used to observe the difference in height between the Tide Gauge and GNSS monument. The levelling route includes a deep driven benchmark array in Pohnpei, which runs approximately 3.4 km. Previous levelling surveys have been conducted along this route using this technique in 2006, 2008, 2009, 2011, 2012, 2014 and 2017. This report contains an analysis of the 2018 Total station differential levelling and GNSS monitoring results as well as a combined comparison of the previous levelling surveys.

Personnel

Personnel involved in the GNSS monitoring and levelling surveys were Andrick Lal, Marika Kalouniviti and Veenil Rattan from the Geodetic Survey at SPC. The GNSS time series analysis and derivation of the tide gauge ellipsoidal height was undertaken by the GNSS analysis team at Geoscience Australia.

2.1 Site Description and Contacts

The levelling benchmark array, GNSS CORS, and SEAFRAME are located between Kolonia and the Pohnpei airport. The levelling run goes from the GNSS CORS site at the NOAA Weather office, through the main road, along the causeway and out to the northern end of the port area where the SEAFRAME equipment is located.

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2.2 Survey Support

The survey team very much appreciated the assistance from the Chief of Lands & Survey Division, who made available their surveyor Mr Raynard Martin to assist with survey duties during the survey.

Gratitude also goes to the Lands & Survey office for their continued support with the project, and the Pohnpei State Weather Office, for the use of their office space and grounds for the project equipment.

3 Measurement Network

3.1 Terrestrial Network

The Total Station differential levelling survey was carried out between the SEAFRAME tide gauge sensors, the GNSS CORS along the existing deep driven benchmark array. This consists of Primary deep driven benchmarks, and temporary holding marks (Table 3.1)

Table 3.1 The primary survey control network. Locality diagrams of these marks are provided in Appendix A

Name	Description
FSM55	SEAFRAME sensor reference benchmark
FSM17	SEAFRAME project plaque benchmark
FSM1	Deep driven benchmark at port security gate
FSM2	Deep driven benchmark at airport freight gate
FSM3	Deep driven benchmark at main port facility
FSM4	Deep driven benchmark along causeway
FMS5	Deep driven benchmark along Spanish wall
POHNBM	Reference benchmark in the base of the GNSS CORS pillar
POHN	Antenna Reference Point (ARP) of GNSS CORS Pillar
RM1	GNSS CORS reference mark 1
RM2	GNSS CORS reference mark 2
RM3	GNSS CORS reference mark 3

Upon inspection, all the deep driven benchmarks were located, found in good order, and undisturbed. Included in the survey were the temporary holding marks; FSM999, FSM8, FSM10, FSM11, FSM12, FSM14, FSM16, FSM25, FSM27, FSM29, FSM31, FSM34, FSM100, FSM44, FSM47 and FSM51

3.1.1 PSLGMP Vertical Reference Frame Wiring Diagram

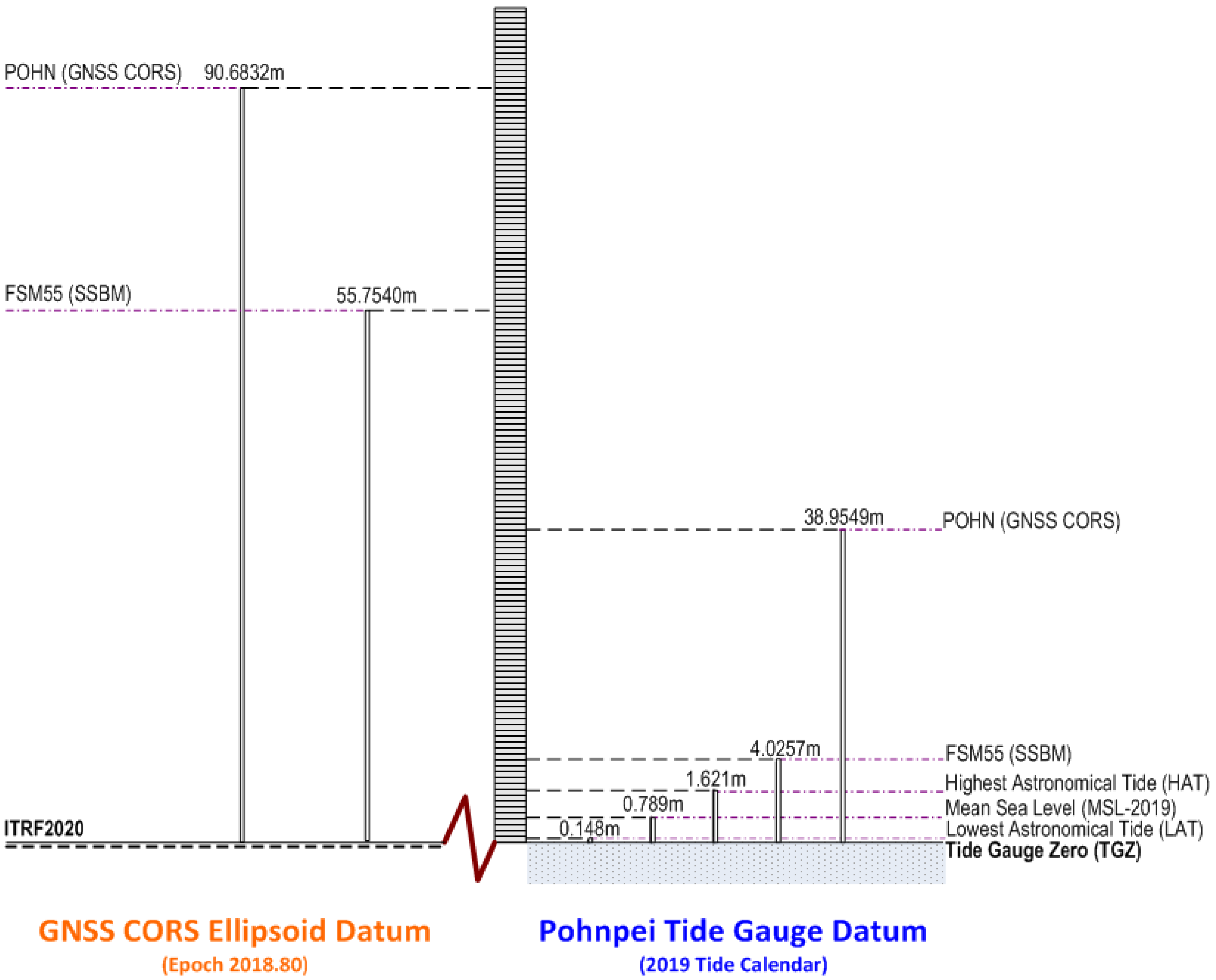


Figure 3.1 Wiring diagram depicting the offsets between surveyed marks. The left-hand side shows the height of the GNSS CORS pillar (POHN), SEAFRAME sensor reference benchmark (FSM55) with respect to the International Terrestrial Reference Frame 2020 at epoch 2018.80. The right-hand side shows the height of POHN, FSM55, and tidal datums with respect to tide gauge zero. For more information on tidal datums, please refer to Pacific Sea Level and Geodetic Monitoring Project File information and Instructions (bom.gov.au)

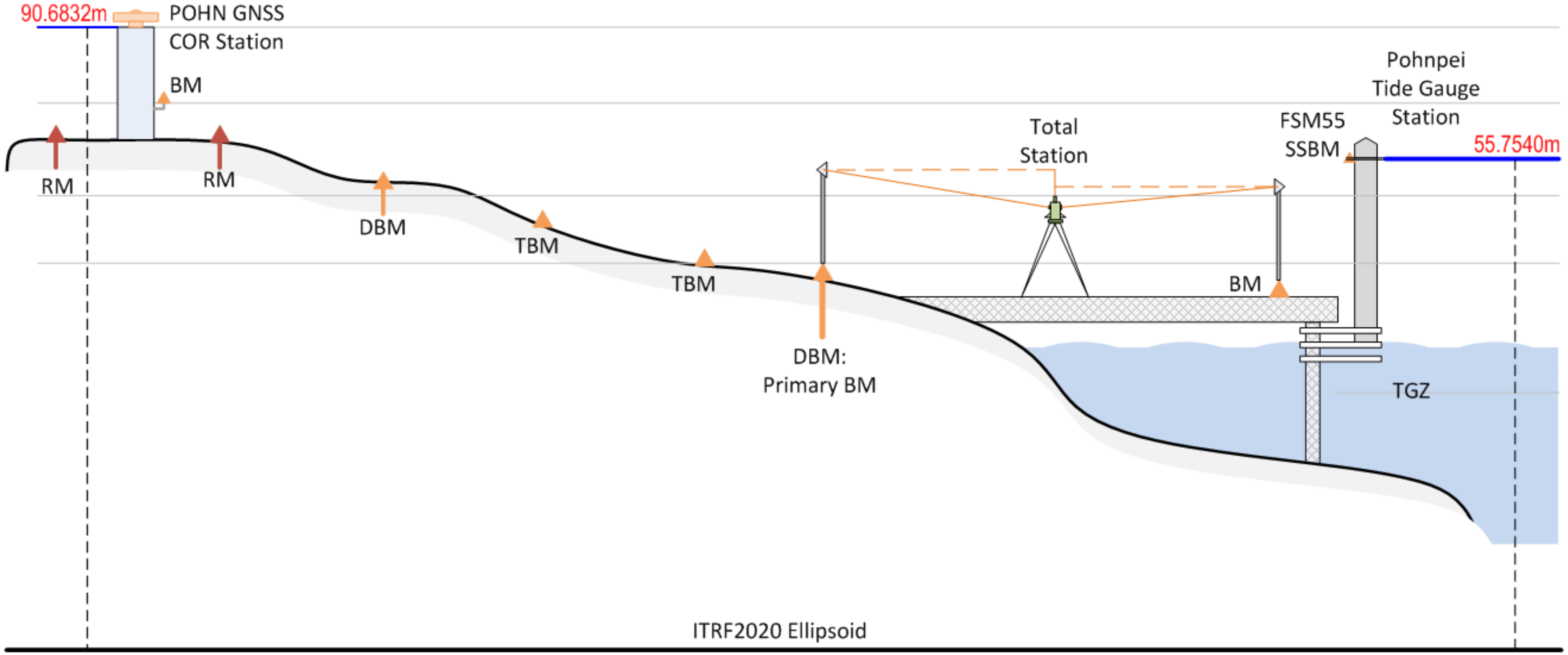


Figure 3.2 Simplified representation of the Total Station differential levelling survey carried out between the GNSS CORS and the SEAFRAME Tide Gauge

Figure 3.3 Tide Gauge Station. The red circle denotes the location of the SEAFRAME sensor reference benchmark (FSM55). Image from 2017.

Figure 3.4 GNSS CORS pillar. The red circle denotes the location of the GNSS CORS benchmark (POHNBM). Image from 2018.

Figure 3.5 Levelling benchmark array. Source: Adopted from Google Maps.

3.1.2 GNSS CORS and Reference Marks

The GNSS CORS site is located within the Pohnpei State Weather Office compound in Kolonia, Pohnpei, FSM. The 1.9m antenna pillar is in the front yard of the compound, and the technical equipment is mounted on a shelf in the main operations room. The pillar is 20 metres from the Weather Office building, access is via arrangement with the office, but should otherwise be open once they have been told of the survey intentions.

Three primary deep driven benchmarks were placed at the time of installation at a distance of 20m to 30m from the GNSS monument at approximately 120 degrees radial spacing from true north, where possible. The RM's consist of capped 20mm stainless steel rods driven to refusal and are protected by 150mm PVC pipe within circular poly carbonate boxes.

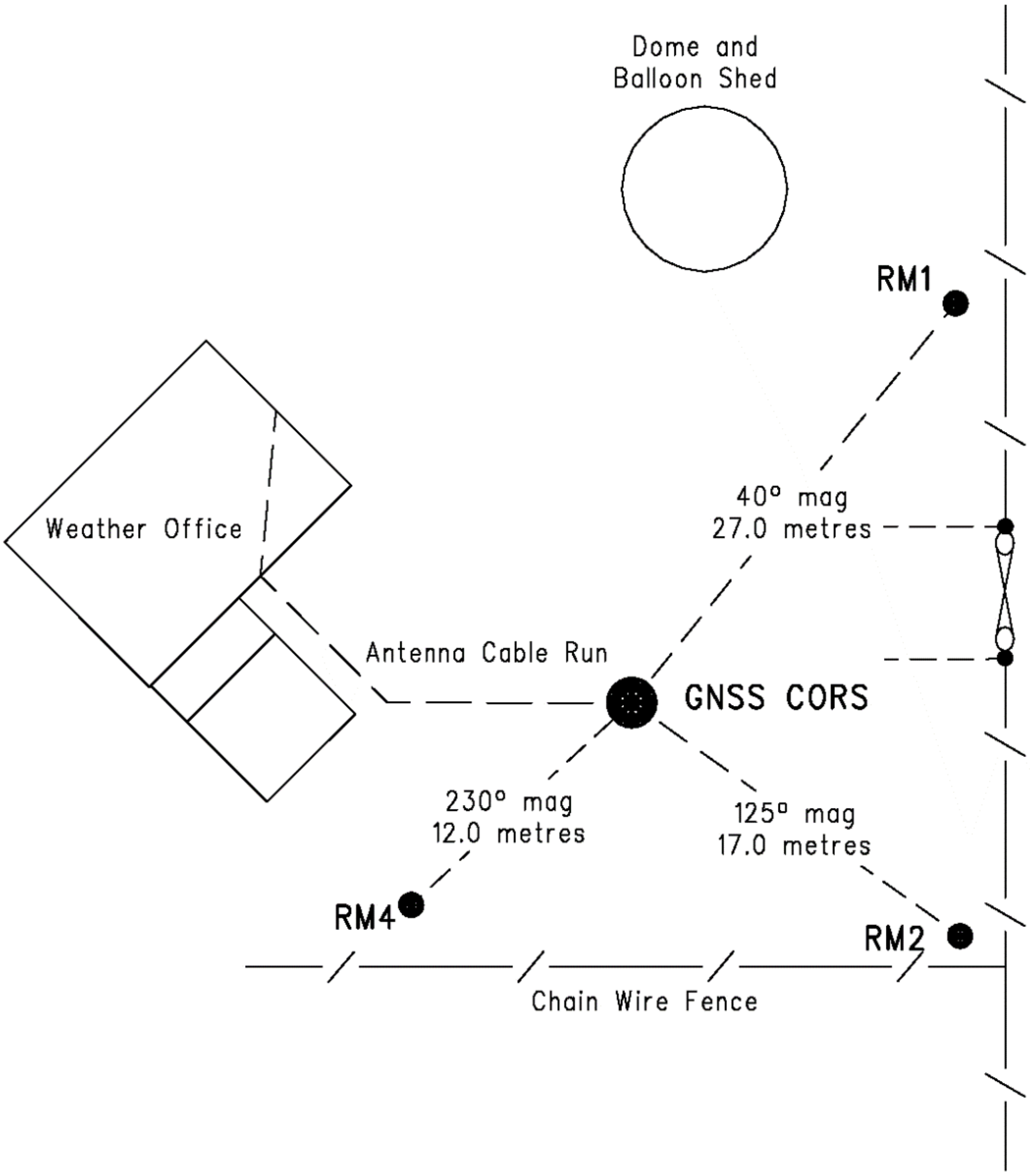


Figure 3.6 GNSS CORS site monitoring survey reference marks.

3.2 Datum

3.2.1 Survey Datum

The adopted reference point for the levelling survey is the levelling benchmark connected to the side of the GNSS CORS pillar (POHNBM).

3.2.2 Historical Survey Datum

In the past, the adopted reference point for the levelling survey was FSM1 fixed at 2.4382 metres.

This value was determined by the National Tidal Centre Australia (NTCA) by:

- 2001 Adopting the height of PNIA; RL = 2.00000 metres (Arbitrary Datum)
- 2003 Adopting the height of FSM1 as derived in the 2001 survey

4 Monitoring Survey

4.1 Background

A local monitoring survey is undertaken routinely to monitor for any local horizontal or vertical movement of the GNSS pillar, relative to the RMs. The RMs are all located within 30 m of the GNSS pillar. We acknowledge that this monitoring does not account for any movement over the wider area – i.e., movements that might be consistent across all RM's.

4.1.1 Methodology

The Total Station is used to observe and record all horizontal and vertical angles and slope distances in the network by setup and observation from each RM.

Two monitoring techniques can be used to determine movement of the GNSS monument.

The conventional 'Direct Method', involves removing the GNSS antenna and setting up the Total Station on the pillar to directly observe to a prism setup on a tripod over each RM. The Total Station is then moved to each RM in turn and observations are made directly to the pillar and other RMs from each setup. This method can also provide a direct observation to the height of the antenna mount, but obviously requires an interruption to the GNSS data when the antenna is removed, which is not ideal.

The 'Indirect Method' was developed to leave the antenna undisturbed. The symmetrical properties of the antenna are used to indirectly measure the centre of the antenna by triangulation from each RM. To measure the horizontal position of the Antenna Reference Point (ARP), angular direction observations are made to symmetrically coupled points on the external profile of the antenna (Figure 4.1) from each RM. The angular observations from all setups can be averaged and intersected to give a position of the central axis of the antenna by way of triangulation from the three RMs.

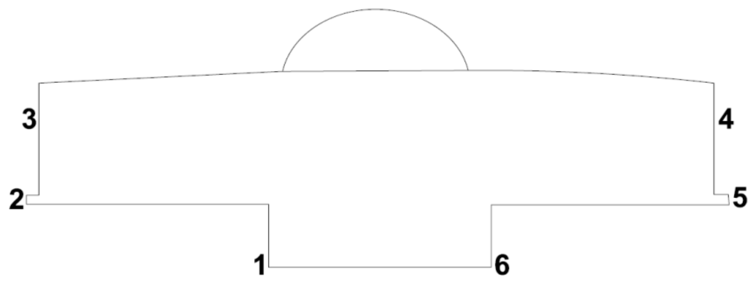


Figure 4.1 Symmetrical points on the antenna profile (TRM59800.00) observed from each RM.

The Indirect Method does not allow for a measurement of the vertical position of the monument. Instead, the result of the RM levelling survey (from each RM to the GNSS BM) is used, and then the known offset from the BM to the antenna mounting plate is applied.

Both techniques used will allow comparison to previous years, to monitor any movement of the pillar over time. The reduced observations are put into a least squares adjustment program, DynAdjust (Fraser et al., 2018), to determine the final coordinates by holding the point at the centre of the GNSS pillar plate fixed, and calculating the relative movement of each RM in ΔE, ΔN & ΔU, and an estimate of the error.

To avoid introducing any discontinuities into the GNSS time-series it is preferred, where possible, that the in-direct method of observation be used.

4.2 Horizontal Observations

The heights of the RMs are observed using the Total Station levelling (EDM height traversing) technique, with a Leica Total Station and two fixed height rods with precision reflectors (see Appendix C).

A horizontal control survey was conducted following the ICSM SP1 Guideline for Conventional Traverse Surveys (ICSM, 2021). Five sets of observations were completed at each standpoint; a set consists of a round of face left observations, followed by a round of face right observations to each of the visible survey marks. For each observation a horizontal direction, zenith angle and slope distance was recorded. At each instrument set-up atmospheric conditions (temperature, pressure and relative humidity) were recorded. Atmospheric conditions were applied during the post-processing stage and not directly into the Total Station. Instrument and target heights were measured using an offset tape.

4.3 Data Analysis and Results

4.3.1 Levelling Survey

Reduction of the digital data was computed using the Geoscience Australia levelling program “leveling1.exe” and LevellingFIELD_3.pl. This program computes the height difference between the two reflectors by taking the mean average of the measured height differences and also providing standard deviations and a misclose for the levelling loop. Refer to Section 5 for a detailed description of the levelling process.

Table 4.3.1 The Reduced Level (RL) shown is the height relative to POHNBM.

From	To	Rise (m)	Fall (m)	RL (m)	Dist (km)	Acc Dist (km)
POHNBM				0.0000	0.0000	0.000
RM1	**RM1**	0.0000	-0.5706	-0.5706	0.0320	0.032
RM2	**RM2**	0.0000	-0.65251	-1.2231	0.0344	0.0659
RM4	**RM4**	0.3739	0.0000	-0.8492	0.0240	0.089
RM2	**RM2**	0.0000	-0.3740	-1.2232	0.0230	
RM1	**RM1**	0.6525	0.0000	-0.5707	0.0344	
	POHNBM	0.5707	0.0000	-0.0001	0.0320	
	Sum:	1.5971	-1.5972			
	Misclose:		-0.0001	-0.0001	0.179	(Total Dist)
			ALLOWABLE (m):	**0.0006**	**2 x Sqrt (km) test:**	**PASS**

From	To	Rise (m)	Fall (m)	RL (m)	Dist (km)	Acc Dist (km)
POHNBM				0.0000		0.000
RM2	**RM2**	0.0000	-1.2234	-1.2234	0.0180	0.018
	POHNBM	1.2234	0.0000	0.0000	0.0180	
	Sum:	1.2234	-1.2234			
	Misclose:		0.0000	0.0000	0.036	(Total Dist)
			ALLOWABLE (m):	**0.0003**	**2 x Sqrt (km) test:**	**PASS**

From	To	Rise (m)	Fall (m)	RL (m)	Dist (km)	Acc Dist (km)
POHNBM				0.000	0.0000	0.000
RM4	**RM4**	0.0000	-0.8494	-0.8494	0.0150	0.015
	POHNBM	0.8494	0.0000	0.0000	0.0150	
	Sum:	0.8494	-0.8494			
	Misclose:		0.0000	0.0000	0.029	(Total Dist)
			ALLOWABLE (m):	**0.0002**	**2 x Sqrt (km) test:**	**PASS**

4.3.2 Geodetic Adjustment

All observations were combined into a geodetic adjustment using DynAdjust (Fraser et al., 2018). In the adjustment, the point on the GNSS pillar plate (POHN) was tightly constrained to its ITRF2014 coordinates and aligned to POHN-RM1 with an azimuth of 46° 18’ 00.20”, which had been determined in the 2003 survey by GNSS observation to RM1. The angular observations were given a precision of 1.0” and the slope distances a precision of 1.0 mm. The estimated coordinates and associated variance-covariance matrix were outputted in a SINEX file format and have been provided to Geoscience Australia.

The ITRF2014@2010.0 latitude and longitude coordinates adopted at POHN as GNSS constraint are taken from the Geoscience Australia GNSS portal[1]. The ellipsoidal height is the ITRF2020 height from the week of the survey. For more information on how this ellipsoidal height was computed, see Brown et al. (2020).

[1] GNSS Network Portal (ga.gov.au)

Table 4.3.2 Latitude, Longitude and Ellipsoidal Height (metres) for the GNSS & RM stations. ITRF2014@2010.0 Latitude, Longitude coordinates, and ITRF2020@2018.8 ellipsoidal height were adopted at POHN. CCC means all 3 dimensions (in XYZ) were constrained in the adjustment FFF means they were all free.

Station	Constraint	Latitude	Longitude	Ellipsoid height (m)
POHN	**CCC**	6° 57’ 35.80291”	158° 12’ 36.4036”	90.6832
RM1	**FFF**	6° 57’ 36.41005”	158° 12’ 37.0394”	89.1598
RM2	**FFF**	6° 57’ 35.37971”	158° 12’ 36.8074”	88.5093
RM4	**FFF**	6° 57’ 35.52101”	158° 12’ 36.0899”	88.8814

Table 4.3.3 Earth Centred Cartesian coordinates and associated standard deviations (metres) for the GNSS & RM stations. ITRF2014@2010.0 Latitude, Longitude coordinates (as per https://gnss.ga.gov.au/network), and ITRF2020@2018.8 ellipsoidal height were adopted at POHN.

Description	X	Y	Z	SD(e)	SD(n)	SD(up)
POHN	-5879158.5511	2350292.1349	767748.3539	0	0	0
RM1	-5879162.2932	2350272.6116	767766.6831	0.0003	0.0003	0.0005
RM2	-5879162.6122	2350280.4070	767735.1854	0.0004	0.0003	0.0005
RM4	-5879154.2907	2350300.8008	767739.5395	0.0003	0.0003	0.0005

Table 4.3.4 Difference in XYZ coordinates between the GNSS pillar and RMs (metres)

FROM	To	ΔE	ΔN	ΔU
POHN	**RM1**	19.5175	18.6513	-1.5235
POHN	**RM2**	12.3975	-13.0009	-2.1739
POHN	**RM4**	-9.6281	-8.6599	-1.8018

4.4 Assessment of Results

Table 4.4.1 and Figures 4.4.1 – 4.4.3 show the movement of the reference marks with respect to the GNSS pillar in ΔE, ΔN and ΔU. No obvious errors or movement are apparent in the time series.

Table 4.4.1 Topocentric vectors showing delta east, delta north and delta up between the GNSS pillar and each Reference Mark (metres).

YEAR	FROM	To	ΔE	ΔN	ΔU
2003	**POHN**	**RM1**	19.5179	18.6518	-1.5209
2004	**POHN**	**RM1**	19.5177	18.6515	-1.5206
2006	**POHN**	**RM1**	19.5183	18.6521	-1.5221
2008	**POHN**	**RM1**	19.5179	18.6518	-1.5204

2009	**POHN**	**RM1**	19.5180	18.6518	-1.5221
2011	**POHN**	**RM1**	19.5179	18.6516	-1.5223
2014	**POHN**	**RM1**	19.5179	18.6517	-1.5224
2015	**POHN**	**RM1**	19.5172	18.651	-1.5226
2017	**POHN**	**RM1**	19.5175	18.6512	-1.5222
2018	**POHN**	**RM1**	19.5175	18.6513	-1.5235
Ref RL	**(as at 2015)**		**19.5179**	**18.6517**	**-1.5217**

YEAR	FROM	To	ΔE	ΔN	ΔU
2003	**POHN**	**RM2**	12.3968	-13.0011	-2.1741
2004	**POHN**	**RM2**	12.3974	-13.0007	-2.1739
2006	**POHN**	**RM2**	12.3979	-13.0012	-2.1752
2008	**POHN**	**RM2**	12.3969	-13.0008	-2.1737
2009	**POHN**	**RM2**	12.3974	-13.0013	-2.1755
2011	**POHN**	**RM2**	12.3975	-13.0012	-2.1755
2014	**POHN**	**RM2**	12.3975	-13.0011	-2.1753
2015	**POHN**	**RM2**	12.3969	-13.0007	-2.1757
2017	**POHN**	**RM2**	12.3974	-13.0012	-2.1753
2018	**POHN**	**RM2**	12.3975	-13.0009	-2.1739
Ref RL	**(as at 2015)**		**12.3973**	**-13.0010**	**-2.1748**

YEAR	FROM	To	ΔE	ΔN	ΔU
2014	**POHN**	**RM4**	-9.6276	-8.6585	-1.8013
2015	**POHN**	**RM4**	-9.6279	-8.6586	-1.8013
2017	**POHN**	**RM4**	-9.6277	-8.6586	-1.8012
2018	**POHN**	**RM4**	-9.6281	-8.6599	-1.8018
Ref RL	**(as at 2015)**		**-9.6278**	**-8.6586**	**-1.8013**

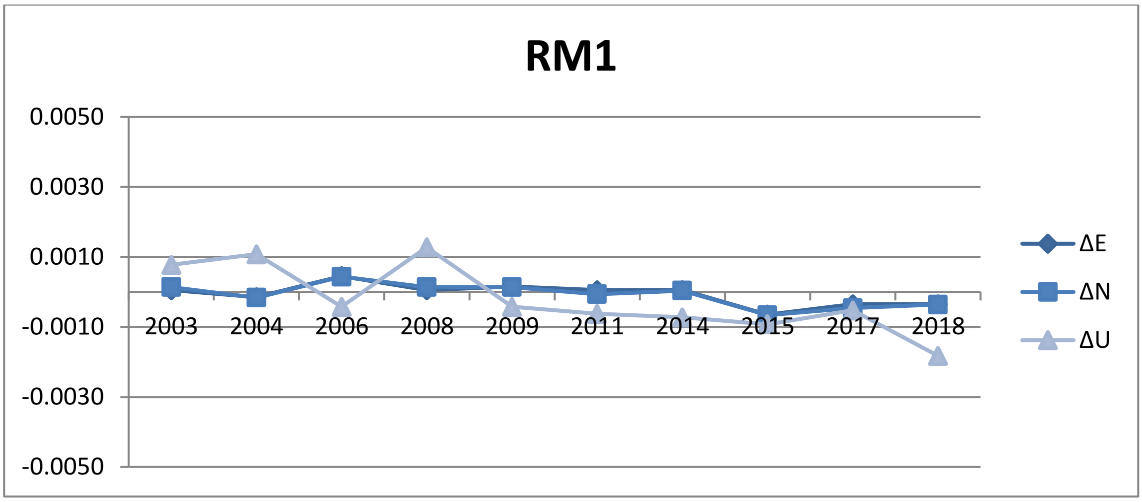


Figure 4.4.1 Time series of RM1 movement relative to GNSS pillar (0 = REF pre 2015 mean).

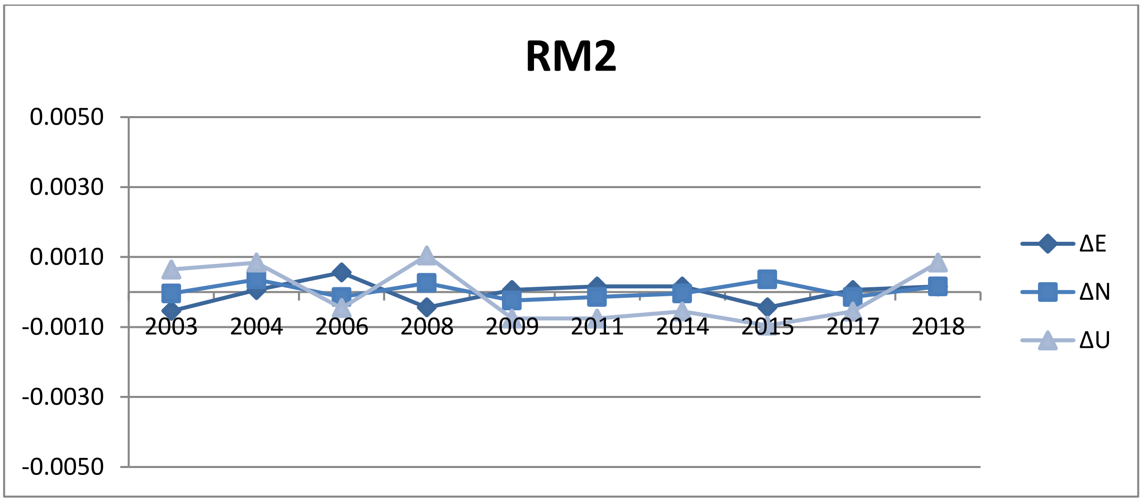


Figure 4.4.2 Time series of RM2 movement relative to GNSS pillar (0 = REF pre 2015 mean).

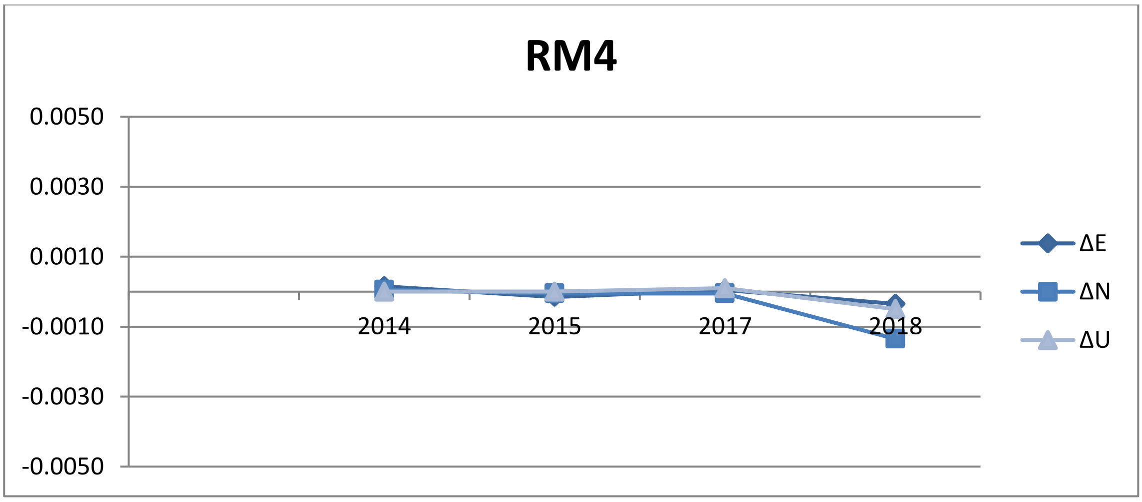


Figure 4.4.3 Time series of RM4 movement relative to GNSS pillar (0 = REF pre 2015 mean).

5 Tide Gauge Level Connection

5.1 Background

The Total Station differential levelling technique was performed in accordance with the SP1 levelling guidelines (ICSM, 2021). After reduction an internal precision of 1mm√K or better was achieved within each survey bay, where K is distance in kilometres.

5.2 Survey Methodology

The Total Station differential levelling technique was used for the Pohnpei tide gauge levelling survey. This technique uses a ‘leap-frog’ method which involves setting up a Total Station midway between two target/reflectors (on a reflector rod with bi-pod). The targets remain at a particular change point for the backsight and foresight observations and all levelling runs start and finish with the same reflector and reflector rod to eliminate any reflector rod ‘zero error’.

This technique can also be performed using a single set-up / single rod configuration which was the case when levelling between benchmarks which are close together e.g., between the GNSS CORS RMs.

The levelling run was divided into bays between each holding benchmark. Observations were completed in both directions within the bay to close each loop along the way. This method provides a closure between bench marks and allows a hold point in the survey in case of severe weather, physical interference, or time restrictions while completing the survey across the week.

In support of the slope distance observations, the ambient temperature, pressure and humidity are recorded (Kestral 4000 pocket weather tracker) and input into the instrument to apply the first velocity correction to the observed distances (Rüeger & Brunner, 1982). Five rounds of observations are taken to the backsight and foresight targets from each instrument setup. The instrument measures slope distances (±1mm) and vertical angle (1”) to derive height differences.

Table 5.2.2 contains the values of the constants or calibrated heights used throughout the analysis.

Table 5.2.2 Calibrations and constants.

Name	Value (m)	Description
POHN (Ellipsoidal ht)	90.6832	Observed RL at the ARP of POHN (Ellipsoidal) @ 2018.80
POHN to POHNBM	-0.9520	Offset constant between BM at GNSS pillar plate
Primary Pole & 1/2m Pole	1.00337	Height difference between poles used (calibrated September 2011)
Primary Pole & TG Pole	1.43252	Height difference between poles used (calibrated September 2011)

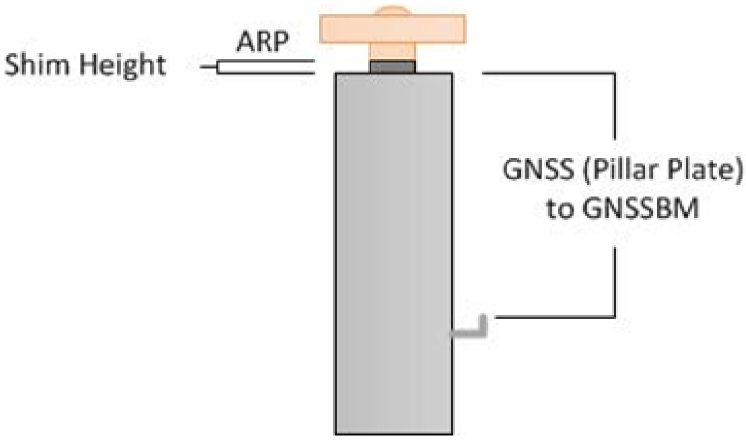


Figure 5.2.1 GNSS Pillar Offsets

5.3 Data Analysis and Results

Reduction of the digital data was computed using the Geoscience Australia levelling program "leveling1.exe" and "levellingFIELD_3pl". This program computes the height difference between the two reflectors by taking the mean average of the measured height differences and also providing standard deviations and a misclose for the input levelling loop.

The Reduced Level (RL) shown in Table 5.3.1 below is the height relative to POHNBM (GNSS BM)

Table 5.3.1 Reduced level data – POHN (GNSS CORS) to FSM1 (Primary Benchmark)

From	To	Rise (m)	Fall (m)	RL (m)	Dist (km)	Acc Dist (km)
POHN				0.9520		
POHNBM	**POHNBM**	0.0000	-0.9520	0.0000	0.000	0.000
51	**51**	0.0000	-0.4575	-0.4575	0.145	0.145
47	**47**	0.0000	-11.8425	-12.3000	0.193	0.338
44	**44**	0.0000	-3.0235	-15.3235	0.201	0.538
100	**100**	0.0000	-0.8372	-16.1607	0.169	0.707
FSM5	**FSM5**	0.0000	-1.2549	-17.4157	0.181	0.888
102	**102**	0.0000	-0.1151	-17.5308	0.101	0.989
34	**34**	0.0000	-13.9929	-31.5237	0.167	1.156
31	**31**	0.0000	-3.4258	-34.9495	0.155	1.310
29	**29**	0.0000	-1.1225	-36.0720	0.190	1.500
27	**27**	0.6071	0.0000	-35.4649	0.184	1.684
25	**25**	0.0000	-0.1740	-35.6389	0.182	1.866
FSM4	**FSM4**	0.0000	-0.6331	-36.2720	0.096	1.961
15	**15**	0.6112	0.0000	-35.6608	0.190	2.152
13	**13**	0.0967	0.0000	-35.5641	0.184	2.335
11	**11**	0.4114	0.0000	-35.1527	0.190	2.525
10	**10**	0.0000	-0.8656	-36.0184	0.175	2.700
FSM3	**FSM3**	0.0712	0.0000	-35.9471	0.085	2.784
8	**8**	0.3027	0.0000	-35.6444	0.199	2.984
FSM2	**FSM2**	0.0000	-0.0216	-35.6661	0.121	3.105
999	**999**	0.0000	-0.3234	-35.9894	0.124	3.229
FSM1	**FSM1**	0.4193	0.0000	-35.5702	0.119	3.348
999	**999**	0.0000	-0.4192	-35.9894	0.119	
FSM2	**FSM2**	0.3237	0.0000	-35.6657	0.124	
8	**8**	0.0214	0.0000	-35.6443	0.121	
FSM3	**FSM3**	0.0000	-0.3030	-35.9473	0.199	
10	**10**	0.0000	-0.0713	-36.0186	0.085	
11	**11**	0.8658	0.0000	-35.1528	0.173	
13	**13**	0.0000	-0.4115	-35.5643	0.190	
15	**15**	0.0000	-0.0968	-35.6611	0.187	
FSM4	**FSM4**	0.0000	-0.6113	-36.2724	0.190	

25	**25**	0.6331	0.0000	-35.6393	0.095	
27	**27**	0.1739	0.0000	-35.4654	0.182	
29	**29**	0.0000	-0.6069	-36.0723	0.184	
31	**31**	1.1226	0.0000	-34.9497	0.183	
34	**34**	3.4261	0.0000	-31.5236	0.154	
102	**102**	13.9933	0.0000	-17.5303	0.167	
FSM5	**FSM5**	0.1151	0.0000	-17.4152	0.101	
100	**100**	1.2553	0.0000	-16.1599	0.178	
44	**44**	0.8372	0.0000	-15.3227	0.166	
47	**47**	3.0235	0.0000	-12.2992	0.200	
51	**51**	11.8426	0.0000	-0.4566	0.190	
POHNBM	**POHNBM**	0.4573	0.0000	0.0007	0.144	
	POHN	0.9520	0.0000	0.9527	0.000	
	Sum:	41.5623	-41.5616			
	Misclose:		0.0007	0.0007	6.683	(Total Dist)
			ALLOWABLE (m):	**0.0037**	**2 x Sqrt (km) test:**	**PASS**

Table 5.3.2 Reduced level data – FSM1 (Primary BM) –FSM17 (Tide Gauge Reference Benchmark)

From	To	Rise (m)	Fall (m)	RL (m)	Dist (km)	Acc Dist (km)
FSM1				-35.5702		3.348
FSM17	**FSM17**	0.6314	0.0000	-34.9388	0.113	3.461
	FSM1	0.0000	-0.6314	-35.5701	0.113	
	Sum:	0.6314	-0.6314			
	Misclose:		0.0000	0.0000	0.226	(Total Dist)
			ALLOWABLE (m):	**0.0007**	**2 x Sqrt (km) test:**	**PASS**

Table 5.3.3 Reduced level data – FSM17 (Primary BM) to FSM55 (Tide Gauge Sensor Benchmark)

From	To	Rise (m)	Fall (m)	RL (m)	Dist (km)	Acc Dist (km)
FSM17				-34.9388		3.461
FSM55	**FSM55**	0.9615	0.0000	-33.9772	0.028	3.489
	FSM17	0.0000	-0.9616	-34.9388	0.028	
	Sum:	0.9615	-0.9616			
	Misclose:		0.0000	-0.0001	0.057	(Total Dist)
			ALLOWABLE (m):	**0.0003**	**2 x Sqrt (km) test:**	**PASS**

Table 5.3.4 Reduced level data – FSM55 (Primary BM) to POHNRG (Tide Radar Gauge Benchmark)

From	To	Rise (m)	Fall (m)	RL (m)	Dist (km)	Acc Dist (km)
FSM55				-33.9772		3.489
POHNRG	**POHNRG**	1.2928	0.0000	-32.6845	0.028	3.517
	FSM55	0.0000	-1.2928	-33.9772	0.028	
	Sum:	1.2928	-1.2928			
	Misclose:		0.0000	0.0000	0.056	(Total Dist)
			ALLOWABLE (m):	**0.0003**	**2 x Sqrt (km) test:**	**PASS**

Table 5.3.5 Measured height differences (in metres) between all BMs (ΔRL_{2018})

	POHNBM	FSM5	FSM4	FSM3	FSM2	FSM1	FSM17	FSM55	POHN	RM1	RM2	RM4
POHNBM	-	-17.4154	-36.2722	-35.9472	-35.6659	-35.5702	-34.9388	-33.9772	0.9520	-0.5707	-1.2232	-0.8492
FSM5	17.4154	-	-18.8567	-18.5318	-18.2505	-18.1547	-17.5233	-16.5618	18.3674	16.8448	16.1923	16.5662
FSM4	36.2722	18.8567	-	0.3250	0.6063	0.7020	1.3334	2.2950	37.2242	35.7015	35.0490	35.4230
FSM3	35.9472	18.5318	-0.3250	-	0.2813	0.3771	1.0085	1.9700	36.8992	35.3765	34.7240	35.0980
FSM2	35.6659	18.2505	-0.6063	-0.2813	-	0.0957	0.7271	1.6887	36.6179	35.0952	34.4427	34.8167
FSM1	35.5702	18.1547	-0.7020	-0.3771	-0.0957	-	0.6314	1.5929	36.5222	34.9995	34.3470	34.7210
FSM17	34.9388	17.5233	-1.3334	-1.0085	-0.7271	-0.6314	-	0.9615	35.8908	34.3681	33.7156	34.0896
FSM55	33.9772	16.5618	-2.2950	-1.9700	-1.6887	-1.5929	-0.9615	-	34.9292	33.4066	32.7540	33.1280
POHN	-0.9520	-18.3674	-37.2242	-36.8992	-36.6179	-36.5222	-35.8908	-34.9292	-	-1.5227	-2.1752	-1.8012
RM1	0.5707	-16.8448	-35.7015	-35.3765	-35.0952	-34.9995	-34.3681	-33.4066	1.5227	-	-0.6525	-0.2785
RM2	1.2232	-16.1923	-35.0490	-34.7240	-34.4427	-34.3470	-33.7156	-32.7540	2.1752	0.6525	-	0.3740
RM4	0.8492	-16.5662	-35.4230	-35.0980	-34.8167	-34.7210	-34.0896	-33.1280	1.8012	0.2785	-0.3740	-

Table 5.3.6 Time-series of Reduced Levels (with respect to POHNBM).

YEAR	POHNBM	FSM5	FSM4	FSM3	FSM2	FSM1	FSM17	FSM55	POHN	RM1	RM2	RM4
2003.2	0.000	-17.4141	-36.2484		-35.6607	-35.5640	-34.9272	-33.9696		-0.5689	-1.2221	
2006.4	0.000	-17.4165	-36.2546		-35.6681	-35.5718	-34.9360	-33.9770				
2006.4	0.000	-17.4145	-36.2534		-35.6665	-35.5709	-34.9359	-33.9777	0.9518	-0.5701	-1.2232	
2008.2	0.000	-17.4151	-36.2520		-35.6645	-35.5678	-34.9337	-33.9755	0.9520	-0.5684	-1.2217	
2009.4	0.000	-17.4167	-36.2553	-35.9396	-35.6675	-35.5709	-34.9371	-33.9775	0.9521	-0.5701	-1.2235	
2011.1	0.000	-17.4154	-36.2530	-35.9393	-35.6656	-35.5694	-34.9364	-33.9763	0.9521	-0.5703	-1.2235	
2012.6	0.000	-17.4153	-36.2538	-35.9403	-35.6660	-35.5698	-34.9361	-33.9762		0.0000		
2014.2	0.000	-17.4155	-36.2544	-35.9441	-35.6674	-35.5714	-34.9390	-33.9794		0.0000	0.0000	-0.8493
2015.8	0.000	-17.4153	-36.2551	-35.9460	-35.6677	-35.5714	-34.9393	-33.9785	0.9519	-0.5697	-1.2230	0.0000
2017.1	0.000	-17.4147	-36.2551	-35.9466	-35.6668	-35.5717	-34.9402	-33.9807	0.9520	-0.5697	-1.2230	-0.8490
2018.8	0.000	-17.4154	-36.2722	-35.9472	-35.6659	-35.5702	-34.9388	-33.9772	0.9520	-0.5707	-1.2232	-0.8492

5.4 Comparison with previous surveys

All historic data has been readjusted relative to the benchmark attached to the base of the GNSS pillar (POHNBM) (Table5.3.6). To investigate whether BMs have moved over time, the RLs from the 2018 survey (RL_{2018}) have been compared to a reference height (RH) defined as the average of all previously calculated RLs. In cases where a site has undergone known movement (e.g., BM removed and reinstalled), the RH is the latest measured RL

5.4.1 Difference in Reference Height values

Table 5.4.1.1 ΔRL_{REF} - ΔRL_{20198} values (in metres). Shows the difference in height between two marks from the current survey compared to the reference height difference.

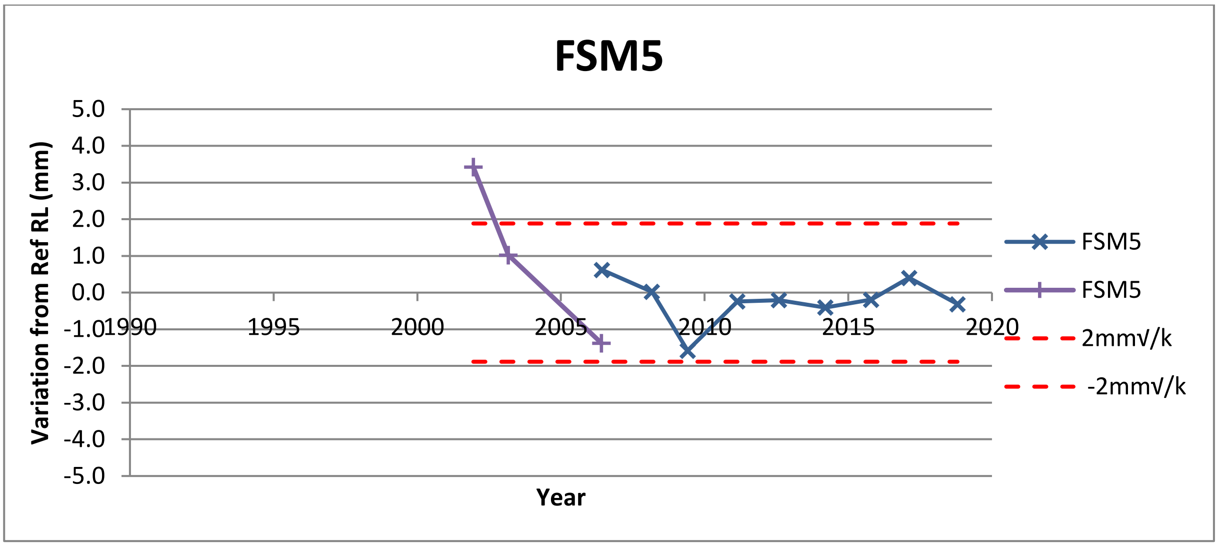
REF - 2018	POHNBM	FSM5	FSM4	FSM3	FSM2	FSM1	FSM17	FSM55	POHN	RM1	RM2	RM4
POHNBM	-	0.0003	**0.0178**	0.0045	-0.0011	-0.0008	0.0024	0.0003	0.0000	0.0011	0.0001	0.0000
FSM5	-0.0003	-	**0.0175**	0.0042	-0.0014	-0.0011	0.0021	0.0000	-0.0003	0.0008	-0.0002	-0.0003
FSM4	**-0.0178**	**-0.0175**	-	**-0.0133**	**-0.0189**	**-0.0186**	**-0.0154**	**-0.0176**	**-0.0179**	**-0.0168**	**-0.0177**	**-0.0178**
FSM3	-0.0045	-0.0042	**0.0133**	-	-0.0056	-0.0053	-0.0021	-0.0043	-0.0046	-0.0035	-0.0044	-0.0045
FSM2	0.0011	0.0014	**0.0189**	0.0056	-	0.0003	0.0035	0.0013	0.0010	0.0021	0.0012	0.0011
FSM1	0.0008	0.0011	**0.0186**	0.0053	-0.0003	-	0.0032	0.0010	0.0007	0.0018	0.0009	0.0008
FSM17	-0.0024	-0.0021	**0.0154**	0.0021	-0.0035	-0.0032	-	-0.0022	-0.0025	-0.0014	-0.0023	-0.0024
FSM55	-0.0003	0.0000	**0.0176**	0.0043	-0.0013	-0.0010	0.0022	-	-0.0003	0.0008	-0.0001	-0.0002
POHN	0.0000	0.0003	**0.0179**	0.0046	-0.0010	-0.0007	0.0025	0.0003	-	0.0011	0.0001	0.0000
RM1	-0.0011	-0.0008	**0.0168**	0.0035	-0.0021	-0.0018	0.0014	-0.0008	-0.0011	-	-0.0009	-0.0010
RM2	-0.0001	0.0002	**0.0177**	0.0044	-0.0012	-0.0009	0.0023	0.0001	-0.0001	0.0009	-	-0.0001
RM4	0.0000	0.0003	**0.0178**	0.0045	-0.0011	-0.0008	0.0024	0.0002	0.0000	0.0010	0.0001	-

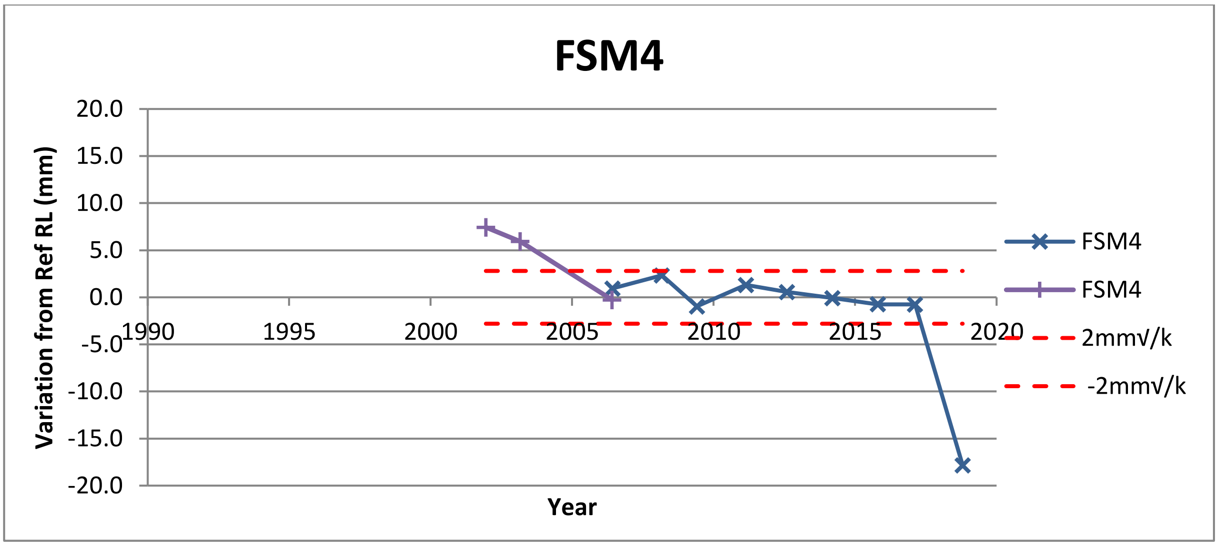
Table 5.4.1.1 values are calculated by subtracting the difference in height between RL_{2018} values (Table 5.3.5) from the difference in height between RL_{REF} values.

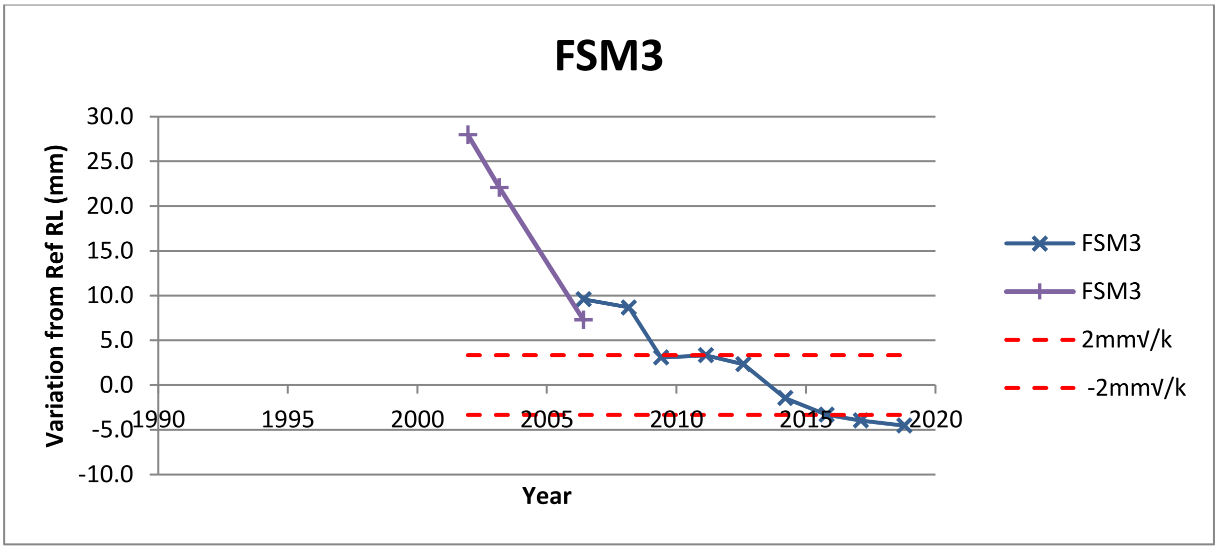
Comparing the change in relative heights between all benchmarks, will help identify movement of a particular BM, inconsistency in survey, or even deformation between the GNSS pillar and levelling run BMs.

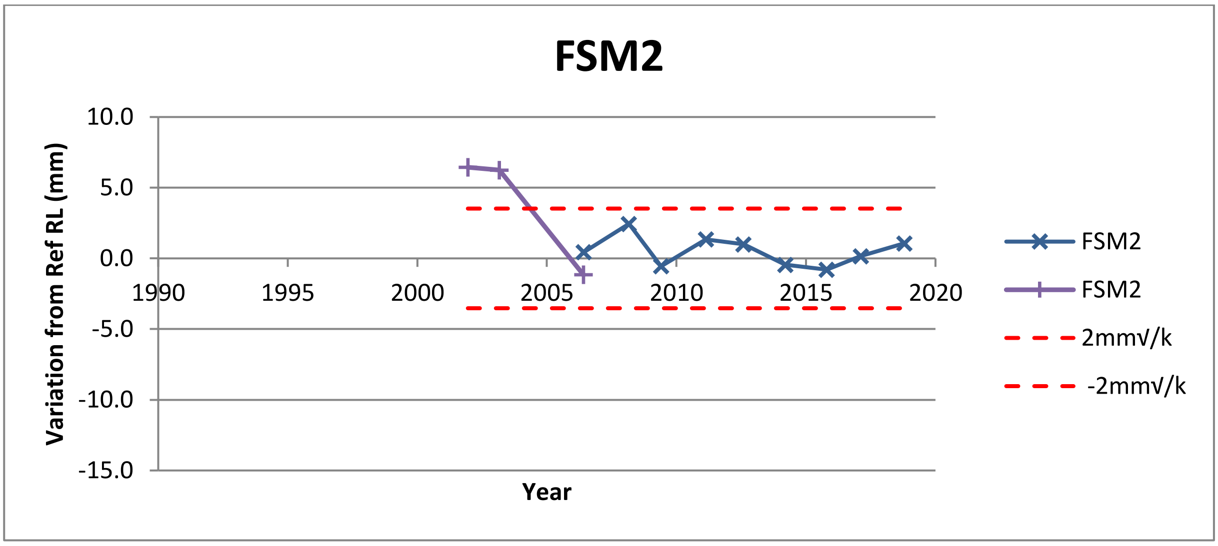
5.4.2 Time Series Charts for each BM

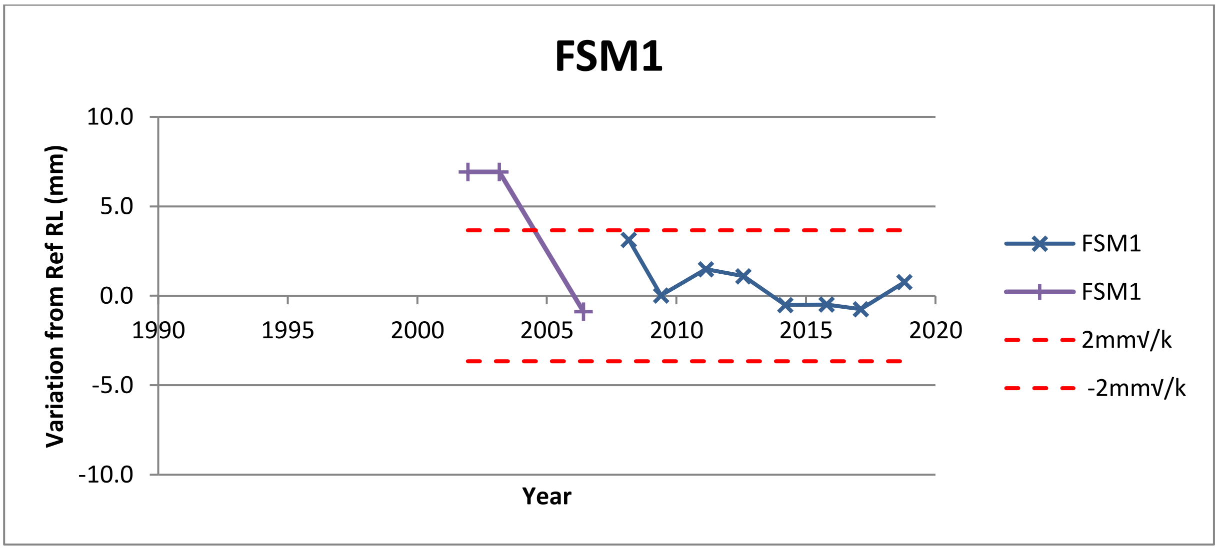
The change in RL over time can be used to detect trends of movement or survey errors. In the series of figures below, the red dashed lines represent the allowable error in height based on the levelling technique used and distance of the benchmark from the GNSS pillar ($2mm\sqrt{K}$). The purple line (with crosses) shows the results achieved using precise differential levelling [with a levelling instrument and survey staff] and the blue line with crosses show the levelling results based on the Total Station differential levelling technique.

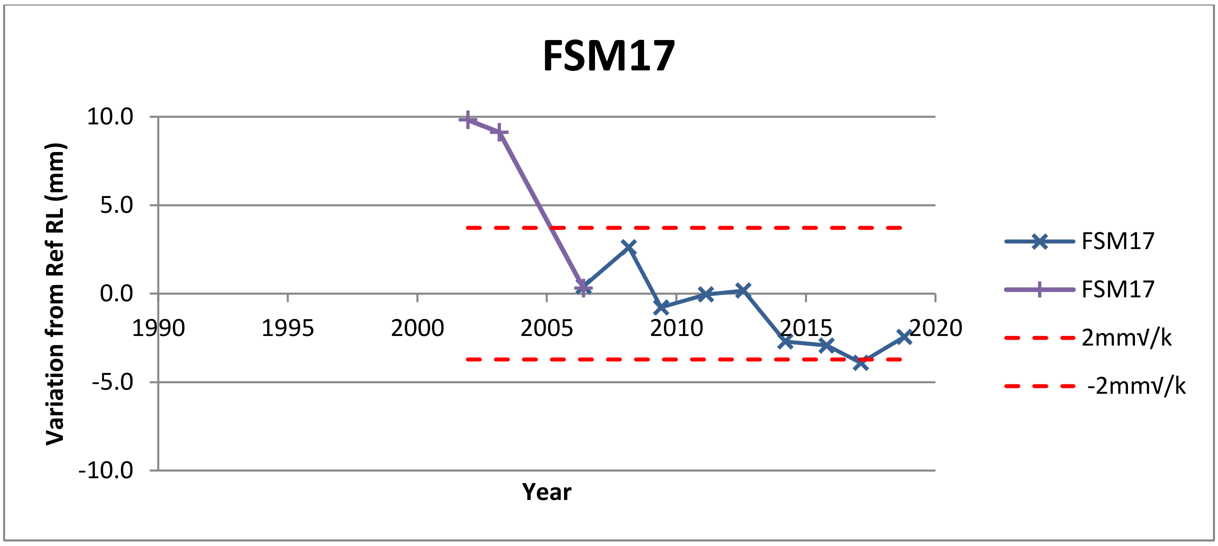


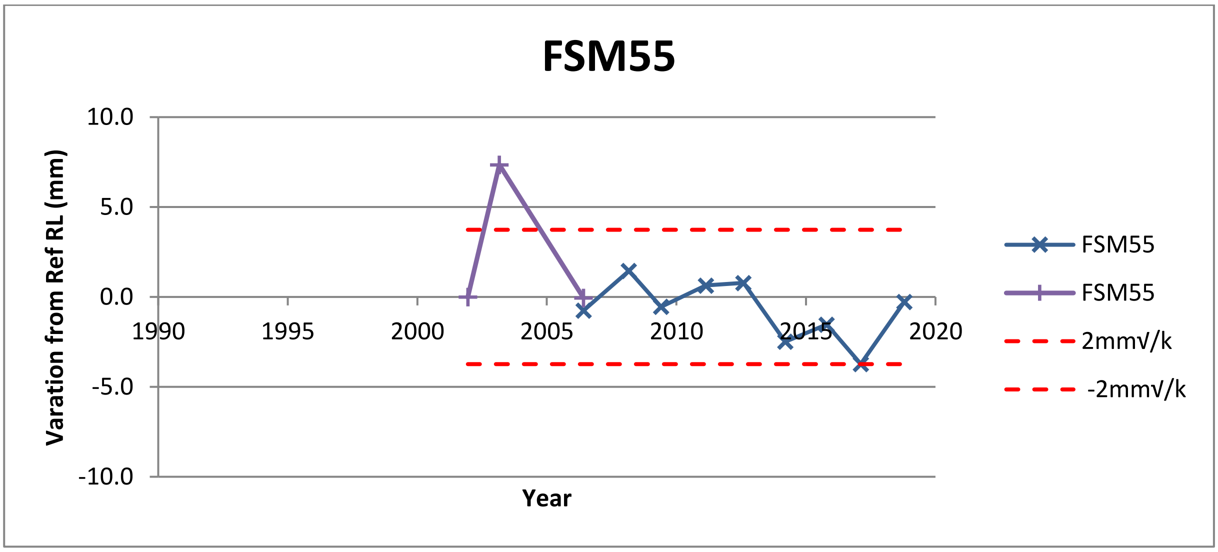



FSM3
Variation from Ref RL (mm)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
-5.0
-10.0
1990
1995
2000
2005
2010
2015
2020
Year
FSM3
FSM3
2mm√/k
-2mm√/k


FSM2
Variation from Ref RL (mm)
10.0
5.0
0.0
-5.0
-10.0
-15.0
1990
1995
2000
2005
2010
2015
2020
Year
FSM2
FSM2
2mm√/k
-2mm√/k


FSM1
Variation from Ref RL (mm)
10.0
5.0
0.0
-5.0
-10.0
1990
1995
2000
2005
2010
2015
2020
Year
FSM1
FSM1
2mm√/k
-2mm√/k


FSM17
10.0
5.0
0.0
-5.0
-10.0
1990
1995
2000
2005
2010
2015
2020
Variation from Ref RL (mm)
Year
FSM17
FSM17
2mm√k
-2mm√k


FSM55
10.0
5.0
0.0
-5.0
-10.0
1990
1995
2000
2005
2010
2015
2020
Varation from Ref RL (mm)
Year
FSM55
FSM55
2mm√k
-2mm√k

6 Assessment of Results

After a full analysis of the monitoring and levelling survey results, the following conclusions can be drawn. There are several differences above 0.003 m:

- FSM4 to all other benchmarks, which is likely due to:
    - localised movement of FSM4 – which is located along the causeway; where there were some earth works done on the surrounding arears, which may have resulted on the movement.
- FSM3 to all other benchmarks, which is likely due to:
    - localised movement of FSM3 – which is in the Pohnpei fisheries compound; where there is movement oh heavy vehicle around the surrounding areas.

The survey from the primary GNSS BM (POHNBM) to the TG Plaque (FSM17) shows no statistically significant change in height. This means the wharf structure is stable, and any movement measured on the tide gauge is not due to deformation at the jetty.

The deep driven benchmark, FSM4 has subsided approximately 2 mm, since the previous survey, this may be due to local subsidence or construction and earthworks taken place around the area and along the causeway.

Table 6.1 Comparison of results with Reference ^H.

PT ID	Reference ^H (m)	2018.8 Value (m)	Difference
POHNBM - Primary BM (FSM1)	-35.5709	-35.5702	-0.0008
FSM1 - TG Plaque BM (FSM17)	0.6346	0.6314	-0.0032
FSM1 - TG ref pin (FSM55)	1.5940	1.5929	-0.0010
FSM17 - FSM55	0.9594	0.9615	0.0022
POHN - TG Plaque	-35.8883	-35.8908	0.0025
POHN - TG BM	-34.9289	-34.9292	0.0003
POHN - TGZ	-38.9547	-38.9549	0.0003

Table 6.2 List of height differences from POHNBM to primary benchmarks, and conversion to TGZ & ITRF2020

PT ID	Reference RL (m)	2018.8 Value (m)	Difference	ITRF2020	TGZ
POHNBM	0.0000	0.0000	0.0000	89.7312	38.0029
FSM5	-17.4151	-17.4154	-0.0003	72.3158	20.5875
FSM4	-36.2543	-36.2722	-0.0178	53.4590	1.7308
FSM3	-35.9427	-35.9472	-0.0045	53.7840	2.0557

FSM2	-35.6669	-35.6659	0.0011	54.0653	2.3370
FSM1	-35.5709	-35.5702	0.0008	54.1610	2.4328
FSM17	-34.9363	-34.9388	-0.0024	54.7924	3.0642
FSM55	-33.9770	-33.9772	-0.0003	55.7540	4.0257
POHN	0.9520	0.9520	0.0000	90.6832	38.9549
RM1	-0.5696	-0.5707	-0.0011	89.1605	37.4323
RM2	-1.2231	-1.2232	-0.0001	88.5080	36.7797
RM4	-0.8492	-0.8492	0.0000	88.8820	37.1537
TGZ	-38.0027	-38.0029	-0.0003	51.7283	0.0000

7 Absolute height of the tide gauge

When combined, the GNSS and levelling data provide information about the absolute movement of the tide gauge. This information can be used by the Bureau of Meteorology to translate relative sea level into absolute sea level.

7.1 GNSS time series analysis

The ellipsoidal height of the GNSS pillar is computed using Geoscience Australia's weekly cumulative GNSS solution and modelled using Chebyshev polynomials[2] (Figure 7.1). Uncertainty regions (95% confidence) were determined using the residuals with respect to the polynomial model. Large outliers (>50cm) were removed manually as they have a significant impact on the estimated uncertainties. The ellipsoidal heights are with respect to the International Terrestrial Reference Frame 2020 (ITRF2020).

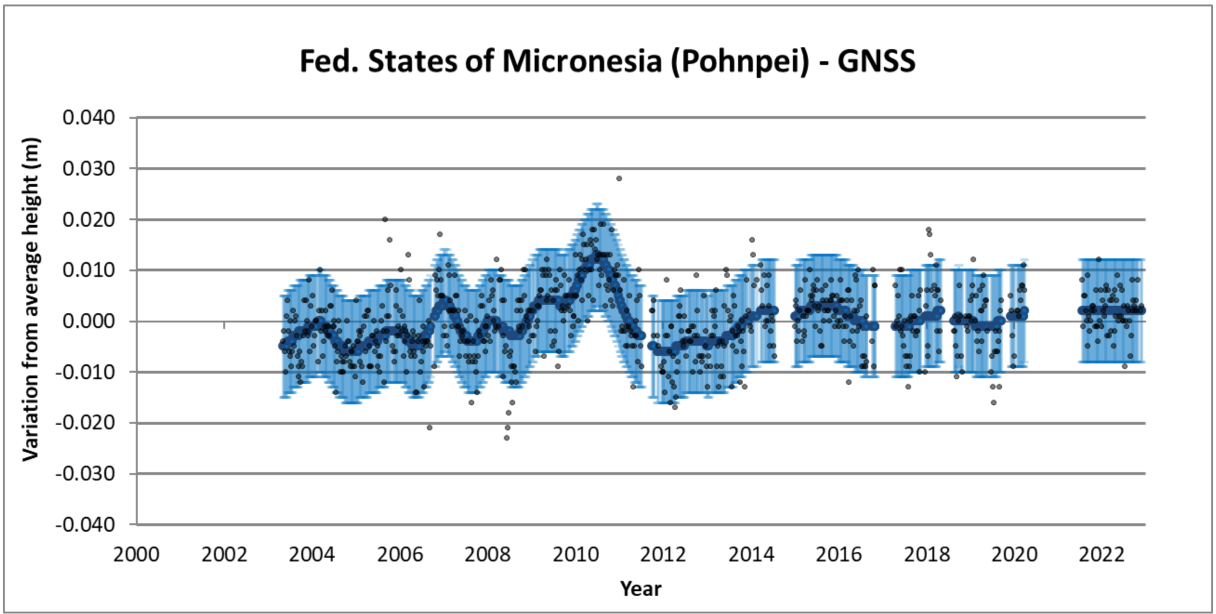


Figure 7.1 Time series of GNSS analysis (dark blue line) with 95%CI uncertainty (light blue lines).

[2] The order of the polynomial was determined iteratively by evaluating the significance of the improvement in model misfit Chi-Squared by an F test. The number of terms used in the preferred models ranged from 2 (i.e. linear) to 10 across the analysed time series and depends on the complexity of the observed signal.

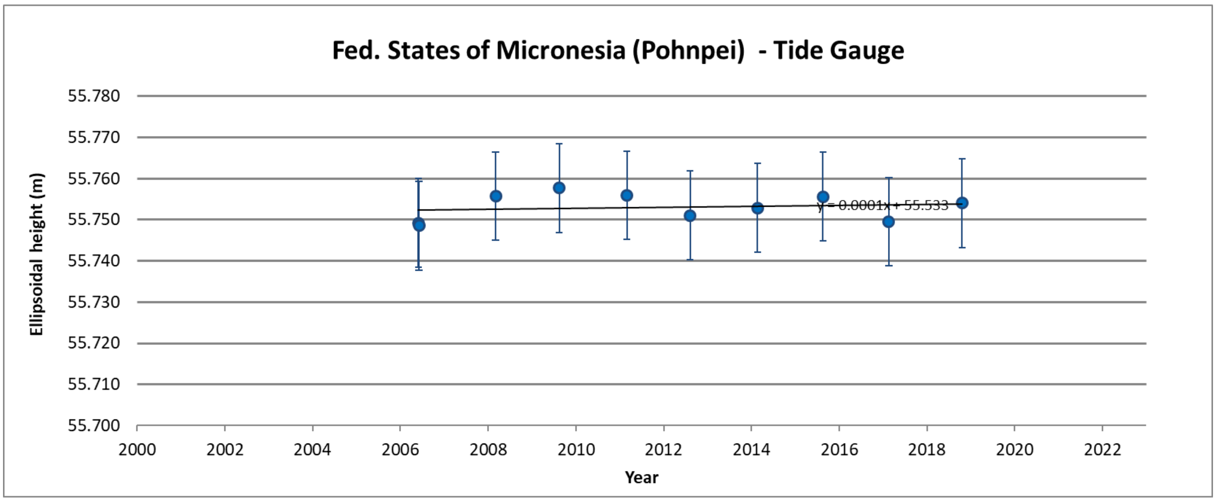


Figure 7.2 The height of the SEAFRAME sensor reference benchmark (with respect to ITRF2020).

The height of the SEAFRAME sensor reference benchmark is the sum of the ellipsoidal height of the GNSS pillar plate and the levelled height difference between the GNSS pillar plate and SEAFRAME sensor reference benchmark (Figure 7.2; Table 7.1))[3]. The height uncertainty is the combined uncertainty from the GNSS analysis and the levelling.

Table 7.1 Height of the SEAFRAME sensor reference benchmark (and 95%CI uncertainty) derived from GNSS time series analysis and levelling. Height is with respect to the International Terrestrial Reference Frame 2014.

Date	Height (m)	Uncertainty (95%CI) (m)
2006.41	55.7492	0.011
2006.42	55.7485	0.011
2008.17	55.7557	0.011
2009.62	55.7577	0.011
2011.16	55.7559	0.011
2012.60	55.7510	0.011
2014.14	55.7528	0.011
2015.63	55.7556	0.011
2017.13	55.7495	0.011
2018.80	55.7540	0.011

[3] It is recognised that the height of the SEAFRAME sensor reference benchmark is the sum of the geometric GNSS ellipsoidal height and the physical orthometric levelling height. No geoid corrections were applied to the levelling data because of the short distance of the levelling run and the lack of high-resolution gravity data in this region.

8 References

Brown, N. J., Lal, A., Thomas, B., McClusky, S., Dawson, J., Hu, G., and Jia, M. 2020. Vertical motion of Pacific Island tide gauges: combined analysis from GNSS and levelling. Record 2020/03. Geoscience Australia, Canberra. http://dx.doi.org/10.11636/Record.2020.003

Fraser, R., Leahy, F., Collier, P., 2018. *DynAdjust User's Guide Version 3.0*. Dynamic Network Adjustment Software.

Intergovernmental Committee on Surveying and Mapping (ICSM) 2021, Guideline for Conventional Traverse Surveys – SP1 V2.2.

Rüeger, J.M. & Brunner, F.K. 1982, '*EDM Height Traversing versus Geodetic Levelling'*, The Canadian Surveyor, vol. 36, no. 1, pp. 69-87.

Rueger, J. M., Brunner, F. K., 1981. *Practical Results from EDM-Height Traversing*. The Australian Surveyor. June 1981, Vol. 30, No 6.

.

Appendix A Locality Diagrams

Source: Google Maps

A 1 Deep Benchmarks

PACIFIC SEA LEVEL MONITORING PROJECT

Australian Aid

Australian Government
Geoscience Australia

SPC Secretariat of the Pacific Community

SURVEY BENCH MARK RECORD

Bench Mark Number: FSM1

Original Bench Mark Established by: *Date: 12/12/2001*
National Tidal Centre Australia, Oceanographic Services,
Bureau of Meteorology, 25 college Rd, Kent Town, SA.

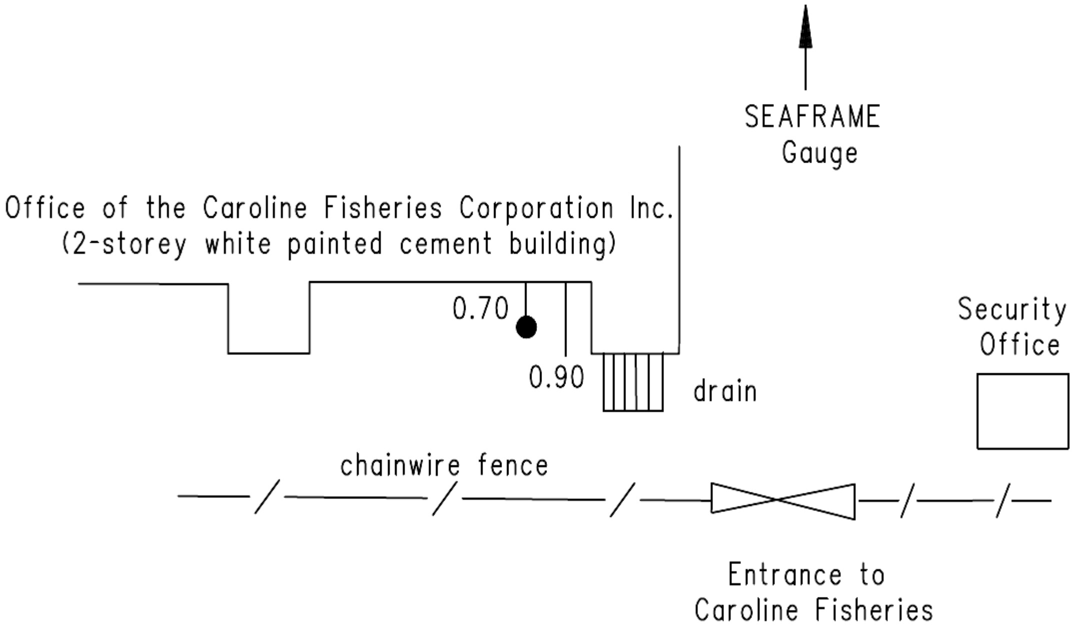
Existing Bench Mark Established by: *Date:*

Notes / References: Deep Survey Benchmark
This survey mark is not in a good locality for GNSS occupation

Country: Federated States of Micronesia
Island: Pohnpei *City: Kolonia*

MARKING AND LOCALITY SKETCH

Bench Mark: 1.5m of 19mm diameter stainless steel capped rod driven until refusal. Rod sheathed with 50mm diameter PVC pipe, filled with bentonite, for 0.5m, top of mark 0.1m below ground level. Locality sketch Mark approximately 125m from the tide gauge station. Not to scale distances in meters & Magnetic bearing



NOT TO SCALE Distances in Metres Magnetic Bearings

Approved by: Geoscience Australia / SPC *Date: Nov 2008*

PACIFIC SEA LEVEL MONITORING PROJECT

Australian Aid

Australian Government
Geoscience Australia

SPC Secretariat of the Pacific Community

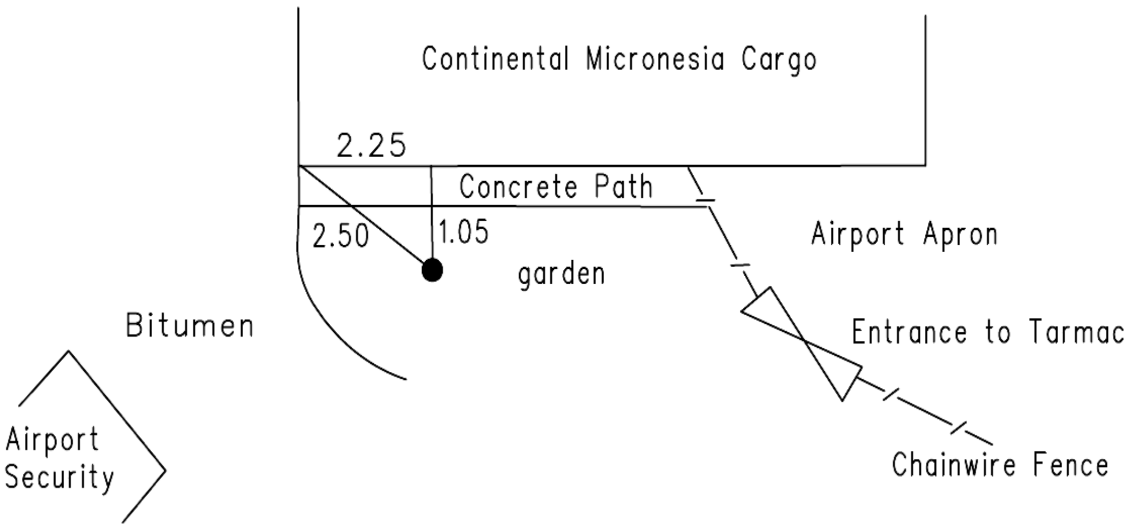
SURVEY BENCH MARK RECORD

Bench Mark Number: FSM2

Original Bench Mark Established by: National Tidal Centre Australia, Oceanographic Services, Bureau of Meteorology, 25 college Rd, Kent Town, SA.	*Date: 12/12/2001*
Existing Bench Mark Established by:	*Date:*
Notes / References: Deep Survey Benchmark This survey mark is not in a good locality for GNSS occupation	
Country: Federated States of Micronesia *Island: Pohnpei*	*City: Kolonia*

MARKING AND LOCALITY SKETCH

Bench Mark: 9.1m of 19mm diameter stainless steel capped rod driven until refusal. Rod sheathed with 50mm diameter PVC pipe, filled with bentonite, for 0.5m, top of mark 0.1m below ground level. Locality sketch Mark approximately 425m from the tide gauge station. Not to scale distances in meters & Magnetic bearing



NOT TO SCALE   Distances in Metres   Magnetic Bearings

Approved by: Geoscience Australia / SPC   *Date: Nov 2008*

PACIFIC SEA LEVEL MONITORING PROJECT

Australian Aid | Australian Government Geoscience Australia | SPC Secretariat of the Pacific Community

SURVEY BENCH MARK RECORD

Bench Mark Number: FSM3

Original Bench Mark Established by: *Date: 11/12/2001*
National Tidal Centre Australia, Oceanographic Services,
Bureau of Meteorology, 25 college Rd, Kent Town, SA.

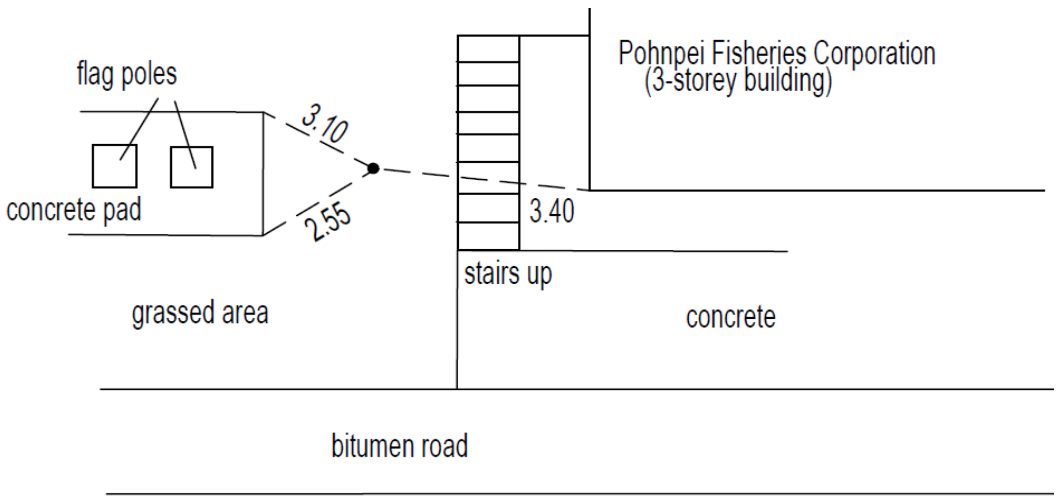
Existing Bench Mark Established by: *Date:*

Notes / References: Deep Survey Benchmark
This survey mark is not in a good locality for GNSS occupation

Country: Federated States of Micronesia
Island: Pohnpei *City: Kolonia*

MARKING AND LOCALITY SKETCH

Bench Mark: 5.4m of 19mm diameter stainless steel capped rod driven until refusal. Rod sheathed with 50mm diameter PVC pipe, filled with bentonite, for 0.5m, top of mark 0.1m below ground level. Locality sketch Mark approximately 750m from the tide gauge station. Not to scale distances in meters & Magnetic bearing



NOT TO SCALE Distances in Metres Magnetic Bearings

Approved by: Geoscience Australia / SPC *Date: Nov 2008*

PACIFIC SEA LEVEL MONITORING PROJECT

Australian Government
Geoscience Australia

SPC Secretariat of the Pacific Community

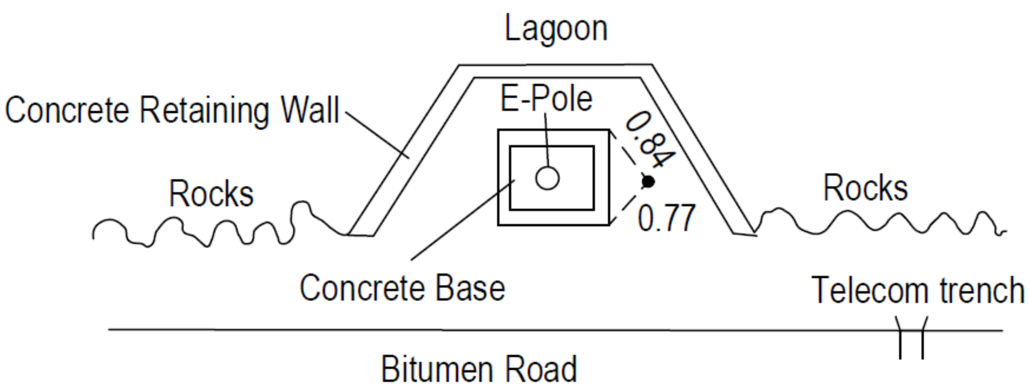
SURVEY BENCH MARK RECORD

Bench Mark Number: FSM4

Original Bench Mark Established by: National Tidal Centre Australia, Oceanographic Services, Bureau of Meteorology, 25 college Rd, Kent Town, SA.	*Date: 12/12/2001*
Existing Bench Mark Established by:	*Date:*
Notes / References: Deep Survey Benchmark This survey mark is in a good locality for GNSS occupation	
Country: Federated States of Micronesia *Island: Pohnpei*	*City: Kolonia*

MARKING AND LOCALITY SKETCH

Bench Mark: 7.0m of 19mm diameter stainless steel capped rod driven until refusal. Rod sheathed with 50mm diameter PVC pipe, filled with bentonite, for 0.5m, top of mark 0.1m below ground level. Locality sketch Mark approximately 1625m from the tide gauge station. Not to scale distances in meters & Magnetic bearing



NOT TO SCALE Distances in Metres Magnetic Bearings

Approved by: Geoscience Australia / SPC *Date: Nov 2008*

PACIFIC SEA LEVEL MONITORING PROJECT

Australian Government
Geoscience Australia

SPC
Secretariat of the Pacific Community

Australian Aid

SURVEY BENCH MARK RECORD

Bench Mark Number: FSM5

Original Bench Mark Established by: *Date: 17/12/2001*
National Tidal Centre Australia, Oceanographic Services,
Bureau of Meteorology, 25 college Rd, Kent Town, SA.

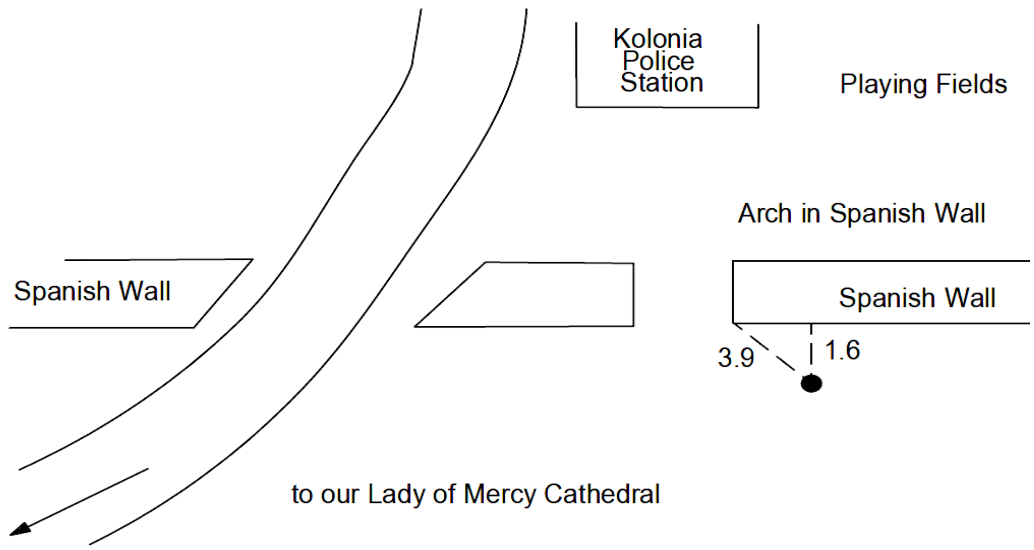
Existing Bench Mark Established by: *Date:*

Notes / References: Deep Survey Benchmark
This survey mark is in a good locality for GNSS occupation

Country: Federated States of Micronesia
Island: Pohnpei *City: Kolonia*

MARKING AND LOCALITY SKETCH

Bench Mark: 3.4m of 19mm diameter stainless steel capped rod driven until refusal. Rod sheathed with 50mm diameter PVC pipe, filled with bentonite, for 0.5m, top of mark 0.1m below ground level. Locality sketch Mark approximately 2700m from the tide gauge station. Not to scale distances in meters & Magnetic bearing

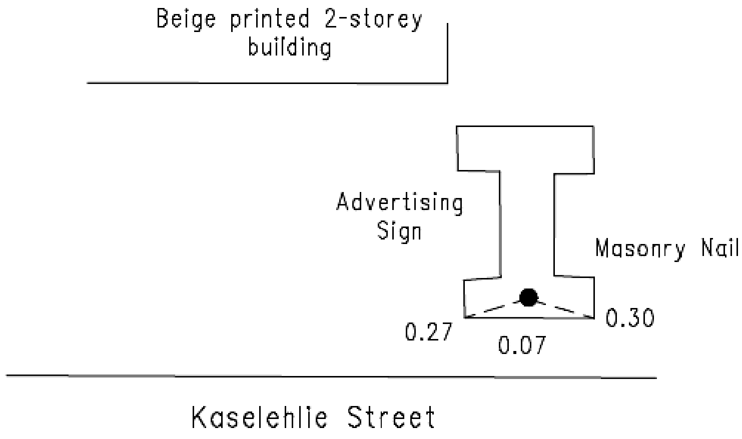


NOT TO SCALE Distances in Metres Magnetic Bearings

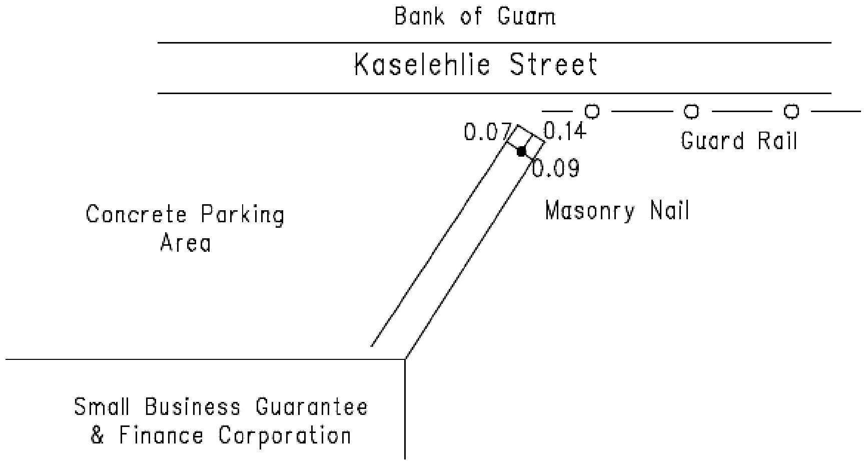
Approved by: Geoscience Australia / SPC *Date: Nov 2008*

A 2 Temporary Holdings Marks

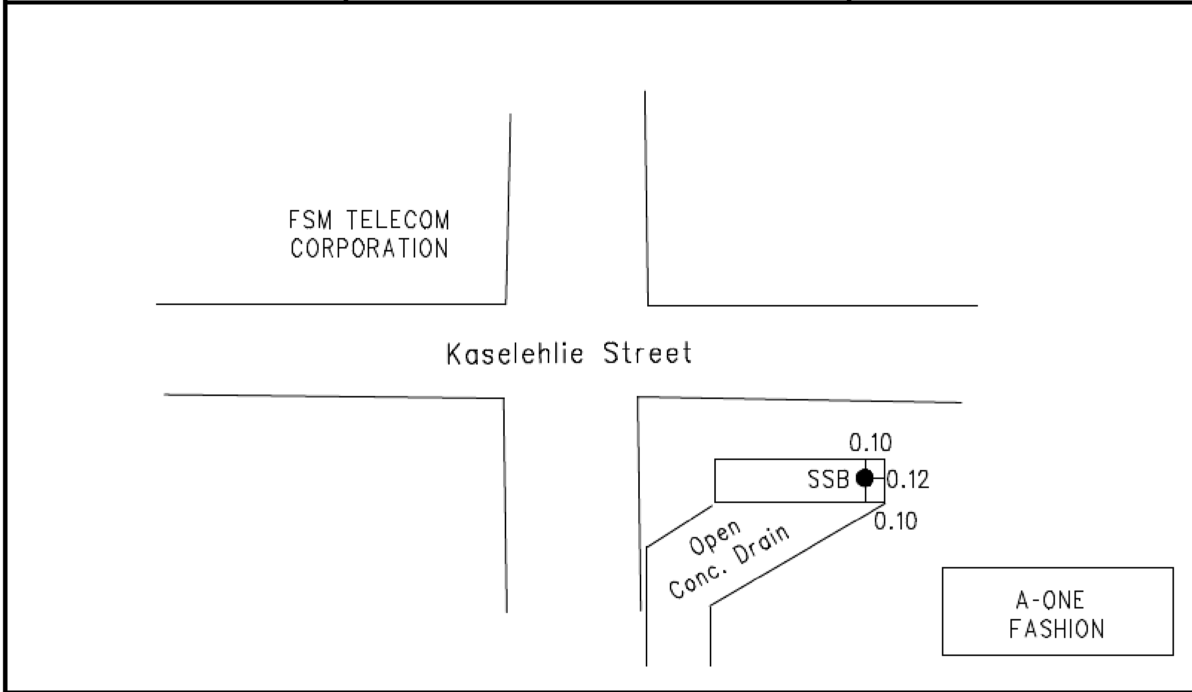
COUNTRY: FSM	ISLAND: Pohnpei CITY: Kolonia	L. D. P. POINT NO. FSM51
PROJECT: SPSLCMP	SURVEYOR: M. Deo & A. Lal	DATE: 14-08-09



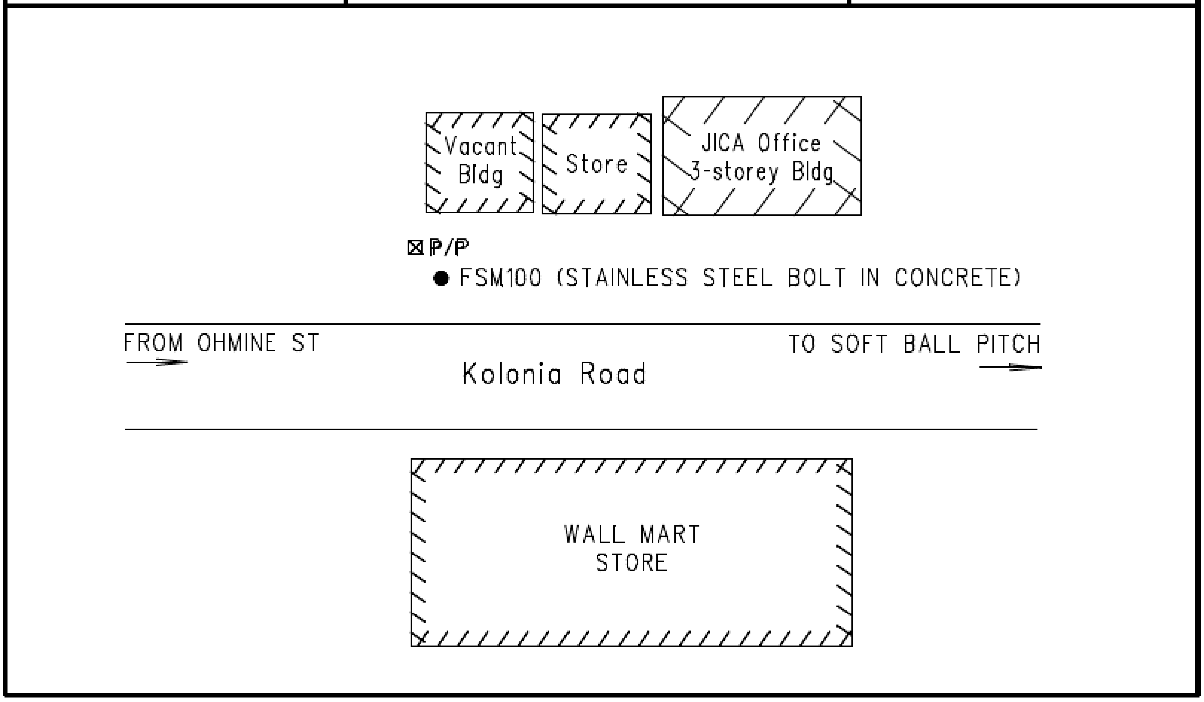
COUNTRY: FSM	ISLAND: Pohnpei CITY: Kolonia	L. D. P. POINT NO. FSM47
PROJECT: SPSLCMP	SURVEYOR: M. Deo & A. Lal	DATE: 14-08-09



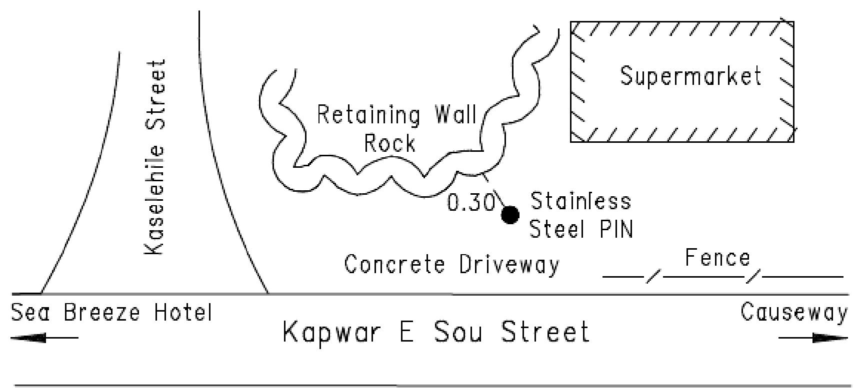
COUNTRY: FSM	ISLAND: Pohnpei CITY: Kolonia	L. D. P. POINT NO. FSM44
PROJECT: SPSLCMP	SURVEYOR: M. Deo & A. Lal	DATE: 14-08-09



COUNTRY: FSM	ISLAND: Pohnpei CITY: Kolonia	L. D. P. 850 POINT NO. FSM100
PROJECT: SPSLCMP	SURVEYOR: M. Deo & A. Lal	DATE: 14-08-09



COUNTRY: FSM	ISLAND: Pohnpei CITY: Kolonia	L. D. P. POINT NO. FSM34
PROJECT: SPSLCMP	SURVEYOR: M. Deo & A. Lal	DATE: 14-08-09



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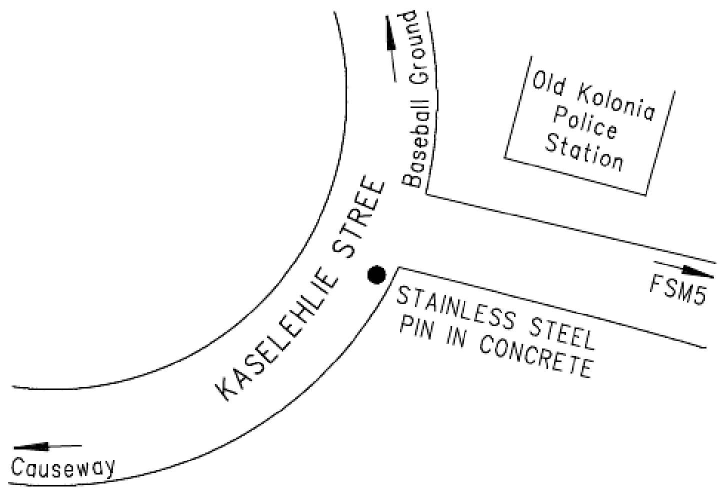
PROJECT: SPSLCMP	SURVEYOR: M. Deo & A. Lal	DATE: 14-08-09



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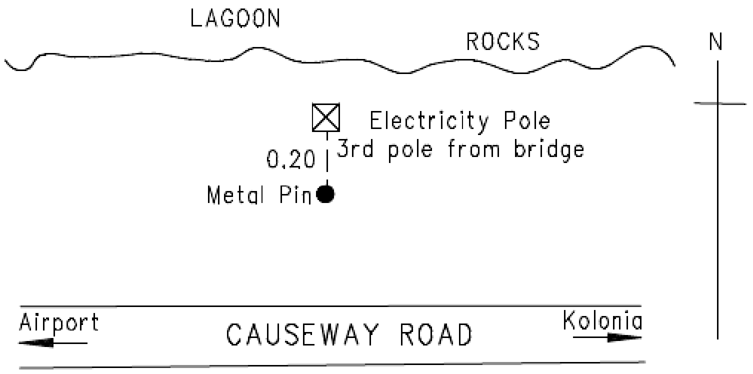
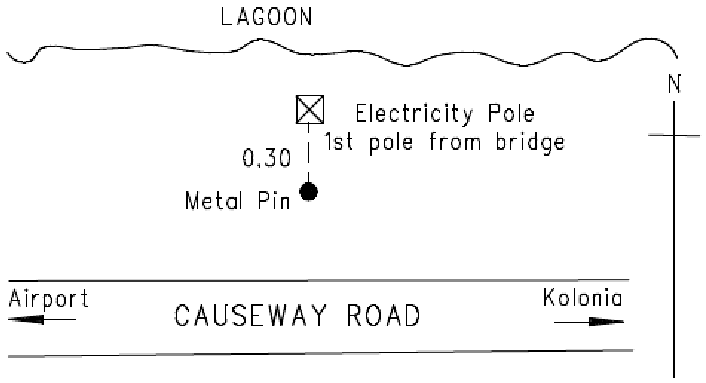
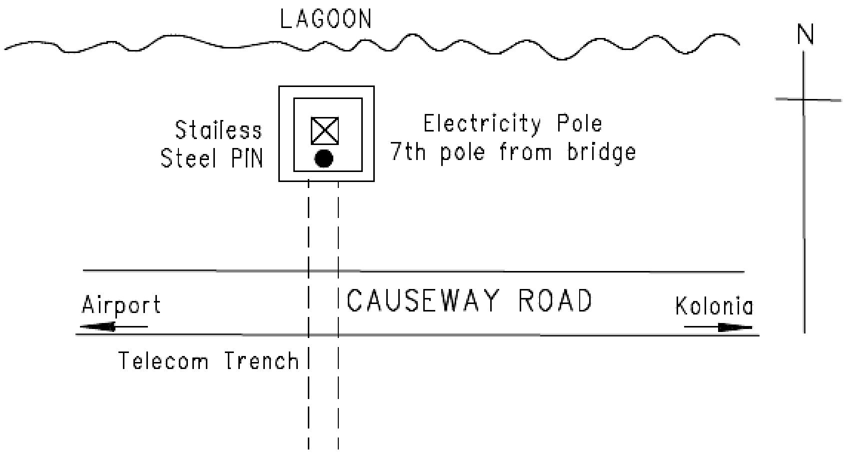
PROJECT: SPSLCMP	SURVEYOR: Yate. S & A. Lal	DATE: 14-08-09



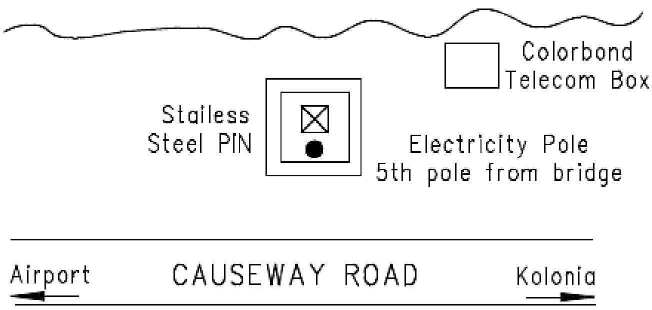
COUNTRY: FSM	ISLAND: Pohnpei CITY: Kolonia	L. D. P. 850 POINT NO. FSM31
PROJECT: SPSLCMP	SURVEYOR: M. Deo & A. Lal	DATE: 14-08-09



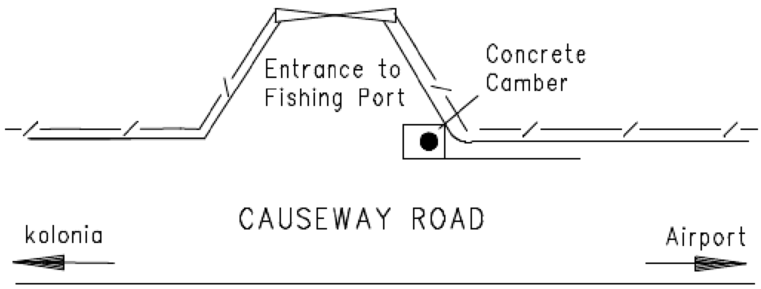
COUNTRY: FSM	ISLAND: Pohnpei CITY: Kolonia	L. D. P. POINT NO. FSM25
PROJECT: SPSLCMP	SURVEYOR: M. Deo & A. Lal	DATE: 14-08-09



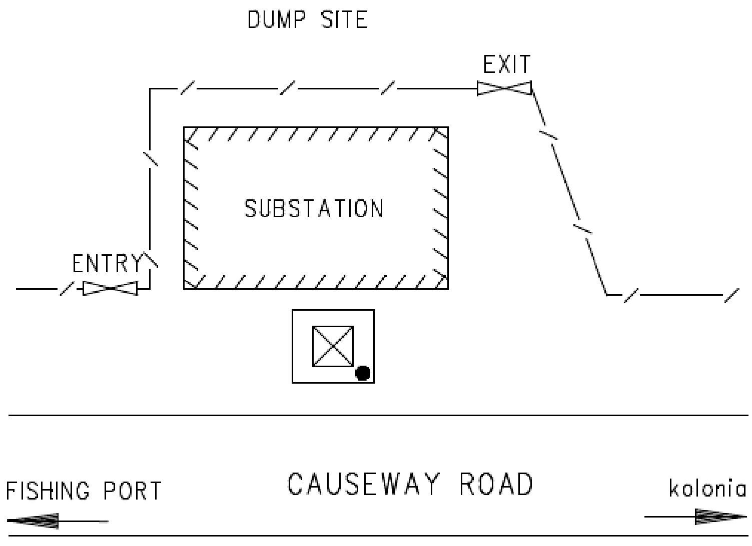
COUNTRY: FSM	ISLAND: Pohnpei CITY: Kolonia	L. D. P. POINT NO. FSM27
PROJECT: SPSLCMP	SURVEYOR: M. Deo & A. Lal	DATE: 14-08-09



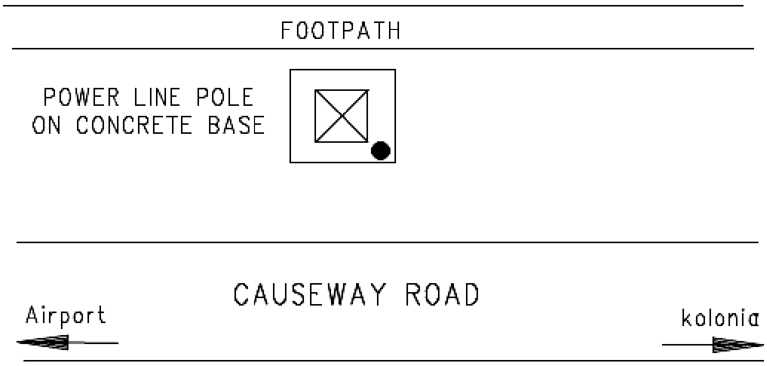
COUNTRY: FSM	ISLAND: Pohnpei CITY: Kolonia	L. D. P. POINT NO. FSM10
PROJECT: SPSLCMP	SURVEYOR: M. Deo & A. Lal	DATE: 14-08-09



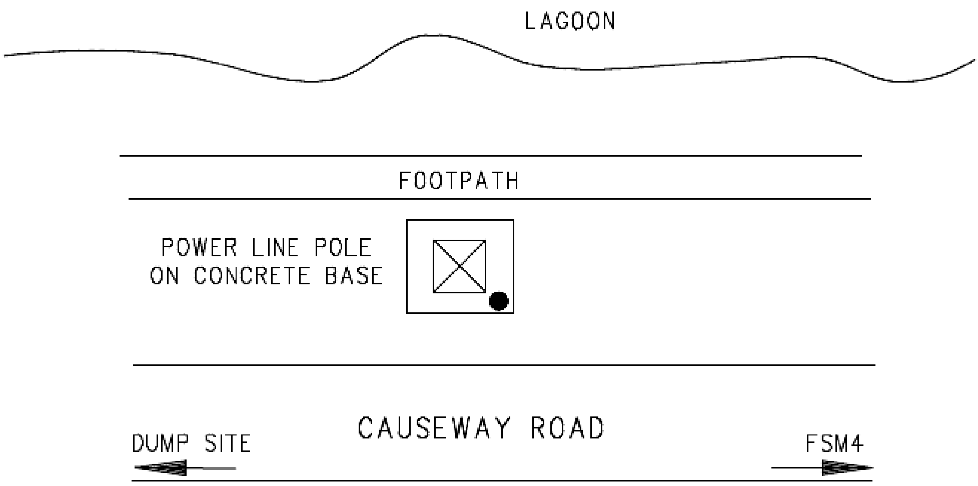
COUNTRY: FSM	ISLAND: Pohnpei CITY: Kolonia	L. D. P. POINT NO. FSM11
PROJECT: SPSLCMP	SURVEYOR: M. Deo & A. Lal	DATE: 14-08-09



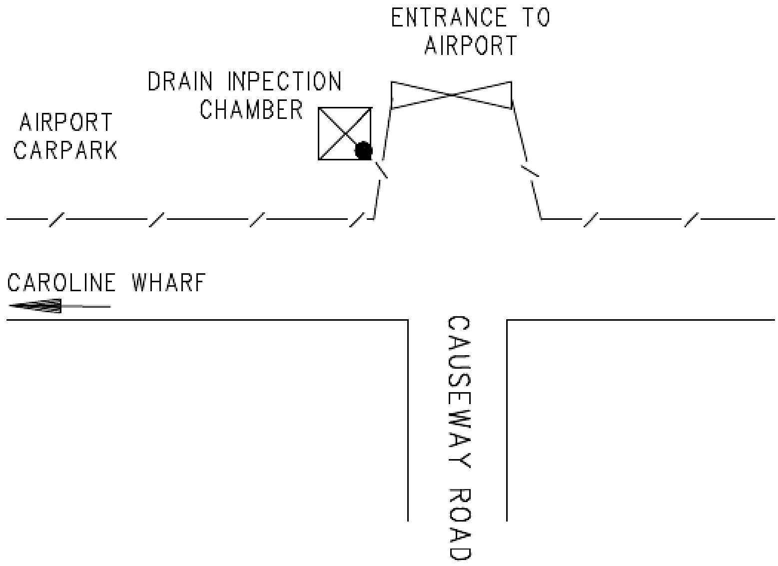
COUNTRY: FSM	ISLAND: Pohnpei CITY: Kolonia	L. D. P. 850 POINT NO. FSM13
PROJECT: SPSLCMP	SURVEYOR: M. Deo & A. Lal	DATE: 14-08-09



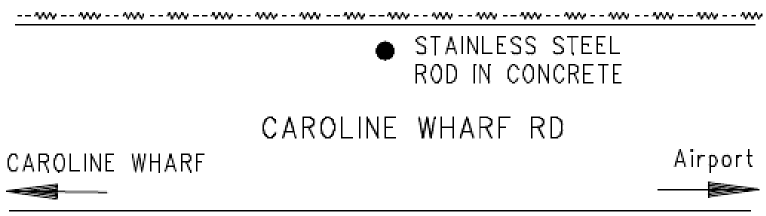
COUNTRY: FSM	ISLAND: Pohnpei CITY: Kolonia	L. D. P. POINT NO. FSM15
PROJECT: SPSLCMP	SURVEYOR: M. Deo & A. Lal	DATE: 14-08-09



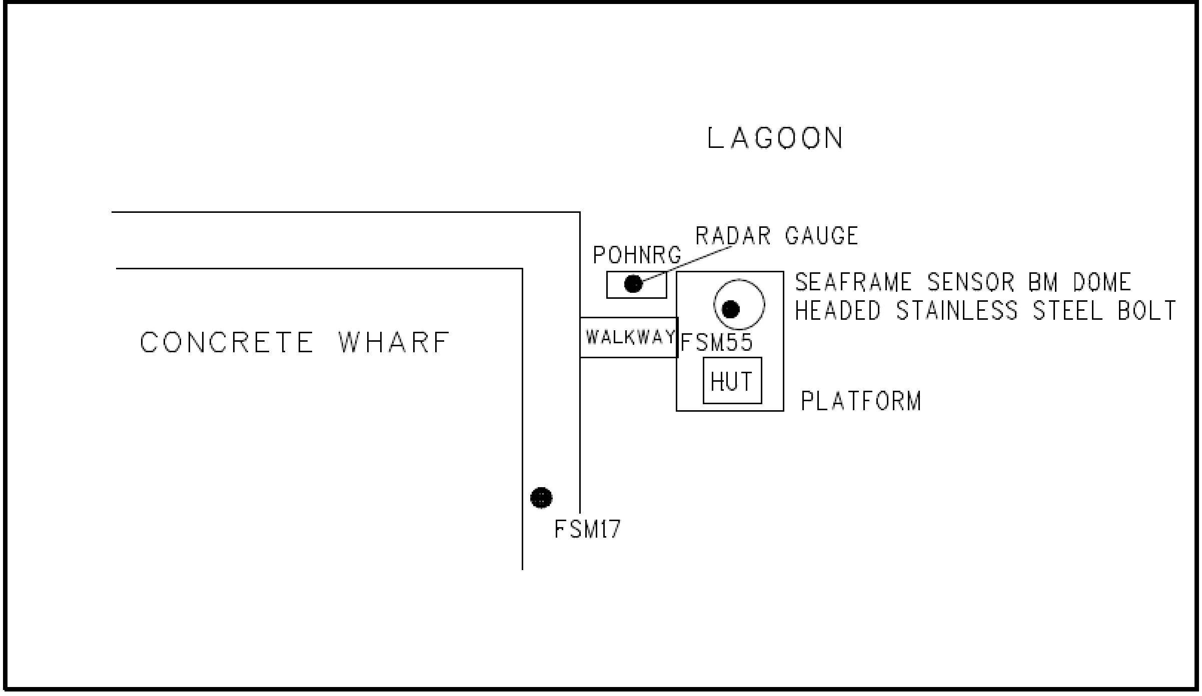
COUNTRY: FSM	ISLAND: Pohnpei CITY: Kolonia	L. D. P. 850 POINT NO. FSM8
PROJECT: SPSLCMP	SURVEYOR: M. Deo & A. Lal	DATE: 14-08-09



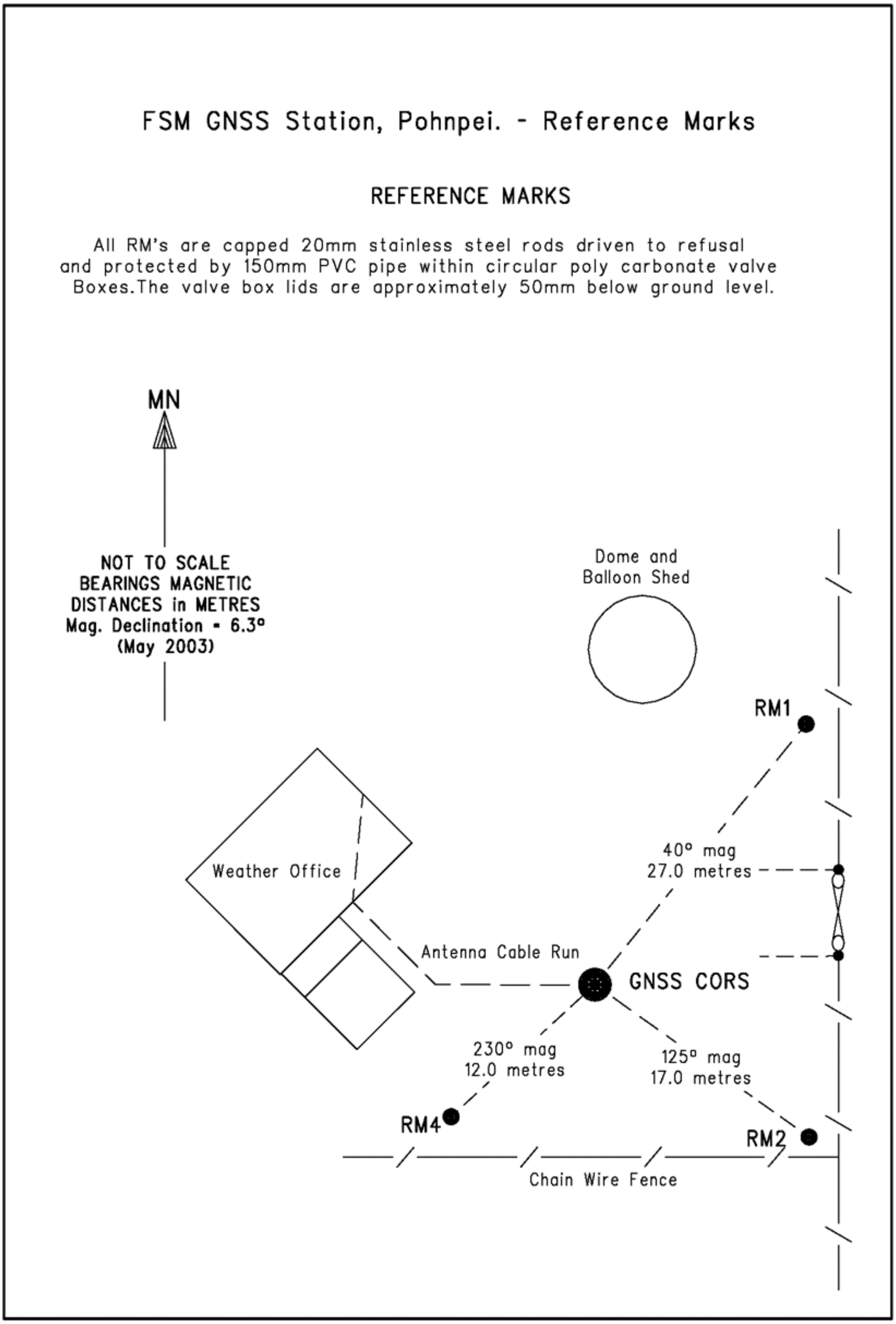
COUNTRY: FSM	ISLAND: Pohnpei CITY: Kolonia	L. D. P. POINT NO. FSM999
PROJECT: SPSLCMP	SURVEYOR: AL, MK, & VR	DATE: 14-08-09



COUNTRY: FSM	ISLAND: Pohnpei CITY: Kolonia	L. D. P. POINT NO. FSM55/17
PROJECT: SPSLCMP	SURVEYOR: M. Deo & A. Lal	DATE: 14-08-09



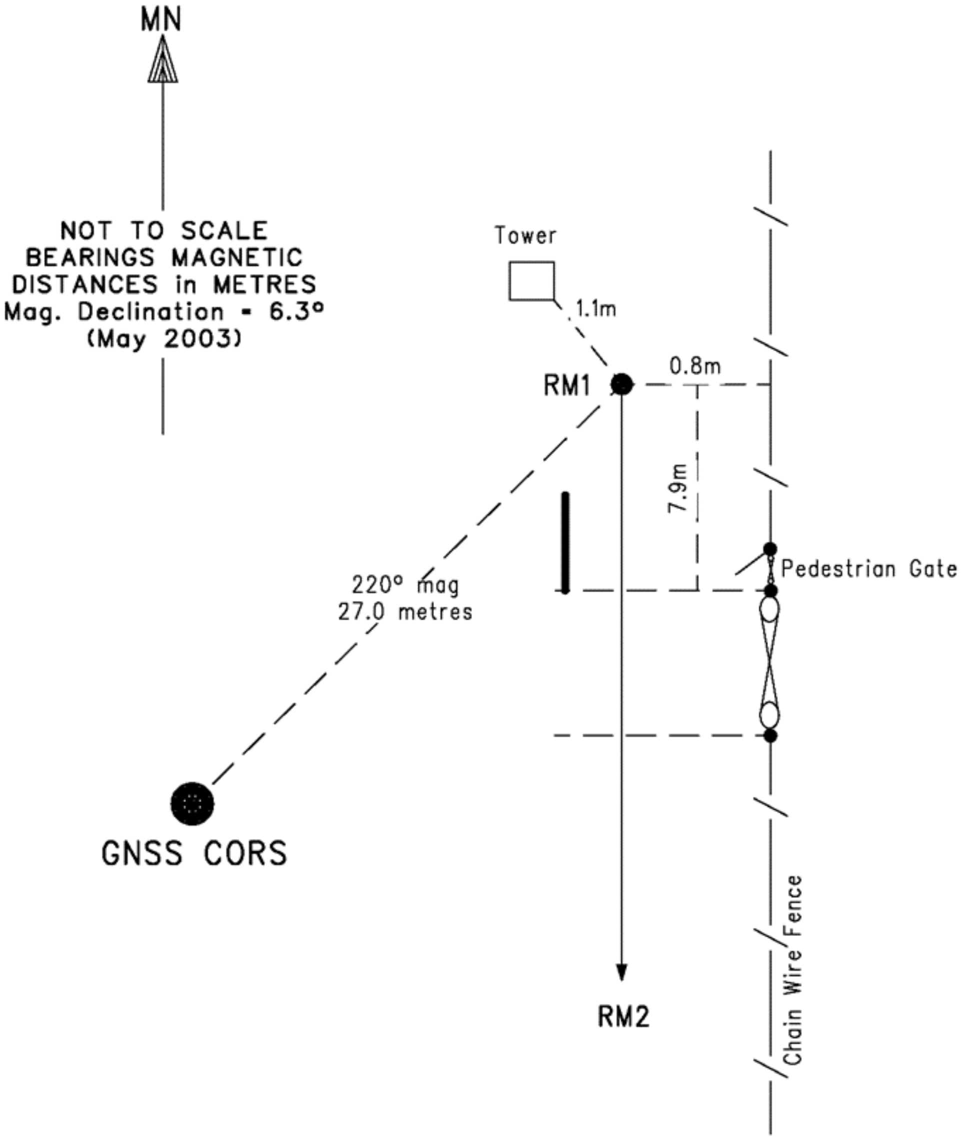
A 3 GNSS Site Reference Marks

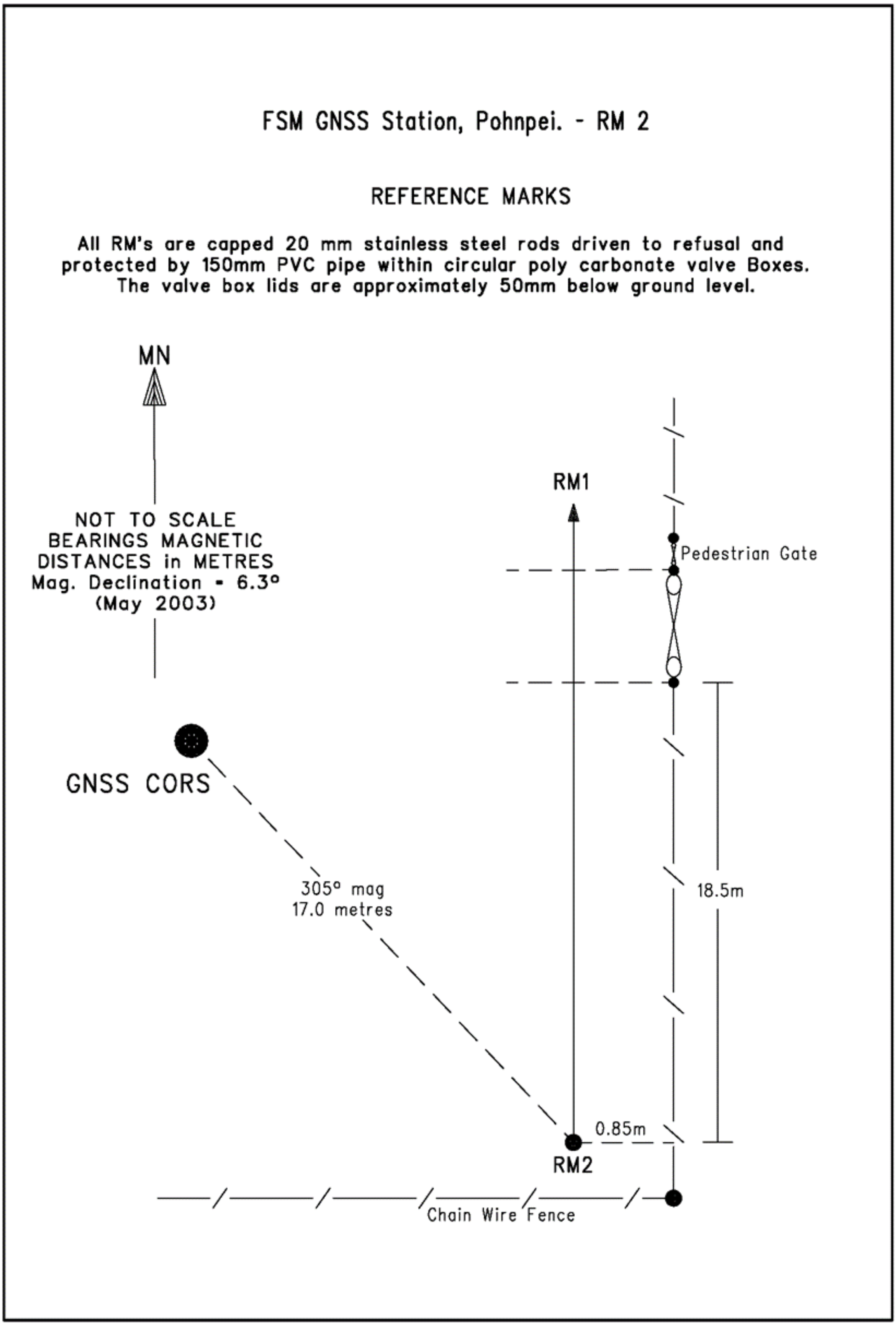


FSM GNSS Station, Pohnpei. - RM 1

REFERENCE MARKS

All RM's are capped 20 mm stainless steel rods driven to refusal and protected by 150mm PVC pipe within circular poly carbonate valve Boxes. The valve box lids are approximately 50mm below ground level.

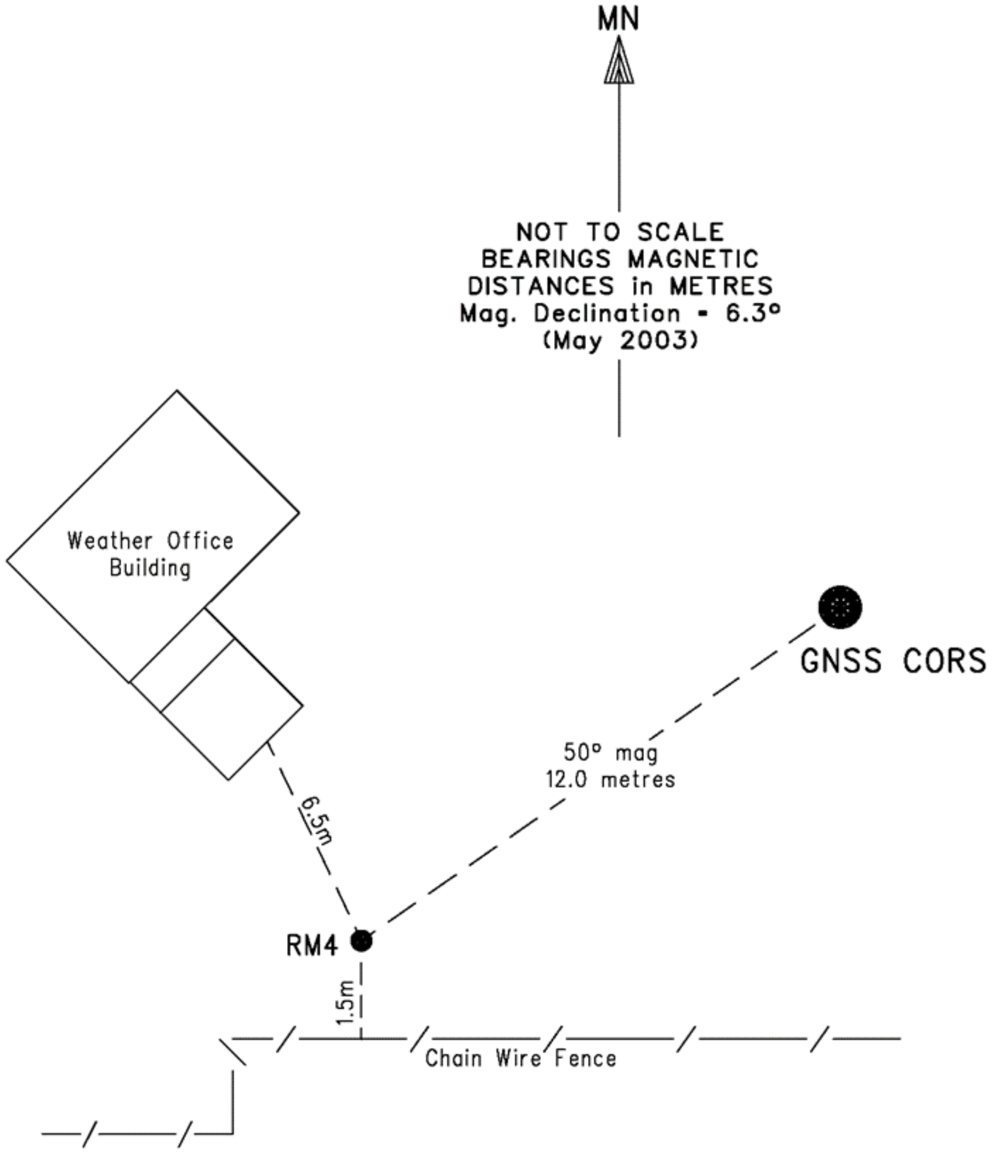



FSM GNSS Station, Pohnpei. - RM 2
REFERENCE MARKS
All RM's are capped 20 mm stainless steel rods driven to refusal and protected by 150mm PVC pipe within circular poly carbonate valve Boxes. The valve box lids are approximately 50mm below ground level.
MN
NOT TO SCALE
BEARINGS MAGNETIC
DISTANCES in METRES
Mag. Declination = 6.3°
(May 2003)
RM1
Pedestrian Gate
GNSS CORS
305° mag
17.0 metres
18.5m
0.85m
RM2
Chain Wire Fence

FSM GNSS Station, Pohnpei. - RM 4

REFERENCE MARKS

All RM's are capped 20mm stainless steel rods driven to refusal and protected by 150mm PVC pipe within circular poly carbonate valve Boxes.The valve box lids are approximately 50mm below ground level.



Appendix B Planning Aspects and Notes

Upon arranging travel to Pohnpei (FSM), make contact with the project focal point of contact at the Survey Office and the Weather Office in country at least one month in advance.

Prior arrangements with the local counterpart should be made for the clearance of the survey equipment from the Customs Authority when it is shipped across. The local SPC office has been very helpful in receiving and storing the equipment until the survey team arrives. The vehicle was hired through SPC North Regional Office

Three tripods are stored with the FSM National Weather Office for the purpose of the RM levelling survey. Please contact Maintenance Manager of FSM Weather Office to access the tripods. These should be cleaned and returned to store here after use.

Access to the GNSS CORS site should be made upon the approval of the FSM National Weather Office Director, being mindful of office hours and gate closed during weekends

Prior to accessing the tide gauge and conducting works in the wharf area, a courtesy call should be made to the Caroline Shipping Authority to advice on working times and intent

The following list of survey equipment is now in the country for future field surveys:-

Quantity	Item & description	Locations
1	**Tool Box**	Tide Gauge Station Hut.
2	*Prism Pole Clamps*	*Tools used by C&M Teams (Bureau & SPC)*
1	*50m Measuring Tape*	
1	*Engineers Hammer*	
1	*Carpenters Hammer*	
1	*Set of Allen Keys*	
1	*Torx Drivers*	
2	*Multigrips pliers*	
1	*Set of Screw Drivers*	
1	**PVC Pipe (1.2m)**	SPC office Pohnpei
1	*Aluminium GST6 tripod with Feet*	
1	**PVC Pipe (1.7m)**	SPC Office Pohnpei
1	*Ground Base Plate*	
4	*Telescopic-Bi-pods*	
2	*Stainless-steel levelling prism poles*	
1	*Half Stainless-steel levelling prism pole*	
3	**Black Bags - Leica GST20 Telescopic Tripods**	Weather Office Pohnpei
1	**Green Bag - Leica GST40 Rigid Tripod**	SPC Office Pohnpei
1	**Spade**	Weather Office Pohnpei
1	**Crowbar**	Weather Office Pohnpei

Appendix C Equipment Specifications

Tachymeters, EDM and Theodolites

A Leica TM30 (S/N 361441) Total Station was used to record all angles and distance measurements.

Specification

- EDM (infrared) distance standard deviation of a single measurement (DIN 18723, part 6): 0.6 mm ± 1 ppm.
- Angular standard deviation of a mean direction measured in both faces (DIN 18723, part 3): 0.3 mgon (≈ 1°).

Calibration

The Leica TM30 electronic distance measuring instrument (Serial No. 361441) was calibrated by the Australian National Measurement Institute (NMI) in July 2013. It was found to have an average error of $0.44\text{x}10^{-6}$ mm, which has been added to the total station.

Meteorological Sensor

Description

A NK Kestrel 4000 Pocket Weather Tracker (S/N 625479) was used to record meteorological observations (temperature, pressure and relative humidity).

Specification

- Temperature is accurate to 1.0°C between -29.0°C and 70.0°C.
- Pressure is accurate to 1.5 mb at 25°C between 750 mb and 1100 mb.
- Relative humidity is accurate to 3.0%.

Forced Centring

Description

An FG0L30 (S/N 609030) zenith and nadir optical plummet was used to centre and level all instrument and target setups.

Specification

- Accuracy is 1:30 000 (1 mm at 30 m).

Targets and Reflectors

Description

The standard target kit includes:

- 4 x Leica GDF21 tribrachs.
- 4 x Leica GZR3 prism carriers with optical plummet.
- 4 x Leica GPH1P precision prisms.

Calibration

The additive constant for the Leica GPH1P precision prism is -34.4 mm which was applied directly into the Leica TM30 Total Station. All prisms were calibrated on a tripod baseline at Geoscience Australia in July 2009. Approximate prism corrections of 0.0 mm were applied to observations during data processing.

Precision Levelling

Levelling Instruments

Refer to section 2.1 for a description of the Leica TM30 Total Station

Levelling Rods

A fixed height stainless steel rod (SP Primary Pole) approximately 1.6 m in height with Leica style bayonet mount on top for mounting a precision prism was used with a Leica bi-pod for stability.

A fixed height short stainless-steel rod (SP 1/2m TG Pole) approximately 0.5 m in height with Leica style bayonet mount on top for mounting a precision prism was used.

A height offset between the pole (SP Primary Pole) and the short pole (SP 1/2m TG Pole) was determined by observing both on a low mark. Multi-set, dual face observations were used to eliminate collimation effects. The resulting height offset was 1.00054m.

Tripods

Description

Leica GST20 heavy-duty timber tripods with adjustable legs was used on all marks, with the exception of the pillars, during the monitoring survey.

A Leica rigid timber tripod was used to mount the TM30 on for the purpose of this levelling survey.

Note: Three Leica adjustable leg tripods was left on site in the current GNSS hut for carrying out the associated RM horizontal survey.

GNSS Equipment

At the time of the survey, the GNSS equipment in use at the GNSS CORS site was:

POHN	-	JAVRINGANT_DM NONE antenna- S/N 02053
	-	Septentrio GNSS receiver SEPT POLARX5 Firmware Version 5.4.0-patch1 (S/N 3025122)