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

Lautoka, Fiji, January 2019

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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 Lautoka, Fiji from 9th to 16th January 2019. 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 30 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 Lautoka, which runs approximately 3.5 km. Previous levelling surveys have been conducted along this route using the Total Station differential levelling technique in 2005, 2007, 2008, 2010, 2011, 2013, 2014, 2016, 2017. This report contains an analysis of the 2019. 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 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 tide gauge are located within the FSC compound. The levelling run goes from tide gauge at the Queens wharf, through the Waterfront Road and into FSC compound where the GNSS CORS is located.

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Email:	Jeff.Aquilina@bom.gov.au
Phone:	+61 8 8366 2621

2.2 Survey Support

The survey team very much appreciate the assistance from the Ministry of Lands and Survey Office for their assistance during the survey and the senior management of the Ministry for their continued support.

3 Measurement Network

3.1 Terrestrial Network

The Total Station differential levelling survey was carried out between the GNSS CORS and the SEAFRAME Tide Gauge using 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
FIJ12	SEAFRAME project plaque benchmark
FIJ13	SEAFRAME sensor reference benchmark
BM3244	Deep driven benchmark
BM3245	Deep driven benchmark
BM3246	Deep driven benchmark
BM3247	Deep driven benchmark.
BM3248	Deep driven benchmark.
LAUTBM	Reference benchmark in the base of the GNSS CORS pillar
LAUT	Antenna Reference Point (ARP) of GNSS CORS Pillar
RM1	GNSS CORS reference mark 1
RM2	GNSS CORS reference mark 2
RM4	GNSS CORS reference mark 4

Upon inspection, all the deep driven benchmarks were located, found in good order, and undisturbed. All other temporary holding marks used in the previous survey were located as per locality diagrams.

3.1.1 PSLGMP Vertical Reference Frame Wiring Diagram

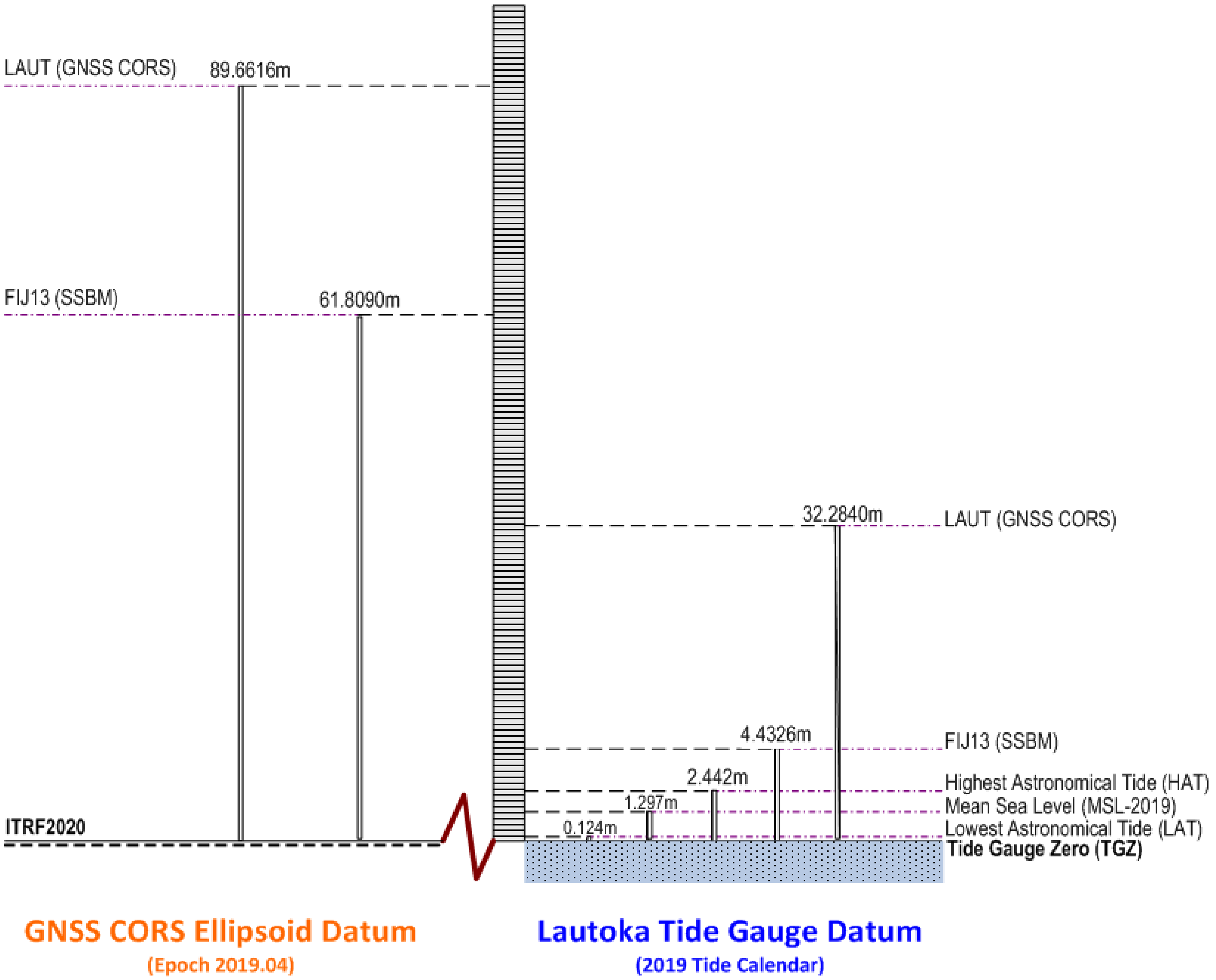


Figure 3.1 Wiring diagram depicting the offsets between surveyed marks. The left-hand side shows the height of the GNSS CORS pillar (LAUT), SEAFRAME sensor reference benchmark (FIJ13) with respect to the International Terrestrial Reference Frame 2020 at epoch 2019.04. The right-hand side shows the height of LAUT, FIJ13, 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)]

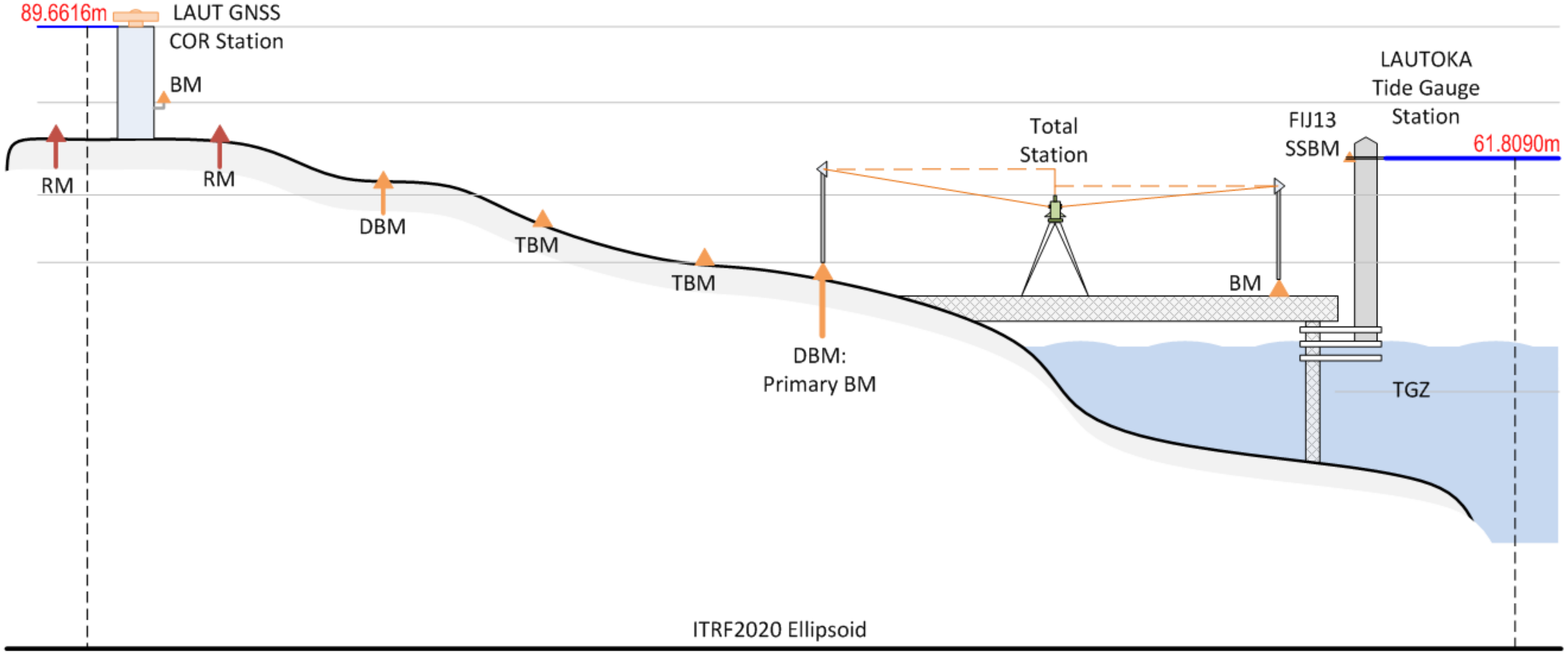


Figure 3.2 Simplified representation of the Total Station differential levelling survey carried out between the GNSS CORS and the SEAFRAME Tide Gauge.

Figure 3.3 Tide Gauge Station. The red circle denotes the location of the SEAFRAME sensor reference benchmark (FIJ13). Image from 2019.

Figure 3.4 GNSS CORS pillar. The red circle denotes the location of the GNSS CORS benchmark (LAUTBM). Image from 2019

3.1.2 Levelling Benchmark Network

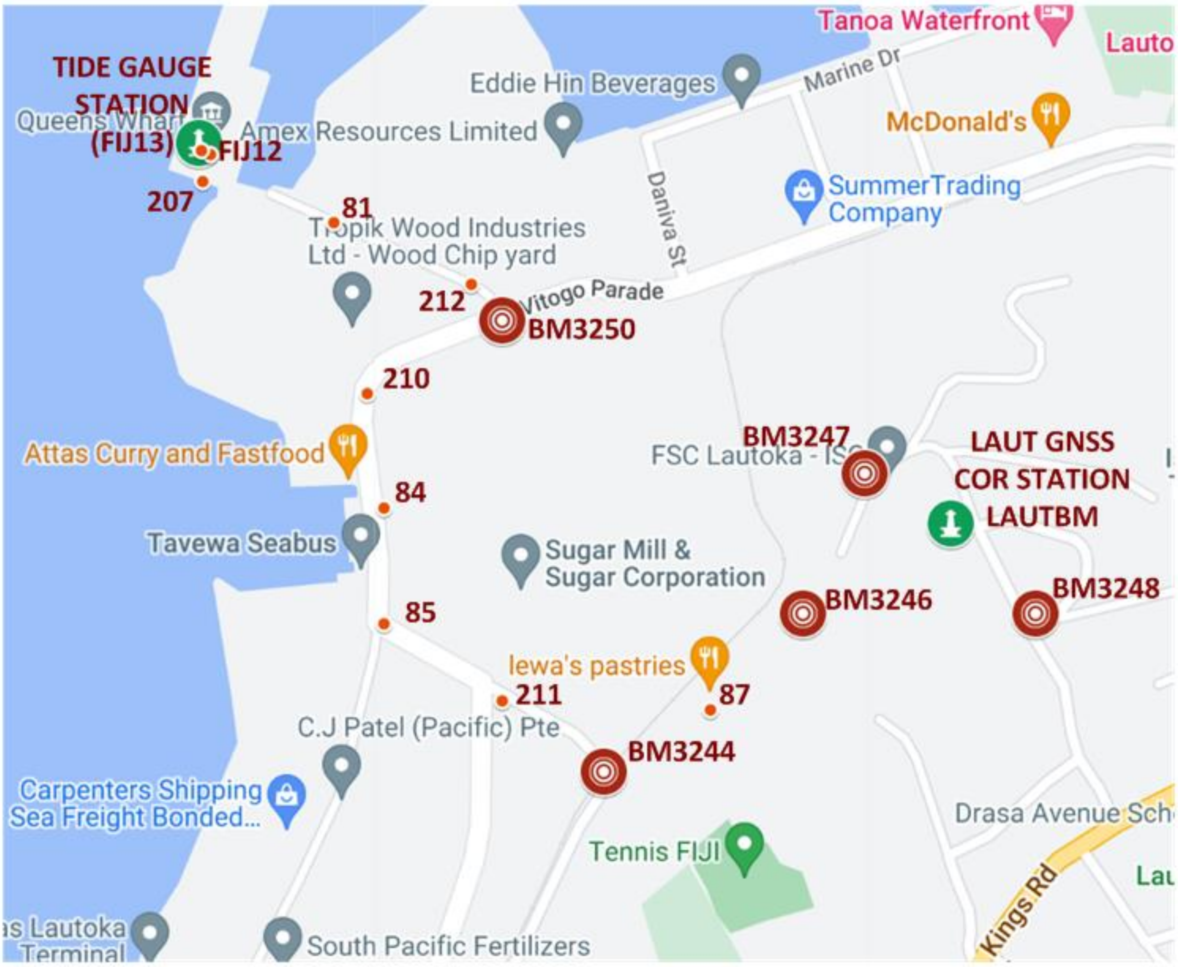


Figure 3.5 Levelling benchmark array. Source: Adopted from Google Maps.

3.1.3 GNSS CORS and Reference Marks

The GNSS CORS site is located within the Fiji Sugar Corporation compound. The site consists of a building to house the technical equipment and a 1.9 m GNSS CORS antenna pillar. The pillar is approximately 20 metres from the building. Access to the compound is by arrangement with the mill manager.

Three primary deep driven Reference Marks (RM) benchmarks were placed at the time of installation at 20m to 30m from the GNSS monument at approximately 120 degrees radial spacing from true north (Fig 3.6). The RM's consist of capped 20 mm stainless steel rods driven to refusal and are protected by 150mm PVC pipe within circular poly carbonate boxes.

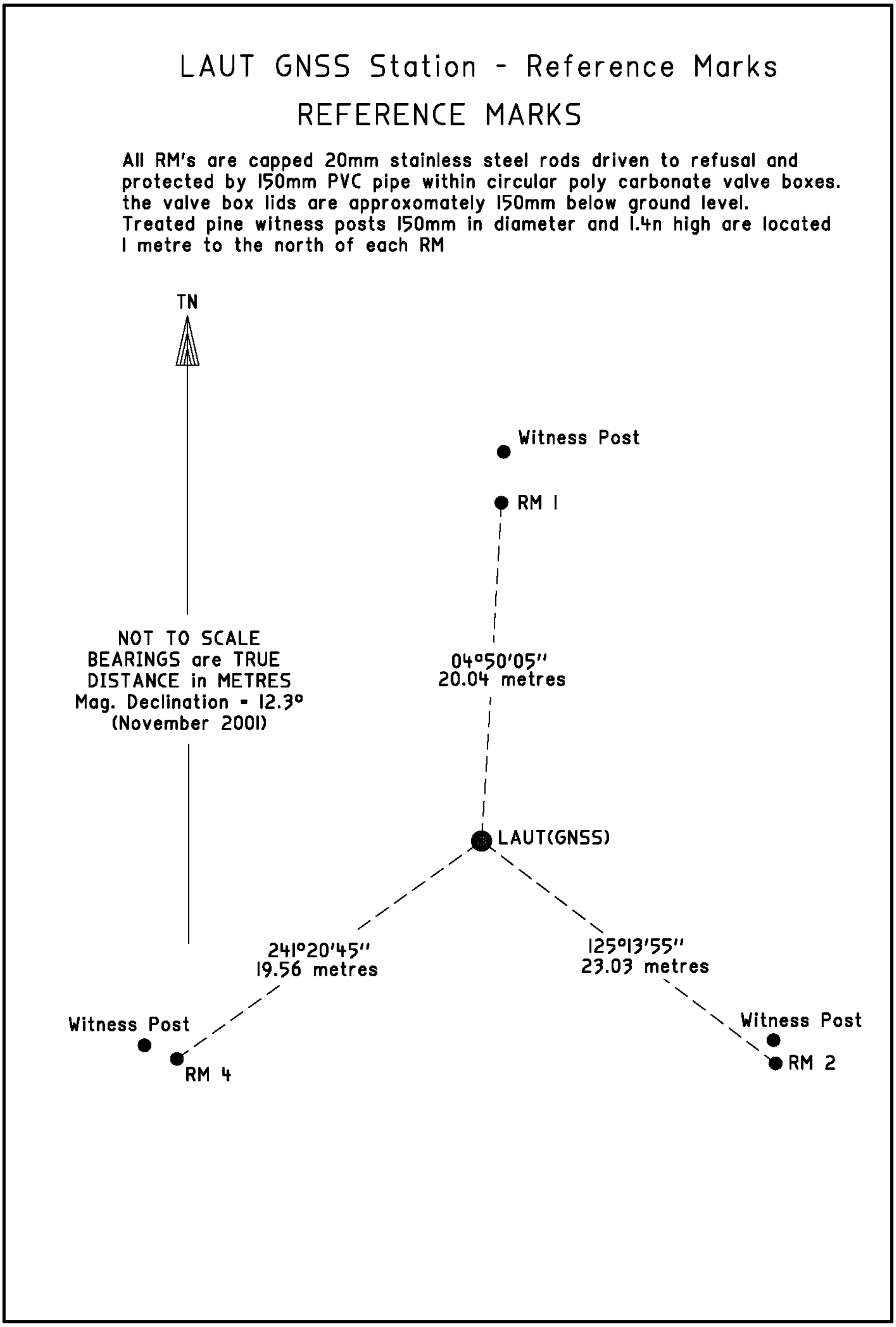


Figure 3.6 GNSS CORS site monitoring survey reference marks.

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 (LAUTBM).

3.2.2.Historical Survey Datum

In the past, the datum for the survey was related Tide Staff Zero (TSZ). Reduction of the data has been calculated holding LAUTBM fixed with Reduced Level of 31.3403m. This value was determined by the Survey Team in July 2011, adopting the reference point, BM3243 held fixed with a RL of 3.1285175m, that was destroyed in 2012. This value was determined by the National Tidal Centre Australia (NTCA) in 1992.

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.

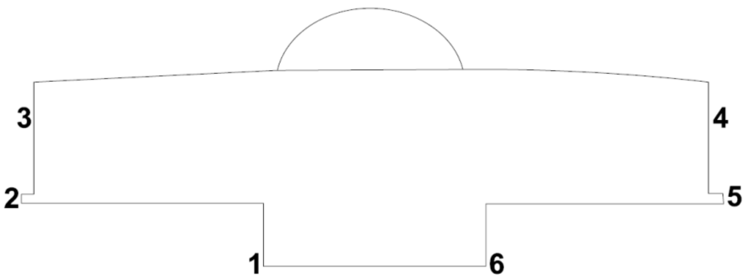


Figure 4.1 Symmetrical points on the antenna profile (TRM59800.00) observed from each RM.

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 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 LAUTBM at the LAUT GNSS CORS site

From	To	Rise (m)	Fall (m)	RL (m)	Dist (km)	Acc Dist (km)
LAUTBM				0.0000	0.0000	0.0000
RM1	**RM1**	0.0000	-2.3289	-2.3289	0.0201	0.0201
RM2	**RM2**	1.3251	0.0000	-1.0038	0.0376	0.0577
RM4	**RM4**	0.3001	0.0000	-0.7037	0.0352	0.0929
RM2	**RM2**	0.0000	-0.3002	-1.0038	0.0366	
RM1	**RM1**	0.0000	-1.3253	-2.3291	0.0376	
	LAUTBM	2.3289	0.0000	-0.0002	0.0201	
	Sum:	3.9541	-3.9543			
	Misclose:		-0.0002	-0.0002	0.187	(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)
LAUTBM				0.0000		0.0000
RM2	**RM2**	0.0000	-1.0036	-1.0036	0.0229	0.0229
	LAUTBM	1.0035	0.0000	-0.0001	0.0229	
	Sum:	1.0035	-1.0036			
	Misclose:		-0.0001	-0.0001	0.0458	(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)
LAUTBM				0.0000		0.0000
RM4	**RM4**	0.0000	-0.7036	-0.7036	0.0191	0.0191
	LAUTBM	0.7036	0.0000	0.0000	0.0191	0.0000
	Sum:	0.7036	-0.7036			
	Misclose:		0.0000	0.0000	0.038	(Total Dist)
			ALLOWABLE (m):	**0.0003**	**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 (LAUT) was tightly constrained to its ITRF2014 coordinates and aligned to LAUT-RM1 with an azimuth of 4° 50' 02.4974", which had been determined in the 2017 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 SOLO 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@2019.04 ellipsoidal height were adopted at LAUT. CCC means all 3 dimensions (in XYZ) were constrained and FFF means they were all free,

Station	Constraint	Latitude	Longitude	Ellipsoidal height (m)
LAUT	**CCC**	17° 36' 31.7243"	177° 26 '47.2647"	89.6616
RM1	**FFF**	17° 36' 31.0772"	177° 26' 47.7484"	86.3776
RM2	**FFF**	17° 36' 32.1564"	177° 26' 48.3295"	87.7036
RM4	**FFF**	17° 36' 32.9998"	177° 26' 47.1474"	88.0015

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. ITRF2020@2019.04 ellipsoidal height were adopted at LAUT.

Description	X	Y	Z	SD(e)	SD(n)	SD(up)
LAUT	-6075194.5734	270923.9939	-1917189.1149	0.0000	0.0000	0.0000
RM1	-6075197.5966	270922.4419	-1917169.1611	0.0001	0.0006	0.0005
RM2	-6075189.5959	270904.9375	-1917201.1885	0.0008	0.0007	0.0005
RM4	-6075189.7181	270939.7278	-1917196.9316	0.0007	0.0006	0.0005

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

Year	From	To	ΔE	ΔN	ΔU
2019	**LAUT**	RM1	1.6824	19.8929	-3.2840
2019	**LAUT**	RM2	18.8135	-13.2879	-1.9580
2019	**LAUT**	RM4	-16.0365	-8.4707	-1.6602

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
2001	**LAUT**	**RM1**	1.683	19.8921	-3.2847
2003	**LAUT**	**RM1**	1.6823	19.8921	-3.2848
2005	**LAUT**	**RM1**	1.6823	19.892	-3.2844
2007	**LAUT**	**RM1**	1.6823	19.8925	-3.2846
2008	**LAUT**	**RM1**	1.6824	19.8928	-3.2847

2010	**LAUT**	**RM1**	1.6824	19.893	-3.285
2013	**LAUT**	**RM1**	1.6822	19.8911	-3.2845
2014	**LAUT**	**RM1**	1.6822	19.8915	-3.2856
2016	**LAUT**	**RM1**	1.6823	19.8918	-3.2839
2017	**LAUT**	**RM1**	1.6823	19.892	-3.2851
2019	**LAUT**	**RM1**	1.6824	19.8929	-3.2840
Ref RL	**(as at 2016)**		**1.6824**	**19.8921**	**-3.2847**

Year	From	To	ΔE	ΔN	ΔU
2001	**LAUT**	**RM2**	18.8135	-13.2874	-1.9592
2003	**LAUT**	**RM2**	18.8154	-13.2891	-1.9601
2005	**LAUT**	**RM2**	18.8156	-13.2864	-1.9584
2007	**LAUT**	**RM2**	18.8152	-13.2867	-1.9586
2008	**LAUT**	**RM2**	18.8159	-13.2876	-1.9588
2010	**LAUT**	**RM2**	18.8144	-13.2874	-1.9597
2013	**LAUT**	**RM2**	18.8151	-13.2863	-1.9567
2014	**LAUT**	**RM2**	18.8144	-13.2874	-1.9575
2016	**LAUT**	**RM2**	18.8128	-13.2885	-1.9612
2017	**LAUT**	**RM2**	18.8129	-13.2886	-1.9577
2019	**LAUT**	**RM2**	18.835	-13.2879	-1.9580
Ref RL	**(as at 2016)**		**18.8147**	**-13.2874**	**-1.9589**

Year	From	To	ΔE	ΔN	ΔU
2013	**LAUT**	**RM4**	-16.0347	-8.4706	-1.6599
2014	**LAUT**	**RM4**	-16.0357	-8.4707	-1.6580
2016	**LAUT**	**RM4**	-16.0357	-8.4713	-1.6587
2017	**LAUT**	**RM4**	-16.0359	-8.4706	-1.6583
2019	**LAUT**	**RM4**	-16.0365	-8.4707	-1.6602
Ref RL	**(as at 2016)**		**-16.0354**	**-8.4709**	**-1.6589**

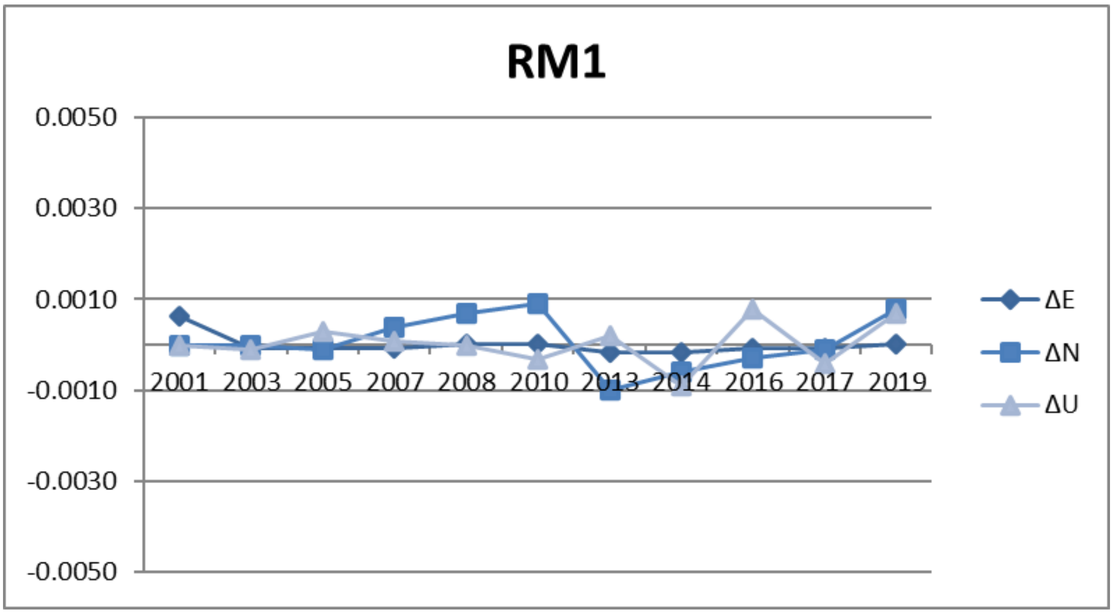


Figure 4.4.1 Time series of RM1 movement relative to GNSS pillar (0 = REF pre 2016 mean).

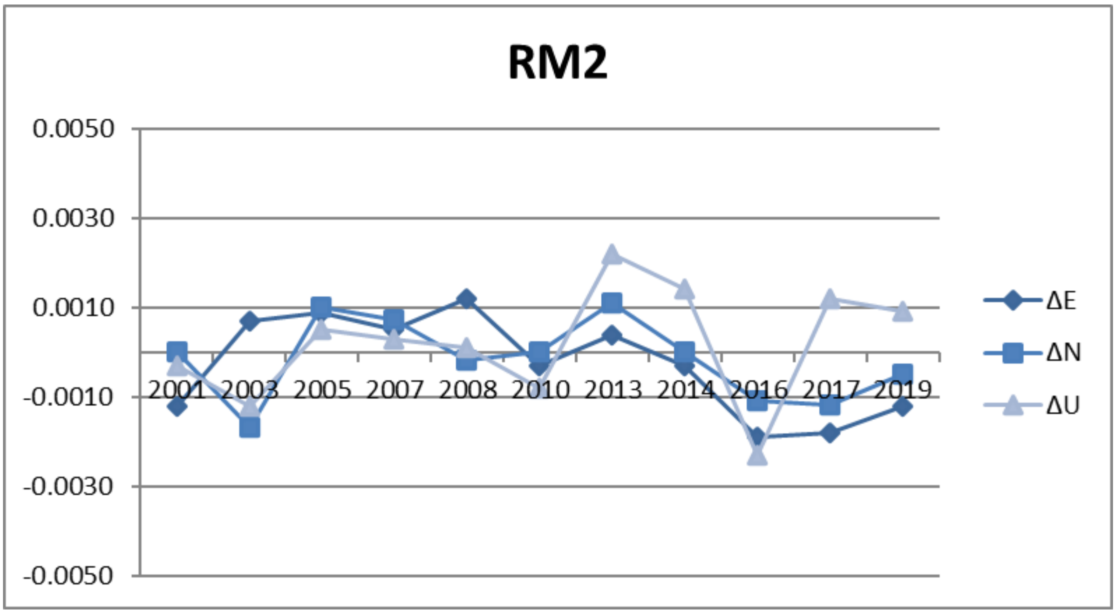


Figure 4.4.2 Time series of RM2 movement relative to GNSS pillar (0 = REF pre 2016 mean).

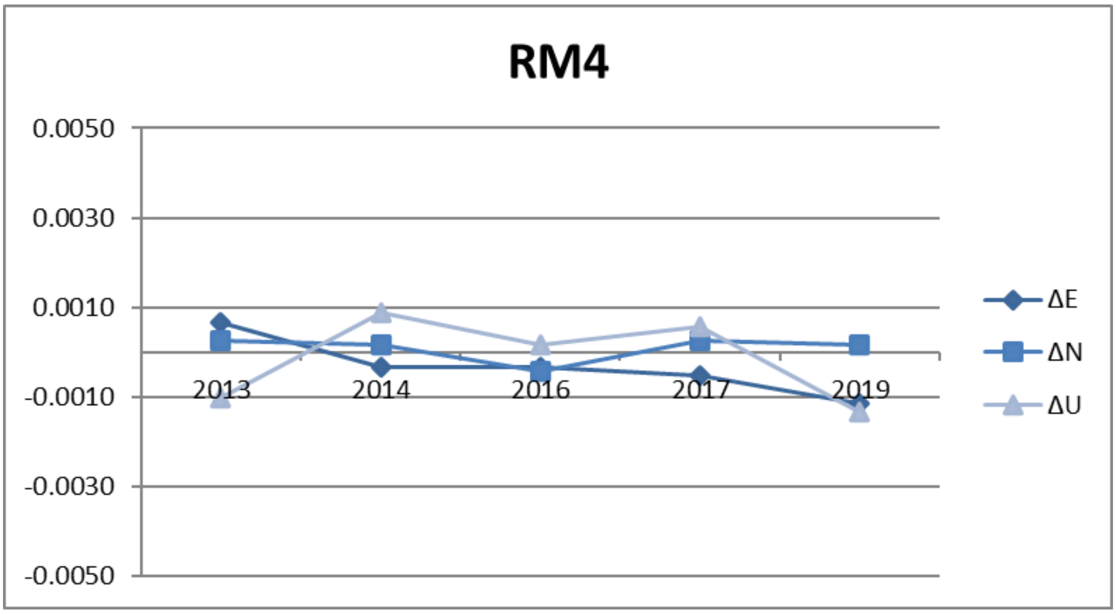


Figure 4.4.3 Time series of RM4 movement relative to GNSS pillar (0 = REF pre 2016 mean).

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 Lautoka 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
LAUT (Ellipsoidal ht)	89.6616	Observed RL at the ARP of LAUT (Ellipsoidal) @ 2019.04
LAUT - LAUTBM	-0.9552	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)

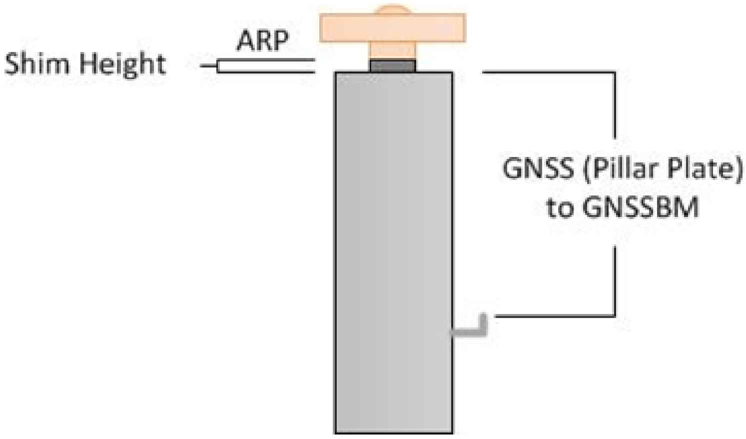


Figure 5.2.1 GNSS Pillar Offsets

5.3.Data Analysis and Results

Reduction of the digital data was computed using the Geoscience Australia levelling program "leveling1.exe" and LevellingFIELD_3.pl.This program computes the height difference between the two reflectors by taking the mean average of the measured height differences and 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 LAUTBM (GNSS BM)

Table 5.3.1 Reduced level data – LAUT (GNSS CORS) to FIJ12 (Tide Gauge Benchmark)

From	To	Rise (m)	Fall (m)	RL (m)	Dist (km)	Acc Dist (km)
LAUT				0.9552		
LAUTBM	**LAUTBM**	0.0000	-0.9552	0.0000	0.000	0.000
BM3247	**BM3247**	0.0000	-10.3795	-10.3795	0.179	0.179
BM3246	**BM3246**	0.0000	-13.1350	-23.5144	0.222	0.401
87	**87**	0.0000	-0.9740	-24.4884	0.139	0.540
BM3244	**BM3244**	0.0000	-2.6808	-27.1692	0.177	0.716
211	**211**	0.0590	0.0000	-27.1102	0.110	0.826
85	**85**	0.0000	-1.0925	-28.2027	0.181	1.007
84	**84**	0.0779	0.0000	-28.1248	0.157	1.164
210	**210**	2.1015	0.0000	-26.0233	0.129	1.293
BM3250	**BM3250**	0.0000	-1.3201	-27.3434	0.158	1.451
212	**212**	0.0000	-0.8513	-28.1947	0.060	1.510
81	**81**	0.0000	-0.4847	-28.6794	0.183	1.693
207	**207**	1.5078	0.0000	-27.1717	0.179	1.872
FIJ12	**FIJ12**	0.0000	-0.0992	-27.2708	0.045	1.916
207	**207**	0.0994	0.0000	-27.1715	0.044	
81	**81**	0.0000	-1.5081	-28.6796	0.179	
212	**212**	0.4844	0.0000	-28.1952	0.183	
BM3250	**BM3250**	0.8511	0.0000	-27.3440	0.060	
210	**210**	1.3202	0.0000	-26.0239	0.158	
84	**84**	0.0000	-2.1018	-28.1257	0.129	
85	**85**	0.0000	-0.0780	-28.2037	0.157	
211	**211**	1.0923	0.0000	-27.1114	0.181	
BM3244	**BM3244**	0.0000	-0.0589	-27.1703	0.110	
87	**87**	2.6806	0.0000	-24.4898	0.177	

BM3246	**BM3246**	0.9740	0.0000	-23.5158	0.139	
BM3247	**BM3247**	13.1349	0.0000	-10.3809	0.222	
LAUTBM	**LAUTBM**	10.3795	0.0000	-0.0013	0.179	
	LAUT	0.9552	0.0000	0.9539	0.000	
	Sum:	35.7177	-35.7190			
	Misclose:		-0.0013	-0.0013	3.833	(Total Dist)
			ALLOWABLE (m):	**0.0028**	**2 x Sqrt (km) test:**	**PASS**

Table 5.3.2 Reduced level data – FIJ12 (Tide Gauge Benchmark) to FIJ13 Tide Gauge Sensor Benchmark)

From	**To**	**Rise** (m)	**Fall** (m)	**RL** (m)	**Dist (Km)**	**Acc Dist(km)**
FIJ12				-27.2708		1.916
FIJ13	**FIJ13**	0.3746	0.0000	-26.8962	0.015	1.931
	FIJ12	0.0000	-0.3746	-27.2708	0.016	
	Sum:	0.3746	-0.3746			
	Misclose:		0.0000	0.0000	0.030	(Total Dist)
			ALLOWABLE (m):	**0.0002**	**2 x Sqrt (km) test:**	**PASS**

Table 5.3.3 Reduced level data – LAUTBM (GNSS CORS Benchmark) to BM3248

From	**To**	**Rise** (m)	**Fall** (m)	**RL** (m)	**Dist (km)**	**Acc Dist (km)**
LAUTBM				0.0000		0.000
BM3248	**BM3248**	3.8957	0.0000	3.8957	0.167	0.167
	LAUTBM	0.0000	-3.8960	-0.0004	0.169	
	Sum:	3.8957	-3.8960			
	Misclose:		-0.0004	-0.0004	0.336	(Total Dist)
			ALLOWABLE (m):	**0.0008**	**2 x Sqrt (km) test:**	**PASS**

Table 5.3.4 Measured height differences (in metres) between all BMs (ΔRL_{2019})

	LAUTBM	BM3247	BM3246	BM3244	BM3250	FIJ12	FIJ13	BM3248	RM1	RM2	RM4	LAUT
LAUTBM	-	-10.3802	-23.5151	-27.1698	-27.3437	-27.2708	-26.8962	3.8957	-2.3290	-1.0038	-0.7037	0.9552
BM3247	10.3802	-	-13.1349	-16.7896	-16.9635	-16.8907	-16.5160	14.2758	8.0512	9.3764	9.6765	11.3354
BM3246	23.5151	13.1349	-	-3.6547	-3.8286	-3.7557	-3.3811	27.4108	21.1861	22.5113	22.8115	24.4703
BM3244	27.1698	16.7896	3.6547	-	-0.1739	-0.1011	0.2736	31.0654	24.8408	26.1660	26.4661	28.1250
BM3250	27.3437	16.9635	3.8286	0.1739	-	0.0729	0.4475	31.2394	25.0147	26.3399	26.6400	28.2989
FIJ12	27.2708	16.8907	3.7557	0.1011	-0.0729	-	0.3746	31.1665	24.9418	26.2670	26.5672	28.2260
FIJ13	26.8962	16.5160	3.3811	-0.2736	-0.4475	-0.3746	-	30.7919	24.5672	25.8924	26.1925	27.8514
BM3248	-3.8957	-14.2758	-27.4108	-31.0654	-31.2394	-31.1665	-30.7919	-	-6.2247	-4.8995	-4.5993	-2.9405
RM1	2.3290	-8.0512	-21.1861	-24.8408	-25.0147	-24.9418	-24.5672	6.2247	-	1.3252	1.6253	3.2842
RM2	1.0038	-9.3764	-22.5113	-26.1660	-26.3399	-26.2670	-25.8924	4.8995	-1.3252	-	0.3001	1.9590
RM4	0.7037	-9.6765	-22.8115	-26.4661	-26.6400	-26.5672	-26.1925	4.5993	-1.6253	-0.3001	-	1.6589
LAUT	-0.9552	-11.3354	-24.4703	-28.1250	-28.2989	-28.2260	-27.8514	2.9405	-3.2842	-1.9590	-1.6589	-

Table 5.3.5 Time-series of Reduced Levels (with respect to LAUTBM).

YEAR	LAUTBM	BM3247	BM3246	BM3244	BM3250	FIJ12	FIJ13	BM3248	RM1	RM2	RM4	LAUT
1992.8	0.0000			-27.1705		-27.2715	-26.8980					
1994.6	0.0000			-27.1705		-27.2705	-26.8966					
1995.9	0.0000			-27.1705		-27.2705	-26.8966					
1997.5	0.0000			-27.1705		-27.2704	-26.8971					
1998.9	0.0000			-27.1705		-27.2711	-26.8975					
2001.0	0.0000			-27.1705		-27.2725	-26.8983					
2002.2	0.0000	-10.3811	-23.5167	-27.1705		-27.2734	-26.8989	3.8946	-2.3289	-1.0034		
2003.4	0.0000	-10.3805	-23.5159	-27.1703		-27.2714	-26.8970	3.8956	-2.3291	-1.0033		
2005.4	0.0000	-10.3804	-23.5156	-27.1696		-27.2718	-26.8979	3.8957				
2005.4	0.0000	-10.3810	-23.5162	-27.1705		-27.2724	-26.8984	3.8955	-2.3292	-1.0032		
2007.1	0.0000	-10.3812	-23.5165	-27.1705		-27.2721	-26.8972	3.8949	-2.3292	-1.0032		
2008.8	0.0000	-10.3813	-23.5165	-27.1709		-27.2727	-26.8983	3.8961	-2.3295	-1.0035		
2010.2	0.0000	-10.3804	-23.5146	-27.1690		-27.2712	-26.8964	3.8957	-2.3293	-1.0040		
2011.6	0.0000	-10.3804	-23.5160	-27.1700		-27.2732	-26.8994	3.8963	-2.3291	-1.0025	-0.7039	
2013.1	0.0000	-10.3802	-23.5147	-27.1674		-27.2691	-26.8945	3.8953	-2.3292	-1.0026	-0.7036	
2014.5	0.0000	-10.3805	-23.5156	-27.1702		-27.2736	-26.8999	3.8963	-2.3291	-1.0026	-0.7037	
2016.1	0.0000	-10.3792	-23.5137	-27.1684	-27.3342	-27.2698	-26.8950	3.8954	-2.3282	-1.0065	-0.7035	0.9552
2017.4	0.0000	-10.3802	-23.5153	-27.1694	-27.3403	-27.2713	-26.8972	3.8958	-2.3291	-1.0026	-0.7037	0.9552
2019.0	0.0000	-10.3802	-23.5151	-27.1698	-27.3437	-27.2708	-26.8962	3.8957	-2.3290	-1.0038	-0.7037	0.9552

5.4.Comparison with previous surveys

All historic data has been readjusted relative to the benchmark attached to the base of the GNSS pillar (LAUTBM) (Table 5.3.5). To investigate whether BMs have moved over time, the RLs from the 2019 survey (RL_{2019}) 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_{2019} values (in metres). Shows the difference in height between two marks from the current survey compared to the reference height difference.

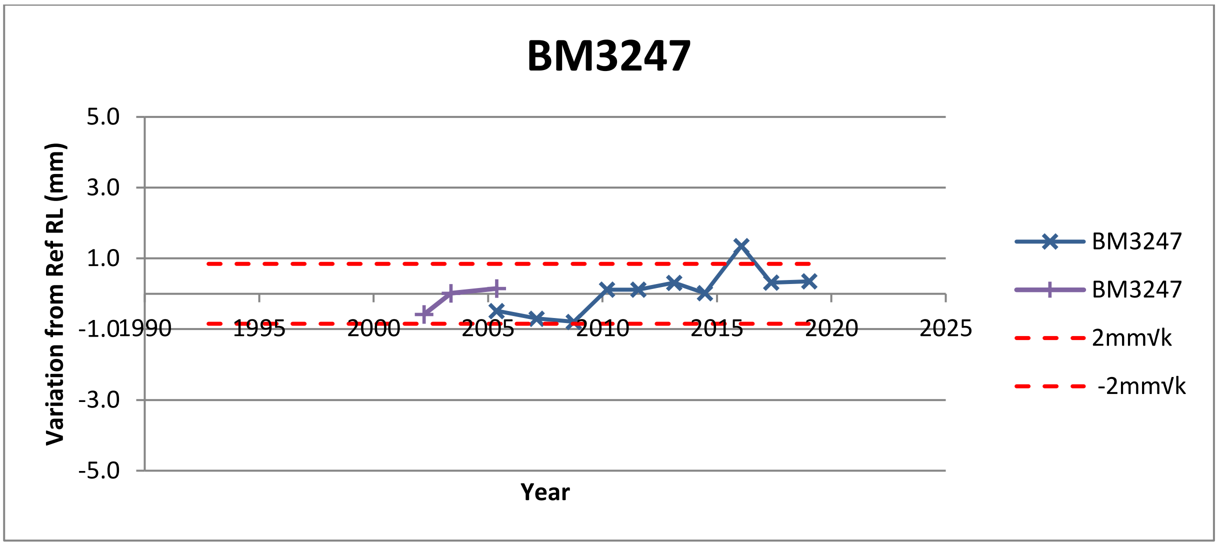
	LAUTBM	BM3247	BM3246	BM3244	BM3250	FIJ12	FIJ13	BM3248	RM1	RM2	RM4	LAUT
LAUTBM	-	-0.0004	-0.0007	-0.0007	**0.0095**	-0.0007	-0.0012	0.0000	-0.0001	0.0008	0.0000	0.0000
BM3247	0.0004	-	-0.0003	-0.0003	**0.0099**	-0.0003	-0.0009	0.0003	0.0002	0.0012	0.0003	0.0004
BM3246	0.0007	0.0003	-	0.0000	**0.0102**	0.0000	-0.0006	0.0006	0.0005	0.0015	0.0007	0.0007
BM3244	0.0007	0.0003	0.0000	-	**0.0102**	0.0000	-0.0005	0.0007	0.0005	0.0015	0.0007	0.0007
BM3250	**-0.0095**	**-0.0099**	**-0.0102**	**-0.0102**	-	**-0.0102**	**-0.0108**	**-0.0095**	**-0.0097**	**-0.0087**	**-0.0095**	**-0.0095**
FIJ12	0.0007	0.0003	0.0000	0.0000	**0.0102**	-	-0.0006	0.0006	0.0005	0.0015	0.0007	0.0007
FIJ13	0.0012	0.0009	0.0006	0.0005	**0.0108**	0.0006	-	0.0012	0.0011	0.0020	0.0012	0.0012
BM3248	0.0000	-0.0003	-0.0006	-0.0007	**0.0095**	-0.0006	-0.0012	-	-0.0001	0.0008	0.0000	0.0000
RM1	0.0001	-0.0002	-0.0005	-0.0005	**0.0097**	-0.0005	-0.0011	0.0001	-	0.0009	0.0001	0.0001
RM2	-0.0008	-0.0012	-0.0015	-0.0015	**0.0087**	-0.0015	-0.0020	-0.0008	-0.0009	-	-0.0008	-0.0008
RM4	0.0000	-0.0003	-0.0007	-0.0007	**0.0095**	-0.0007	-0.0012	0.0000	-0.0001	0.0008	-	0.0000
LAUT	0.0000	-0.0004	-0.0007	-0.0007	**0.0095**	-0.0007	-0.0012	0.0000	-0.0001	0.0008	0.0000	-

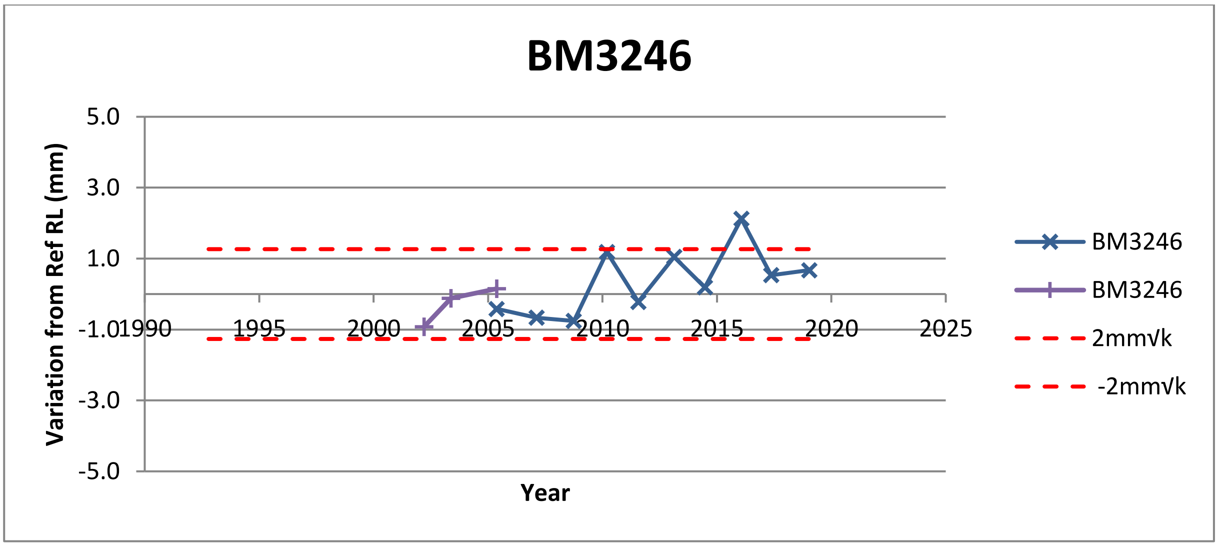
Table 5.4.1.1 values are calculated by subtracting the difference in height between RL_{2019} values (Table 5.3.4) from the difference in height between RL_{REF} values.

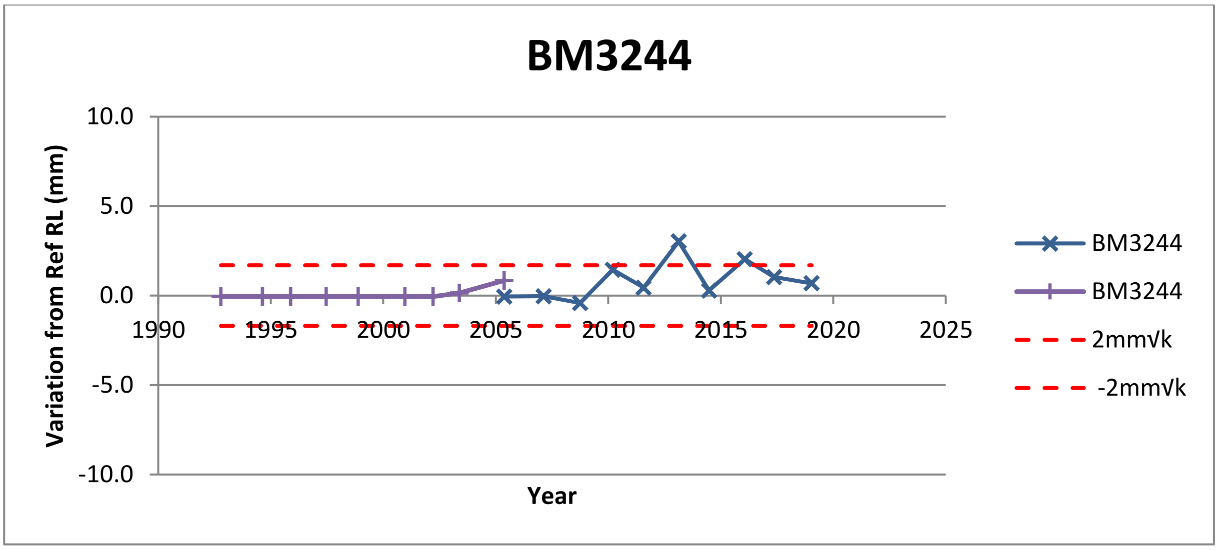
Comparing the change in relative heights between all benchmarks can help identify movement of a particular BM, inconsistency in survey, or even deformation between the GNSS pillar and levelling run BMs.

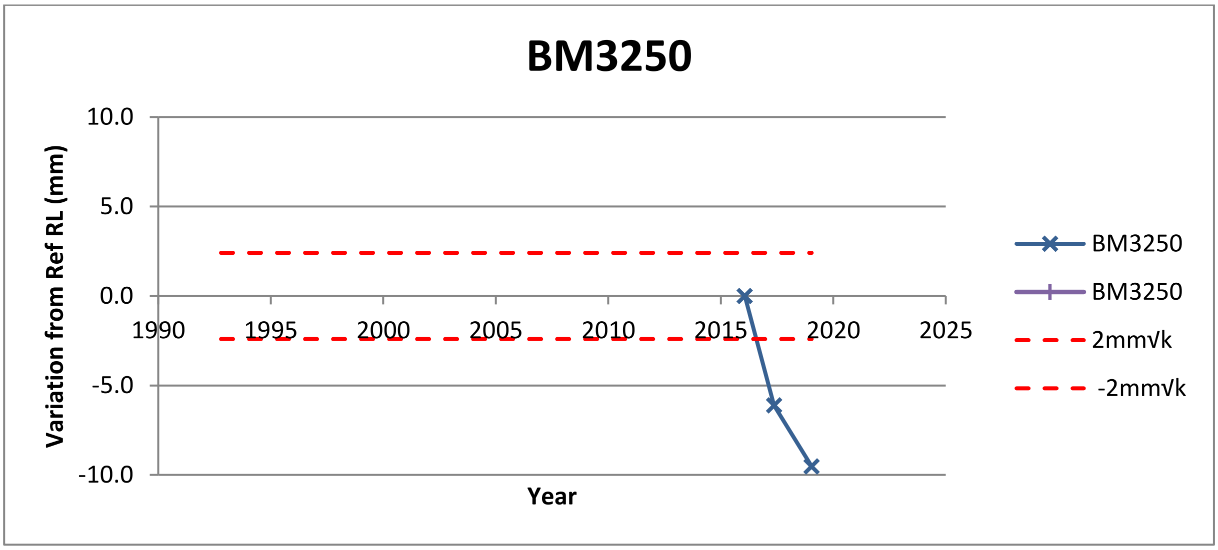
5.4.2 Time Series Charts for each BM

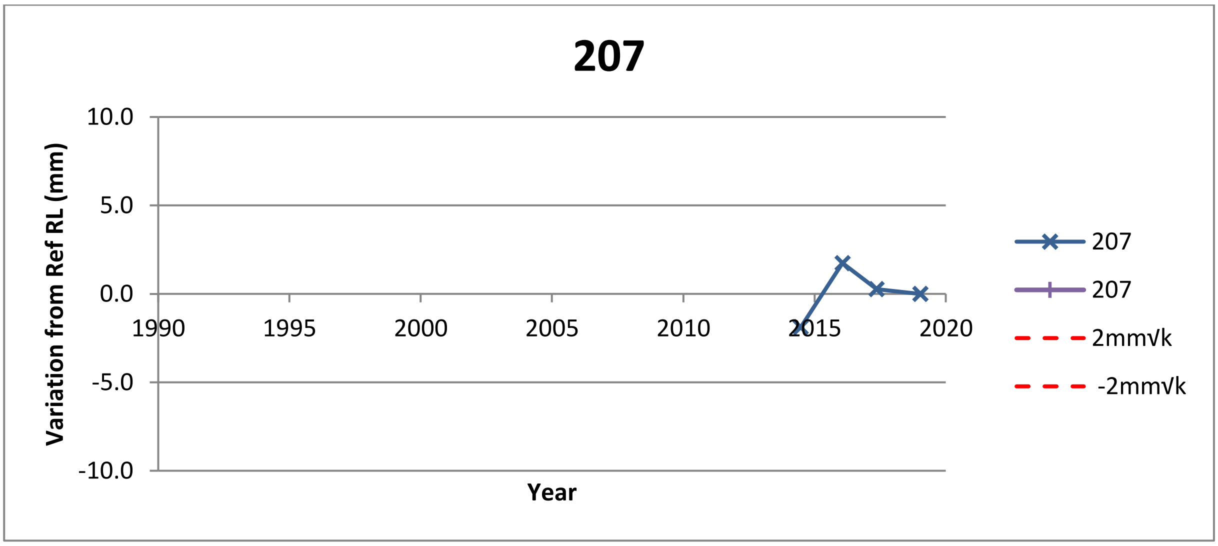
The change in RL over time can be used to detect trends of movement or survey errors. In the series of figures below, the red dashed lines represent the allowable error in height based on the levelling technique used and distance of the benchmark from the GNSS pillar ($2mm\sqrt{K}$). The purple line (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.

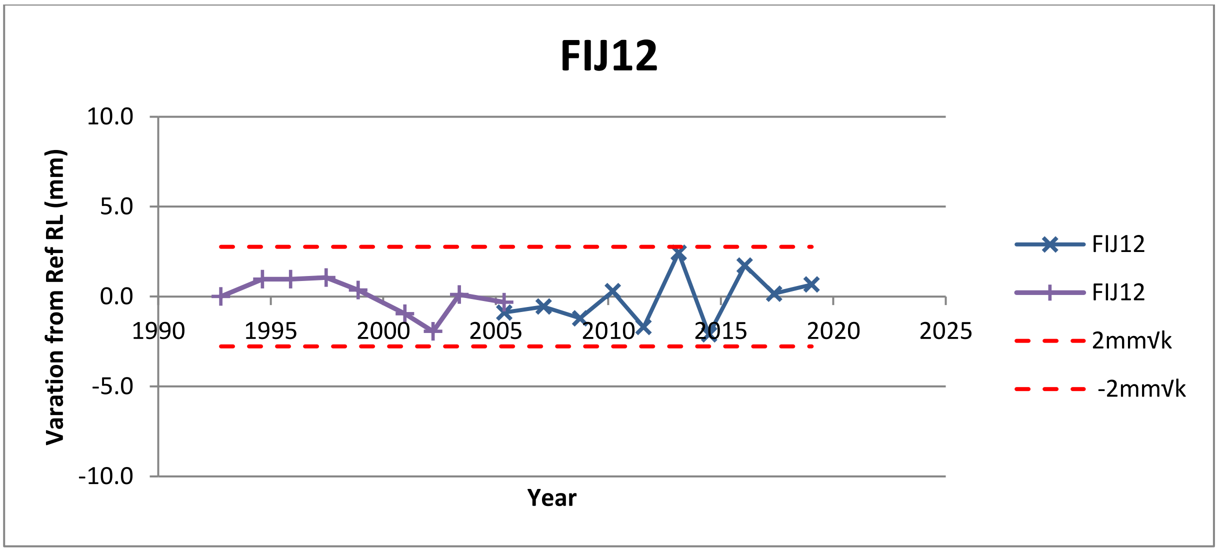


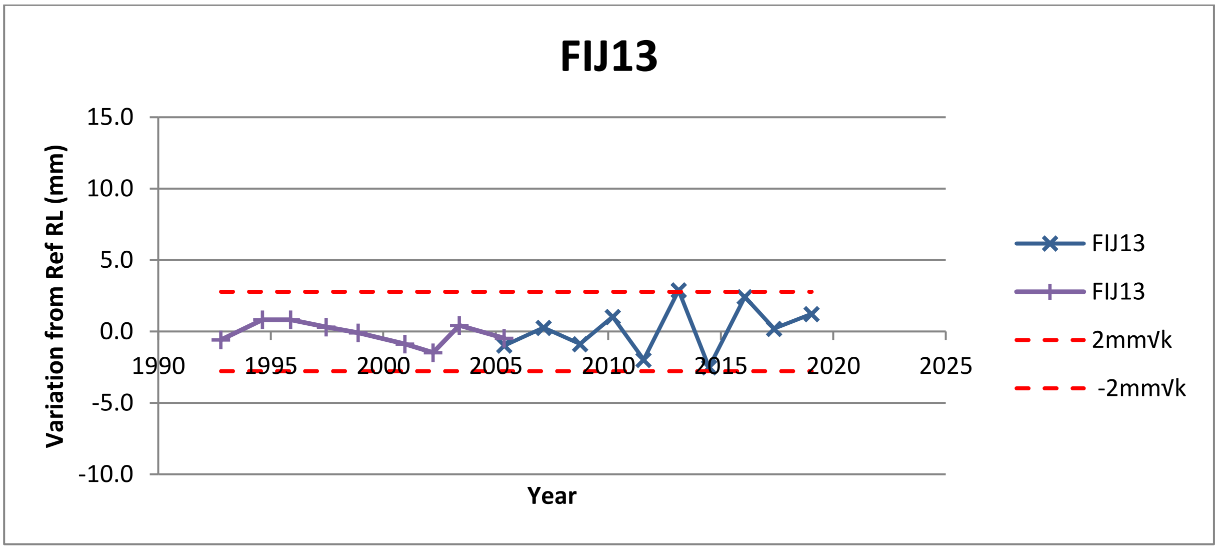


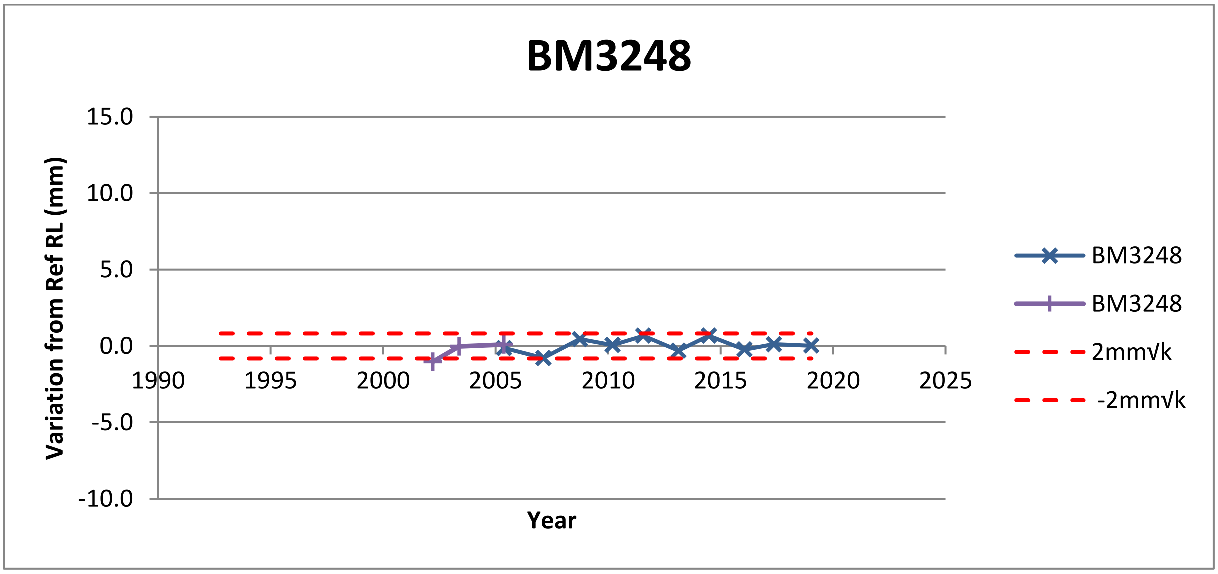

BM3244
10.0
5.0
0.0
-5.0
-10.0
1990
1995
2000
2005
2010
2015
2020
2025
Variation from Ref RL (mm)
Year
BM3244
BM3244
2mm√k
-2mm√k


BM3250
10.0
5.0
0.0
-5.0
-10.0
1990
1995
2000
2005
2010
2015
2020
2025
Variation from Ref RL (mm)
Year
BM3250
BM3250
2mm√k
-2mm√k


207
10.0
5.0
0.0
-5.0
-10.0
1990
1995
2000
2005
2010
2015
2020
Variation from Ref RL (mm)
Year
207
207
2mm√k
-2mm√k


FIJ12
Varation from Ref RL (mm)
10.0
5.0
0.0
-5.0
-10.0
1990
1995
2000
2005
2010
2015
2020
2025
Year
FIJ12
FIJ12
2mm√k
-2mm√k


FIJ13
Variation from Ref RL (mm)
15.0
10.0
5.0
0.0
-5.0
-10.0
1990
1995
2000
2005
2010
2015
2020
2025
Year
FIJ13
FIJ13
2mm√k
-2mm√k


BM3248
Variation from Ref RL (mm)
15.0
10.0
5.0
0.0
-5.0
-10.0
1990
1995
2000
2005
2010
2015
2020
2025
Year
BM3248
BM3248
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 is one difference above 0.003 m:

- BM3250, which is likely due to:
    - localised movement of BM3250 – which is located at the centre of the roundabout leading into Lautoka Port, where there is a lot of movement of heavy vehicles, transporting goods into the wharf, that may influence the movement of the deep driven benchmark. It has subsided approximately 3mm, since the previous survey

The survey from the primary GNSSBM (LAUTBM) to the TG Plaque (FIJ12 shows no statistically significant change in height. This means the wharf structure is solid, and any movement measured on the tide gauge is not due to deformation at the jetty.

The survey from the primary GNSSBM (LAUTBM) to the TG Ref Pin (FIJ13) show that the tide gauge is stable, and no deformation has occurred since the previous survey.

Table 6.1 Comparison of results with Reference ^H.

PT ID	Reference ^H (m)	2019.04 Value (m)	Difference
LAUTBM - Primary BM (BM3250)	-27.3342	-27.3437	0.0095
BM3250 - TG Plaque BM (FIJ12)	0.0627	0.0729	0.0102
BM3250 - TG ref pin (FIJ13)	0.4368	0.4475	0.0108
LAUTBM - BM3244	-27.1704	-27.1698	-0.0007
BM3244 - FIJ12	-0.1011	-0.1011	0.0000
FIJ12 - FIJ13	0.3741	0.3746	0.0006
LAUT - TG Plaque	-28.2267	-28.2260	-0.0007
LAUT - TG BM	-27.8526	-27.8514	-0.0012
LAUT - TGZ	-32.2852	-32.2840	-0.0012

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

PT ID	Reference RL (m)	2019.04 Value (m)	Difference	ITRF2020	TGZ
LAUTBM	0.0000	0.0000	0.0000	88.7064	31.3288
BM3247	-10.3805	-10.3802	0.0004	78.3262	20.9486
BM3246	-23.5158	-23.5151	0.0007	65.1913	7.8137
BM3244	-27.1704	-27.1698	0.0007	61.5366	4.1590
BM3250	-27.3342	-27.3437	-0.0095	61.3627	3.9851
FIJ12	-27.2715	-27.2708	0.0007	61.4356	4.0580
FIJ13	-26.8974	-26.8962	0.0012	61.8102	4.4326
BM3248	3.8956	3.8957	0.0000	92.6021	35.2245
RM1	-2.3291	-2.3290	0.0001	86.3774	28.9998
RM2	-1.0030	-1.0038	-0.0008	87.7026	30.3250
RM4	-0.7037	-0.7037	0.0000	88.0027	30.6251
LAUT	0.9552	0.9552	0.0000	89.6616	32.2840
TGZ	-31.3300	-31.3288	0.0012	57.3776	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 Bureau 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).

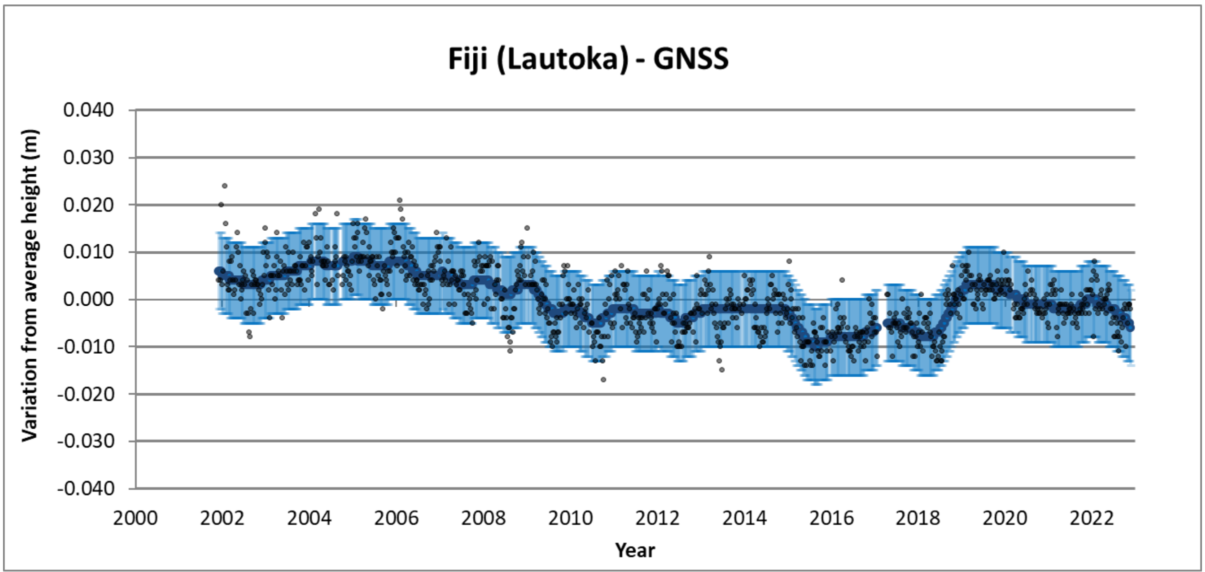


Figure 7.1 Time series of GNSS analysis (dark blue line) with 95%CI uncertainty (light blue lines).

[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.

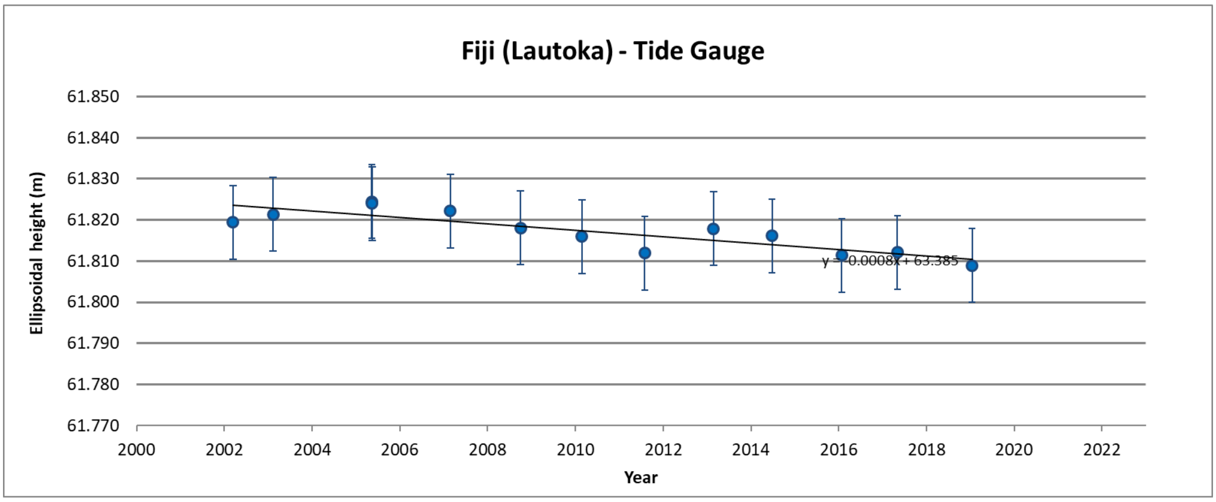


Figure 7.2 The height of the SEAFRAME sensor reference benchmark (with respect to ITRF2020).

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 2020.

Date	Height (m)	Uncertainty (95%CI) (m)
2002.20	61.8195	0.0089
2003.11	61.8214	0.0089
2005.36	61.8245	0.0089
2005.37	61.8240	0.0089
2007.15	61.8222	0.0089
2008.75	61.8181	0.0089
2010.15	61.8160	0.0089
2011.58	61.8120	0.0089
2013.15	61.8179	0.0089
2014.48	61.8162	0.0089
2016.07	61.8114	0.0089
2017.34	61.8122	0.0089
2019.04	61.8090	0.0089

[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

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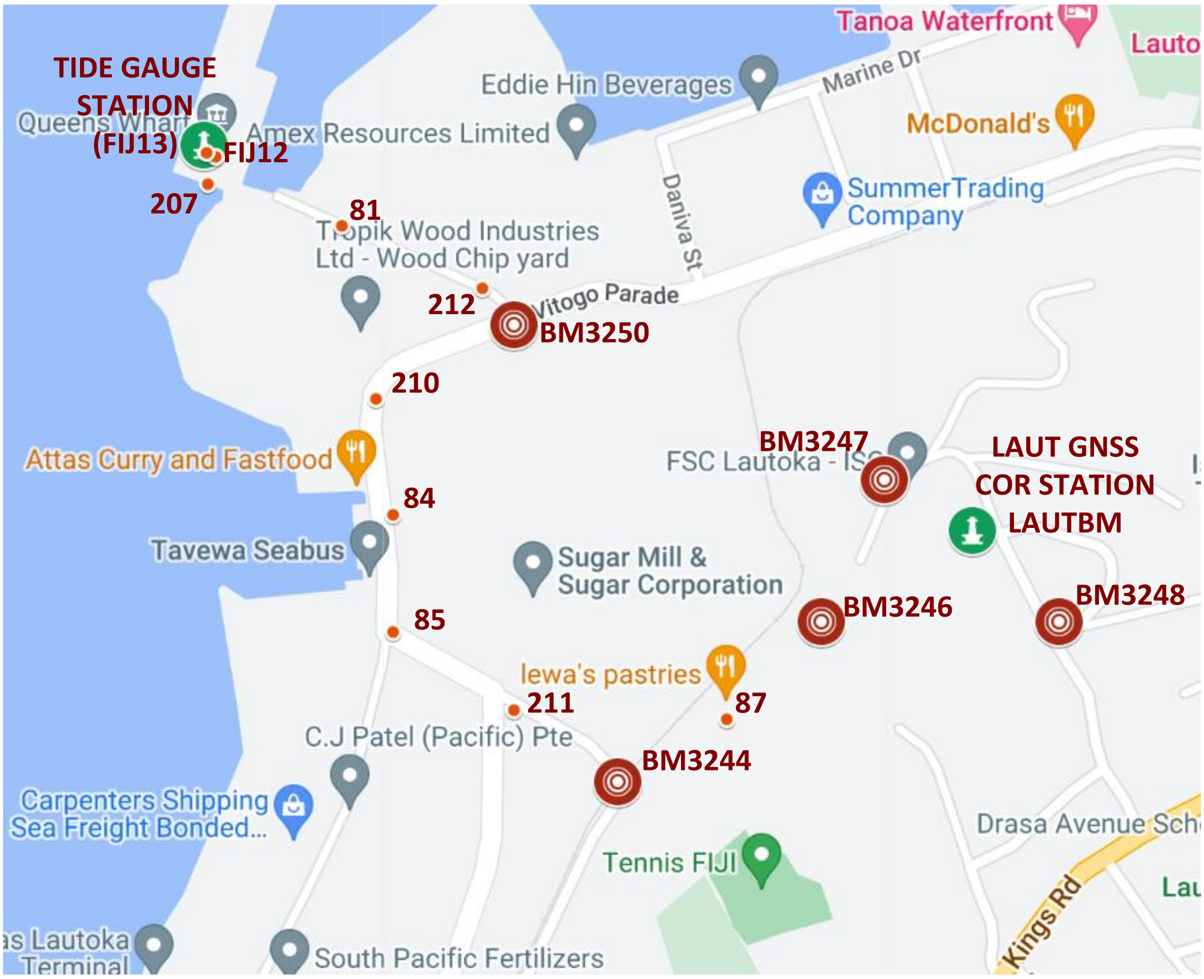
Appendix A Locality Diagrams



Source: Adopted from Google Map

A 1 Deep Benchmark

PACIFIC SEA LEVEL MONITORING PROJECT

Australian Government
Geoscience Australia

SURVEY BENCH MARK RECORD

Pacific Community
Communauté du Pacifique

Bench Mark Number: MB3246

Original Bench Mark Established by: *Date: 27/02/2002*
National Geospatial Reference Systems, Geospatial & Earth Monitoring Division (GEMD), Geoscience Australia

Existing Bench Mark Established by: *Date:*

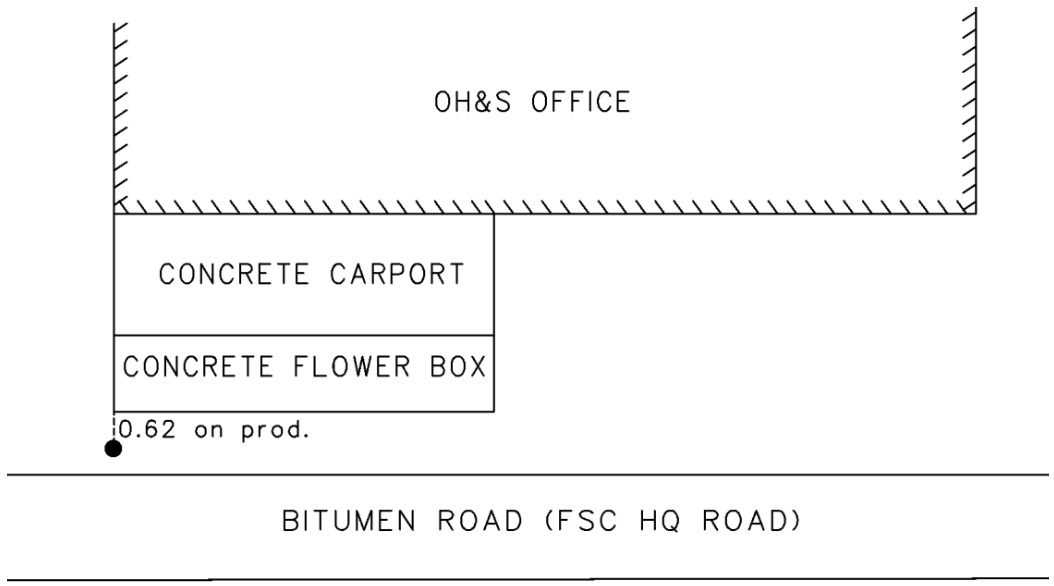
Notes / References: Deep Benchmark
This survey mark is not in a good locality for GNSS occupation.

Country: Fiji Islands
Island: Viti Levu *City: Lautoka*

MARKING AND LOCALITY SKETCH

Bench Mark: 6.9m of 19mm diameter stainless steel capped rod driven to refusal. Rod sheathed with 50mm diameter PVC tube, filled with bentonite, for top 0.5m. Top of mark 0.1m below ground level.

Locality sketch: Mark approximately 1600m from the tide gauge station



NOT TO SCALE Distances in Metres Magnetic Bearings

Approved by: Geoscience Australia / SPC *Date: Dec 2007*

PACIFIC SEA LEVEL MONITORING PROJECT

SURVEY BENCH MARK RECORD

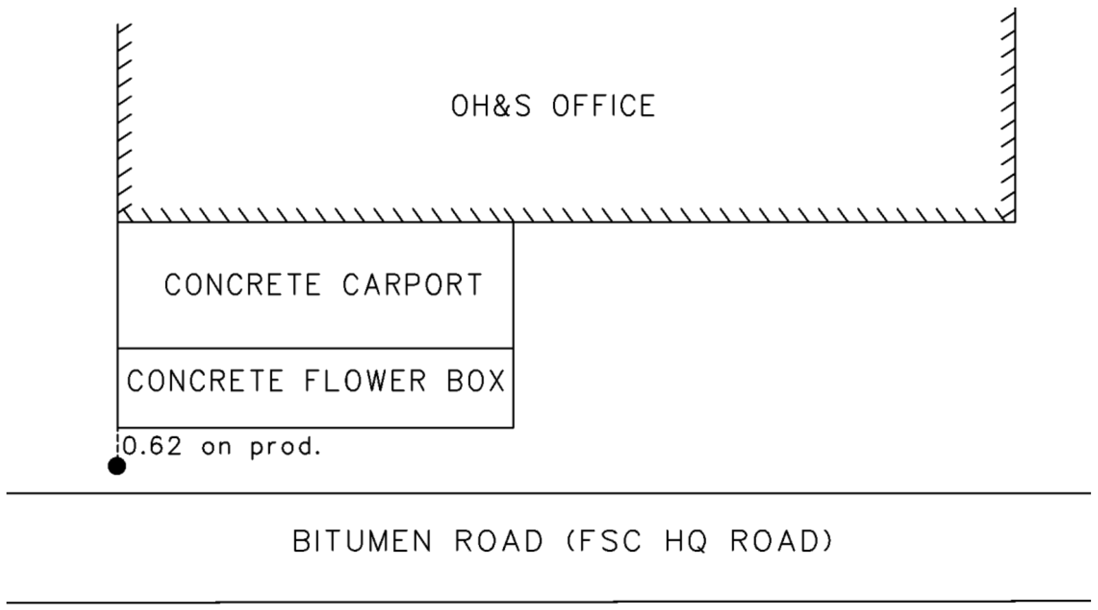
Bench Mark Number: BM3246

Original Bench Mark Established by: National Geospatial Reference Systems, Geospatial & Earth Monitoring Division (GEMD), Geoscience Australia	*Date: 27/02/2002*
Existing Bench Mark Established by:	*Date:*
Notes / References: Deep Benchmark This survey mark is not in a good locality for GNSS occupation.	
Country: Fiji Islands *Island: Viti Levu*	*City: Lautoka*

MARKING AND LOCALITY SKETCH

Bench Mark: 6.9m of 19mm diameter stainless steel capped rod driven to refusal. Rod sheathed with 50mm diameter PVC tube, filled with bentonite, for top 0.5m. Top of mark 0.1m below ground level.

Locality sketch: Mark approximately 1600m from the tide gauge station



NOT TO SCALE | Distances in Metres | Magnetic Bearings

Approved by: Geoscience Australia / SPC | *Date: Dec 2007*

PACIFIC SEA LEVEL MONITORING PROJECT

SURVEY BENCH MARK RECORD

Bench Mark Number: BM3247

Original Bench Mark Established by: *Date: 27/02/2002*

National Geospatial Reference Systems, Geospatial & Earth Monitoring Division (GEMD), Geoscience Australia

Existing Bench Mark Established by: *Date:*

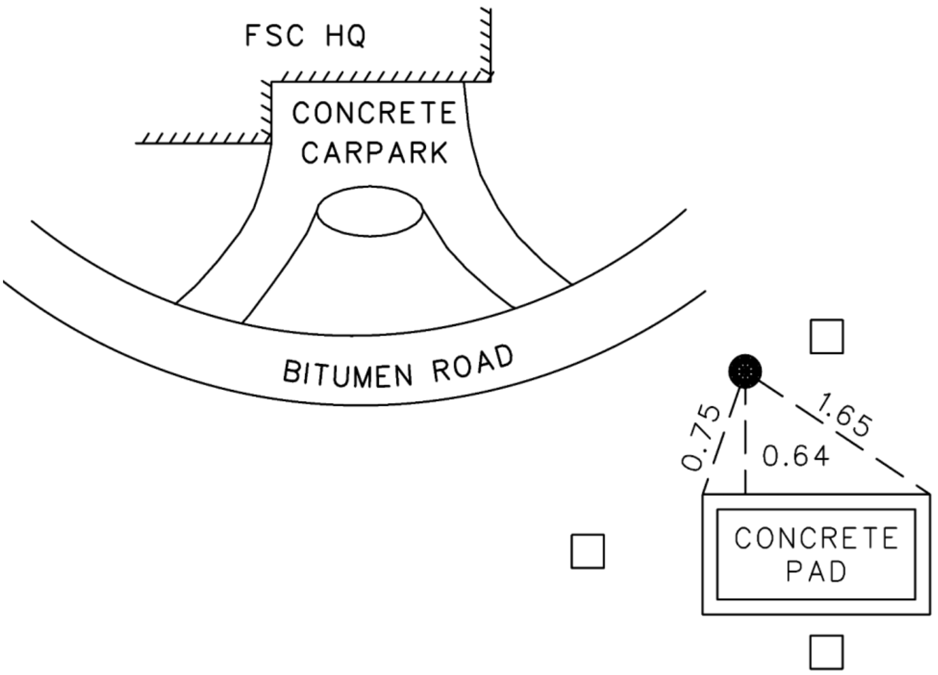
Notes / References: Deep Benchmark
This survey mark is in a good locality for GNSS occupation.

Country: Fiji Islands
Island: Viti Levu
City: Lautoka

MARKING AND LOCALITY SKETCH

Bench Mark: 4.2m of 19mm diameter stainless steel capped rod driven to refusal. Rod sheathed with 50mm diameter PVC tube, filled with bentonite for top 0.3m. Top of mark 0.1m below ground level.

Locality sketch: Mark approximately 1800m from the tide gauge station



NOT TO SCALE Distances in Metres Magnetic Bearings

Approved by: Geoscience Australia / SPC *Date: Dec 2007*

PACIFIC SEA LEVEL MONITORING PROJECT

SURVEY BENCH MARK RECORD

Bench Mark Number: BM3248

Original Bench Mark Established by: *Date: 27/02/2002*
National Geospatial Reference Systems, Geospatial & Earth Monitoring Division (GEMD), Geoscience Australia

Existing Bench Mark Established by: *Date:*

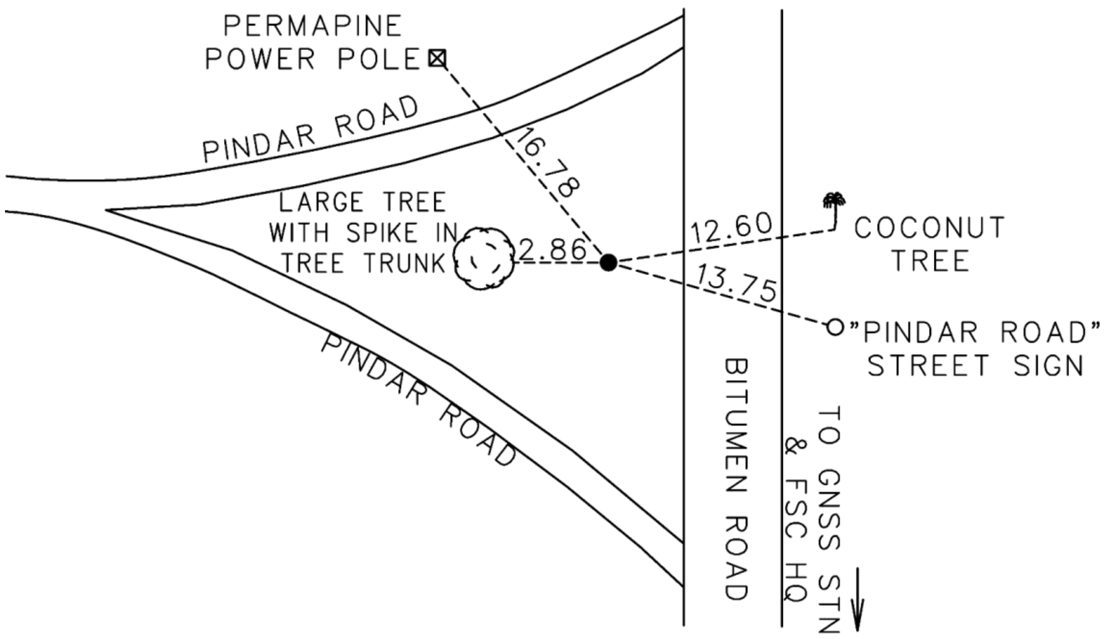
Notes / References: Deep Benchmark
This survey mark is not in a good locality for GNSS occupation.

Country: Fiji Islands
Island: Viti Levu *City: Lautoka*

MARKING AND LOCALITY SKETCH

Bench Mark: 4.2m of 19mm diameter stainless steel capped rod driven to refusal. Rod sheathed with 50mm diameter PVC tube, filled with bentonite for top 0.3m. Top of mark 0.1m below ground level.

Locality sketch: Mark approximately 2250m from the tide gauge station



NOT TO SCALE Distances in Metres Magnetic Bearings

Approved by: Geoscience Australia / SPC *Date: Dec 2007*

PACIFIC SEA LEVEL MONITORING PROJECT

Australian Government
Geoscience Australia

Pacific Community
Communauté du Pacifique

SURVEY BENCH MARK RECORD

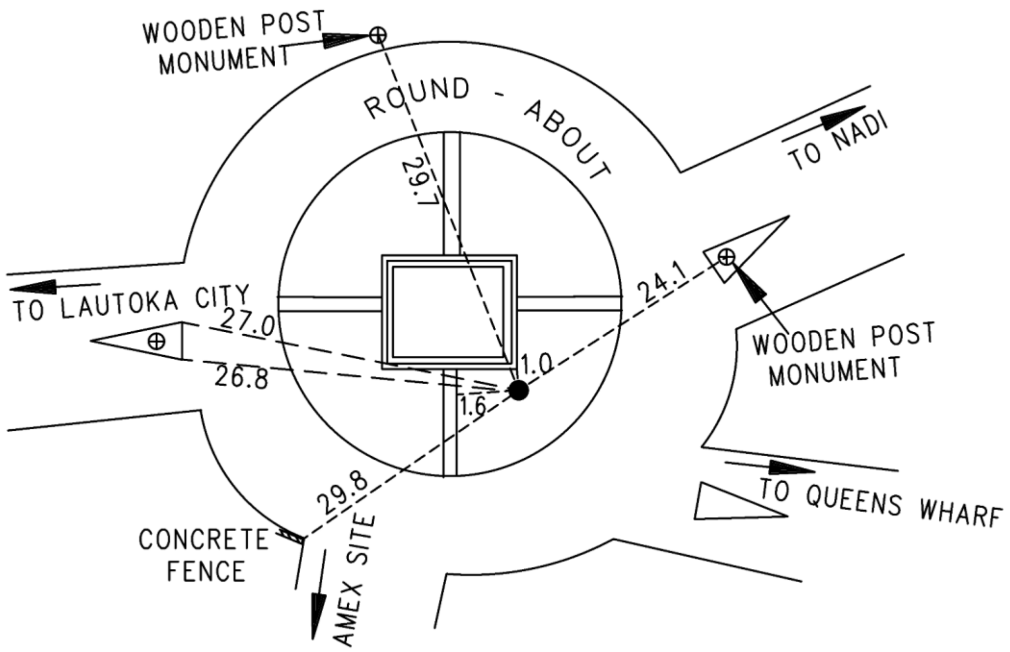
Bench Mark Number: BM3250

Original Bench Mark Established by: National Geospatial Reference Systems, Geospatial & Earth Monitoring Division (GEMD), Geoscience Australia	*Date: 29/01/2016*
Existing Bench Mark Established by:	*Date:*
Notes / References: Deep Benchmark This survey mark is in a good locality for GNSS occupation.	
Country: Fiji Islands *Island: Viti Levu*	*City: Lautoka*

MARKING AND LOCALITY SKETCH

Bench Mark: 3.0m of 19mm diameter stainless steel capped rod driven to refusal. Rod sheathed with 50mm diameter PVC tube. Top of mark 0.1m below ground level.

Locality sketch: Mark approximately 300m from the tide gauge station

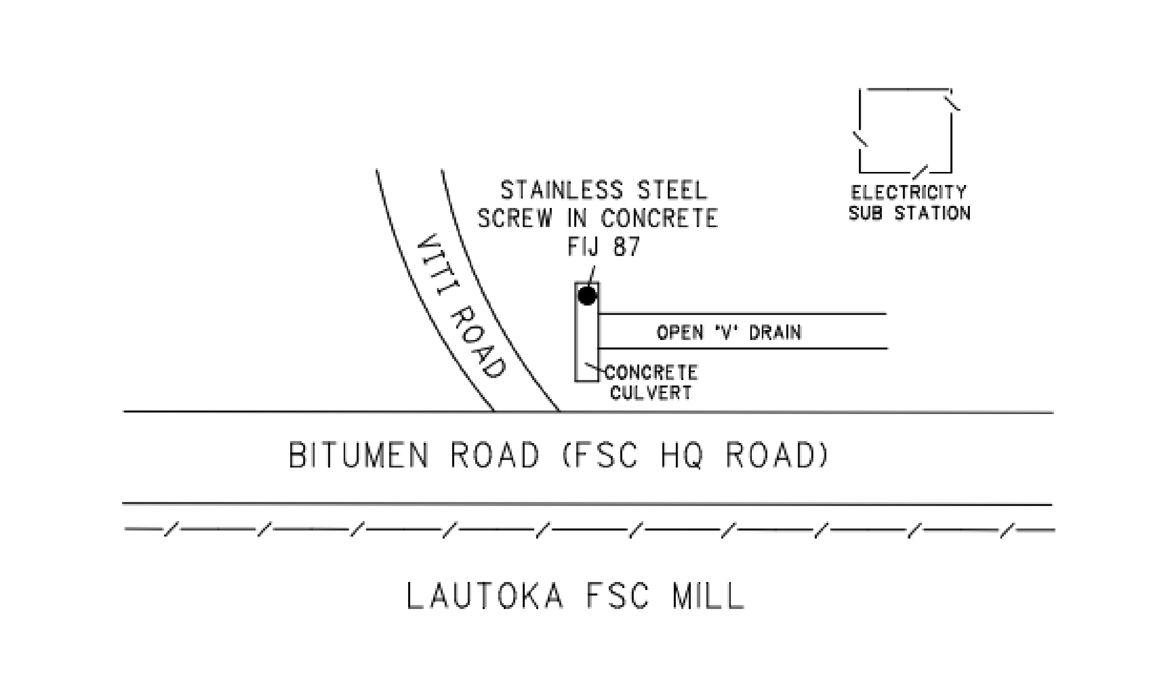


NOT TO SCALE   Distances in Metres   Magnetic Bearings

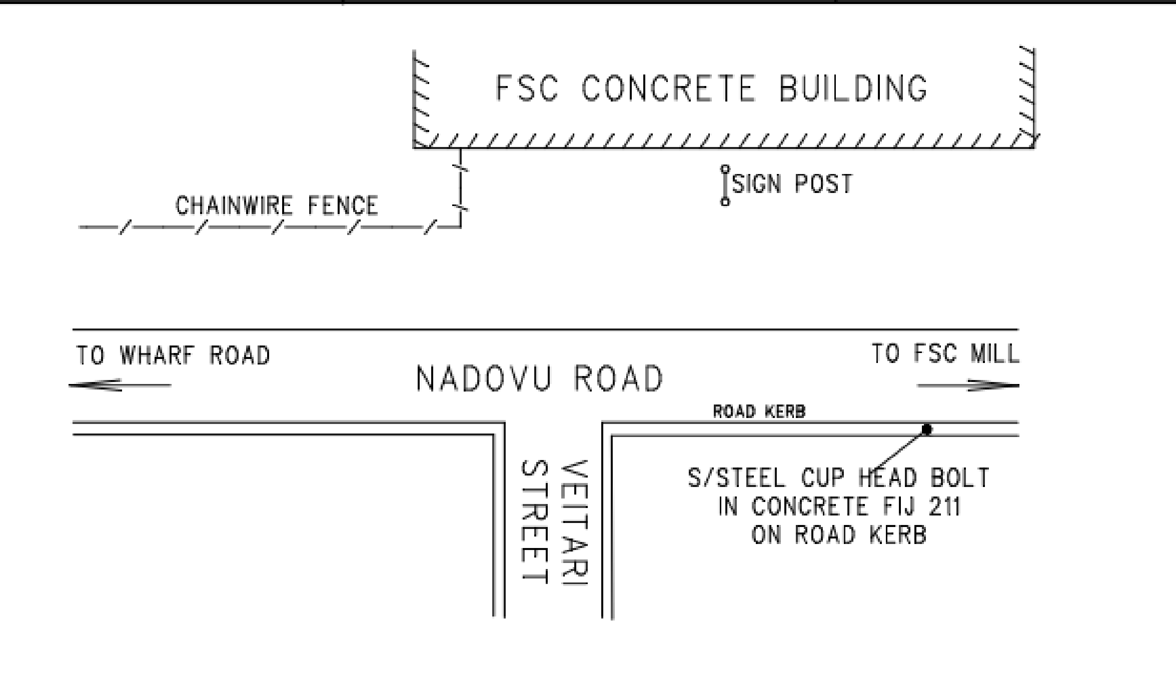
Approved by: Geoscience Australia / SPC   *Date: Dec 2007*

A 2 Temporary Holdings Marks

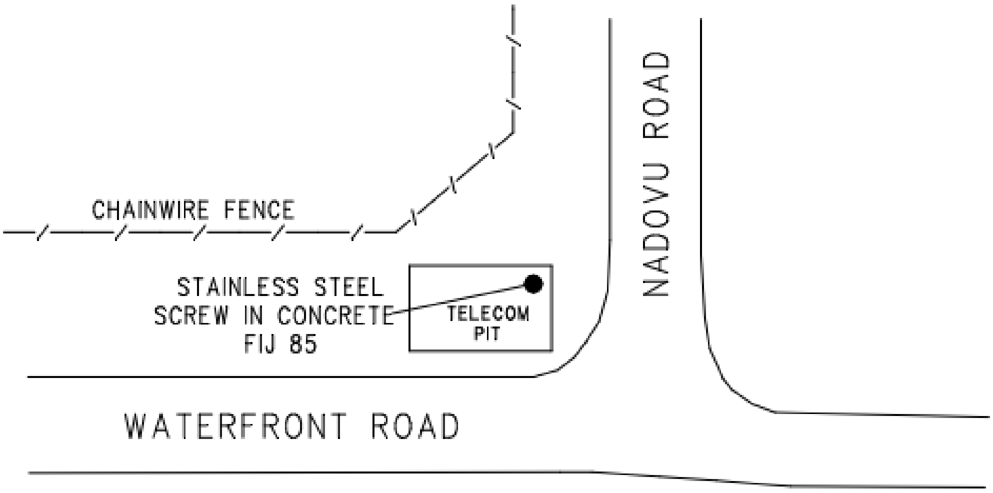
COUNTRY: Fiji Islands	ISLAND: Viti Levu CITY: Lautoka	L. D. P. 860 POINT NO. FIJ87
PROJECT: PSLGM	SURVEYOR: S Yates & A Lal	DATE: 03-10-08



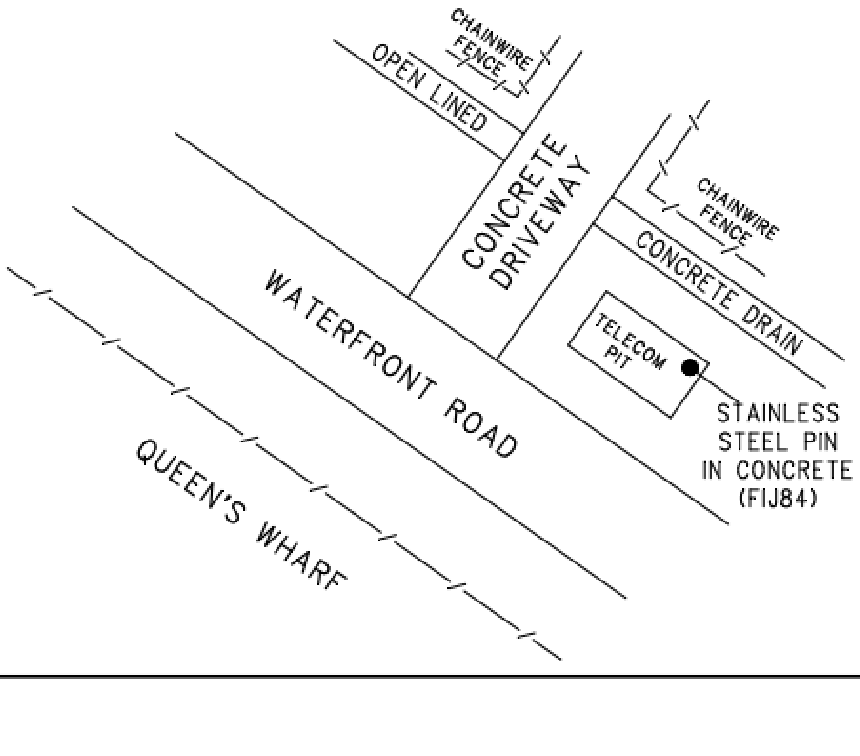
COUNTRY: Fiji Islands	ISLAND: Viti Levu CITY: Lautoka	L. D. P. 854 POINT NO. FIJ211
PROJECT: PSLGM	SURVEYOR: M Deo & A Lal	DATE: 22-02-10



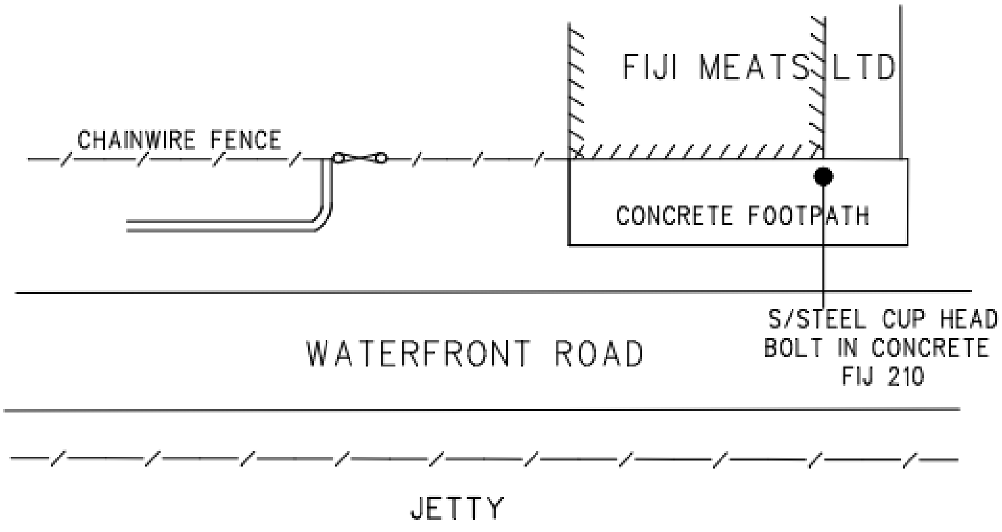
COUNTRY: Fiji Islands	ISLAND: Viti Levu CITY: Lautoka	L. D. P. 858 POINT NO. FIJ85
PROJECT: PSLGM	SURVEYOR: S Yates & A Lal	DATE: 03-10-08



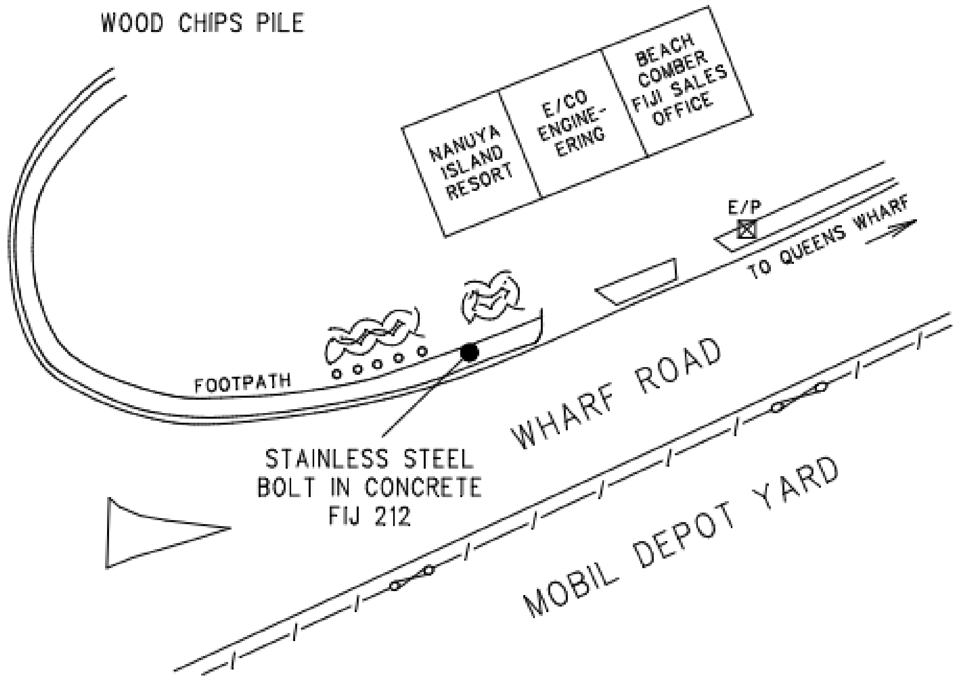
COUNTRY: Fiji Islands	ISLAND: Viti Levu CITY: Lautoka	L. D. P. 857 POINT NO. FIJ84
PROJECT: PSLGM	SURVEYOR: S Yates & A Lal	DATE: 03-10-08



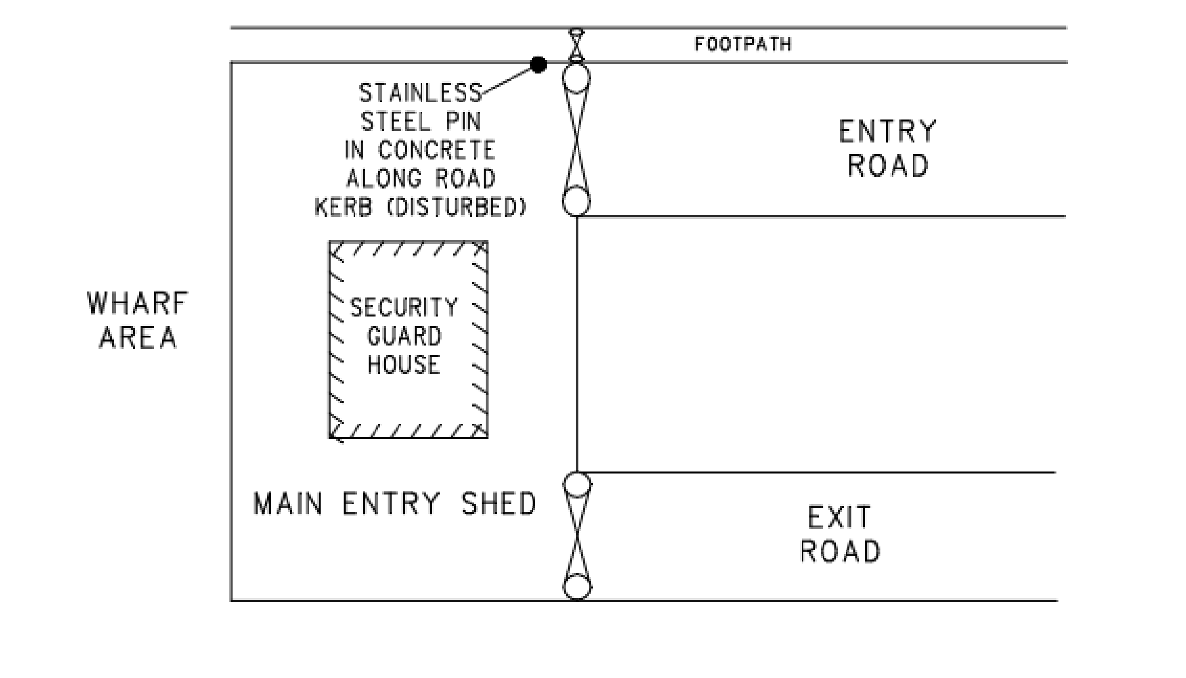
COUNTRY: Fiji Islands	ISLAND: Viti Levu CITY: Lautoka	L. D. P. 856 POINT NO. FIJ210
PROJECT: PSLGM	SURVEYOR: M Deo & A Lal	DATE: 22-02-10



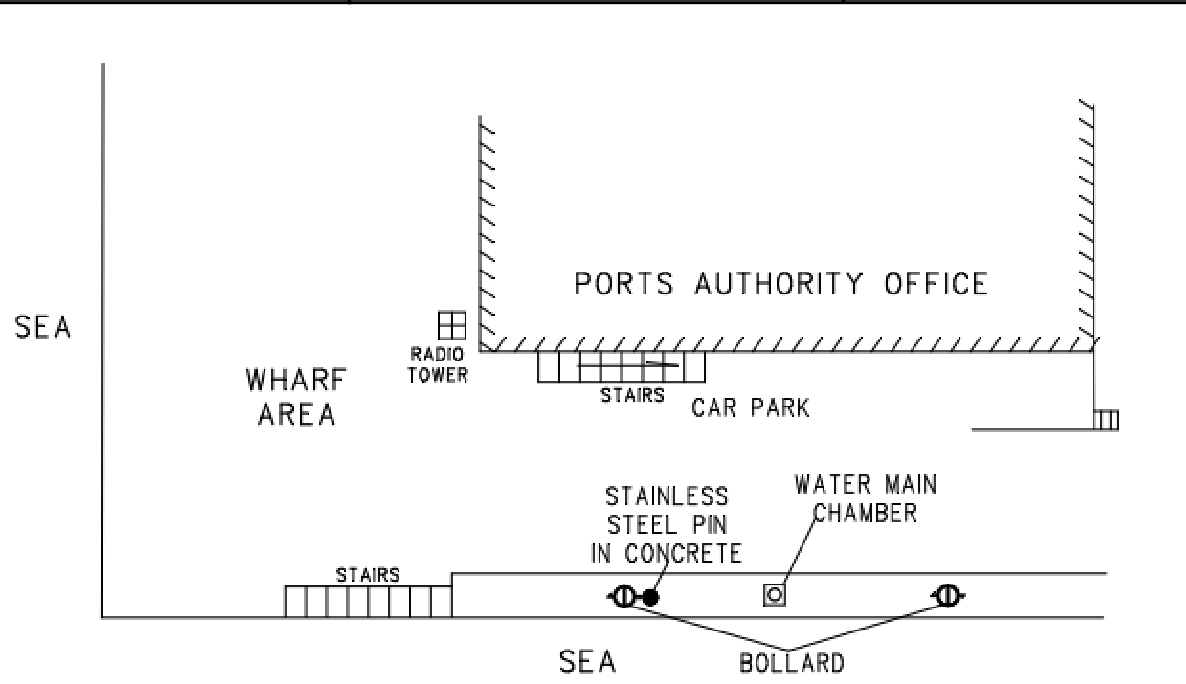
COUNTRY: Fiji Islands	ISLAND: Viti Levu CITY: Lautoka	L. D. P. 870 POINT NO. FIJ212
PROJECT: SPSLCMP	SURVEYOR: S Yates & A Lal	DATE: 27-07-11



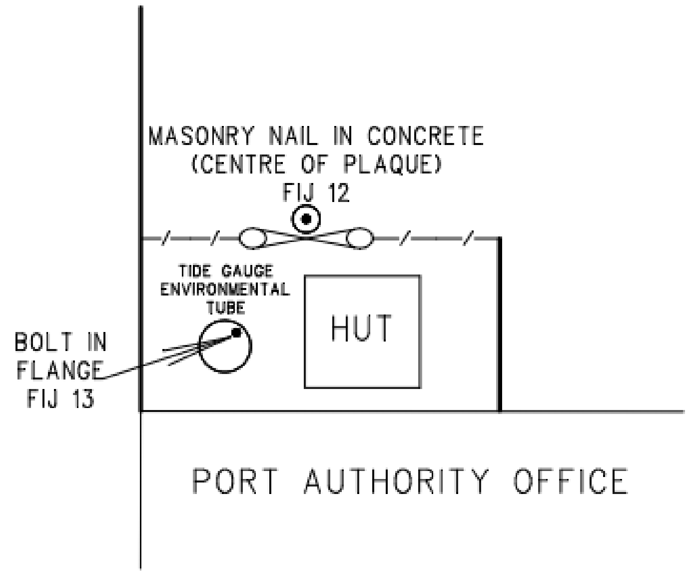
COUNTRY: Fiji Islands	ISLAND: Viti Levu CITY: Lautoka	L. D. P. 851 POINT NO. FIJ81
PROJECT: PSLGM	SURVEYOR: S Yates & A Lal	DATE: 03-10-08



COUNTRY: Fiji Islands	ISLAND: Viti Levu CITY: Lautoka	L. D. P. 853 POINT NO. FIJ207
PROJECT: PSLGM	SURVEYOR: S Yates & A Lal	DATE: 03-10-08



COUNTRY: Fiji Islands	ISLAND: Viti Levu CITY: Lautoka	L. D. P. 850 POINT NO. FIJ12 & 13
PROJECT: PSLGM	SURVEYOR: S Yates & A Lal	DATE: 03-10-08

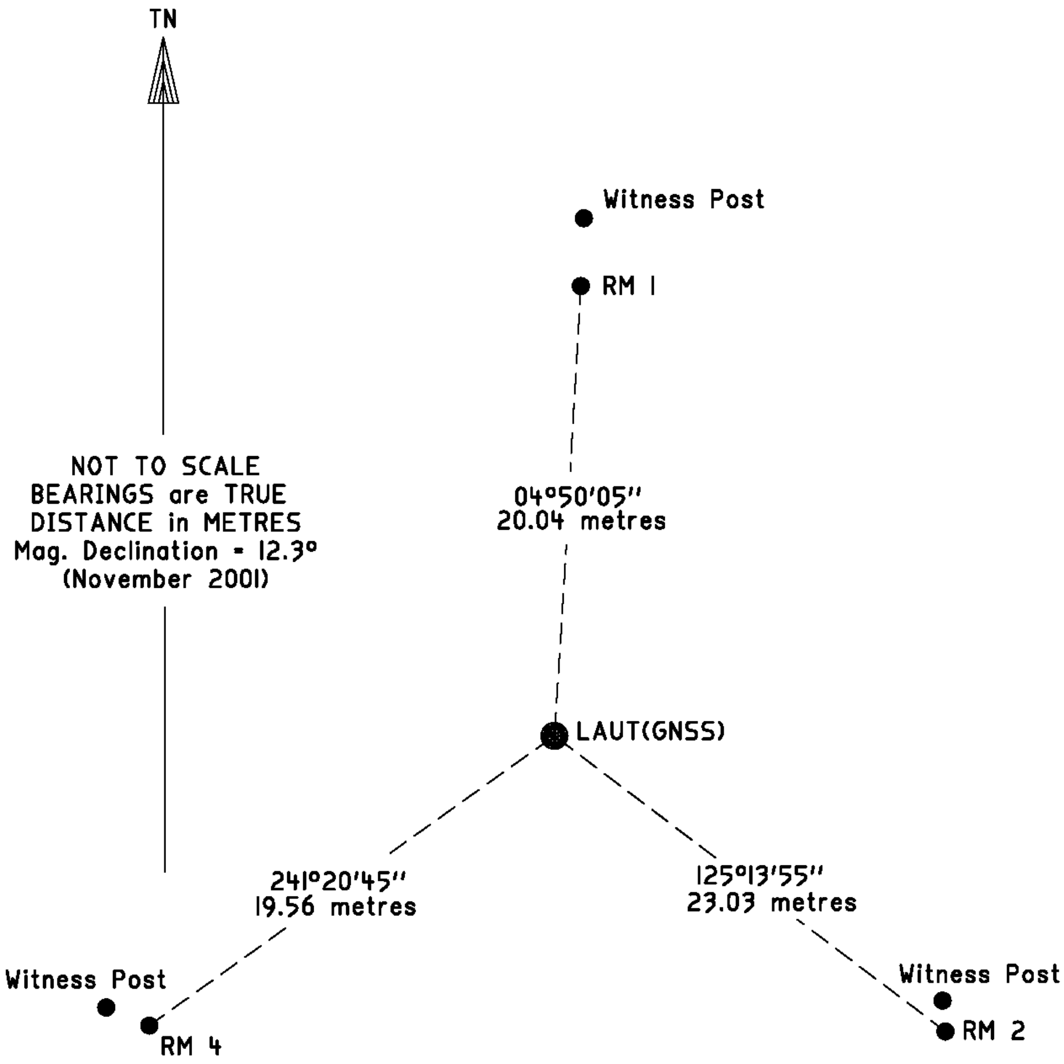


A 3 GNSS Site Reference Marks

LAUT GNSS Station - Reference Marks

REFERENCE MARKS

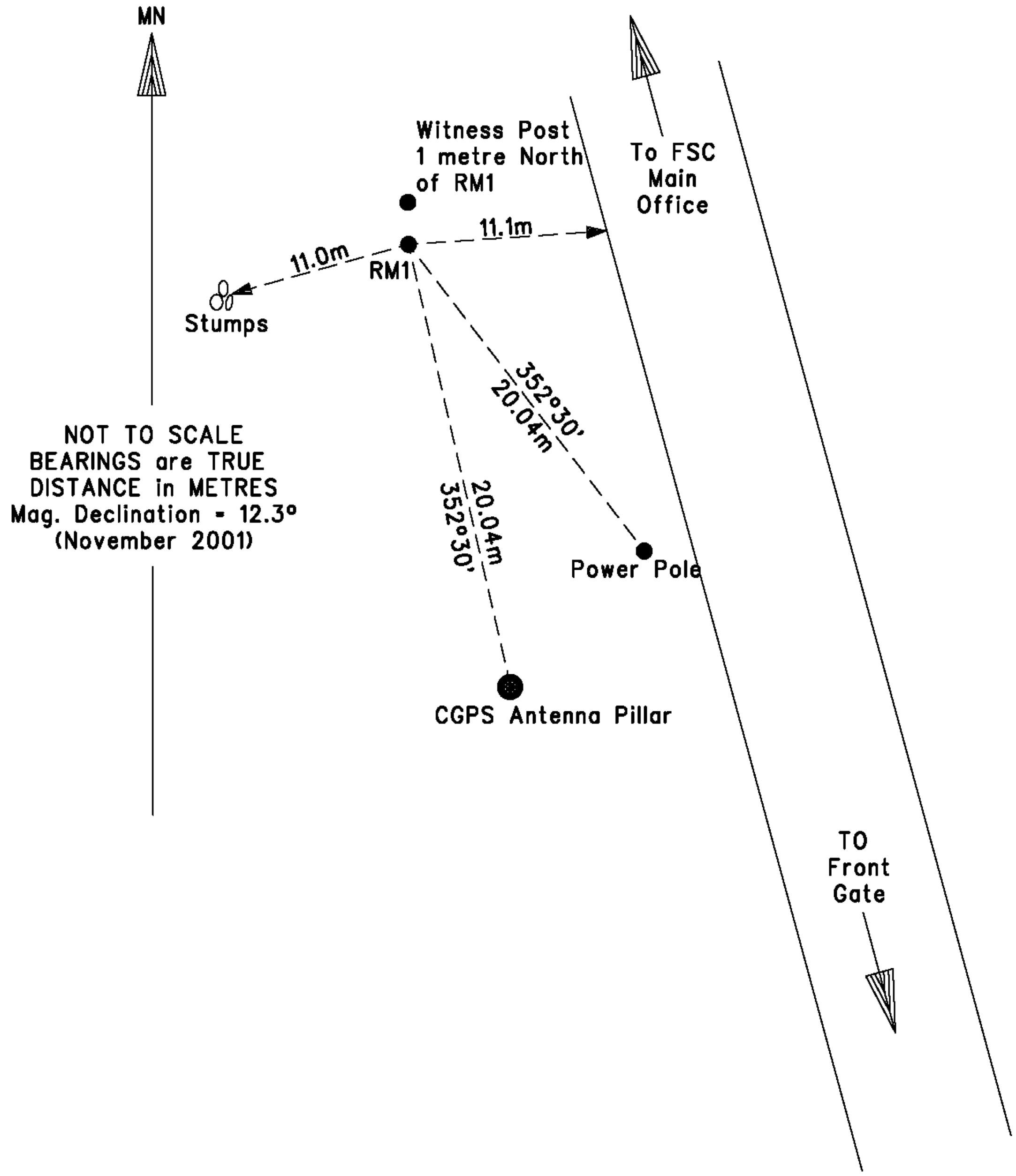
All RM's are capped 20mm stainless steel rods driven to refusal and protected by 150mm PVC pipe within circular poly carbonate valve boxes. the valve box lids are approxomately 150mm below ground level. Treated pine witness posts 150mm in diameter and 1.4n high are located 1 metre to the north of each RM



FIJI GNSS Station, FSC Lautoka - RM 1 Location Diagram

REFERENCE MARKS

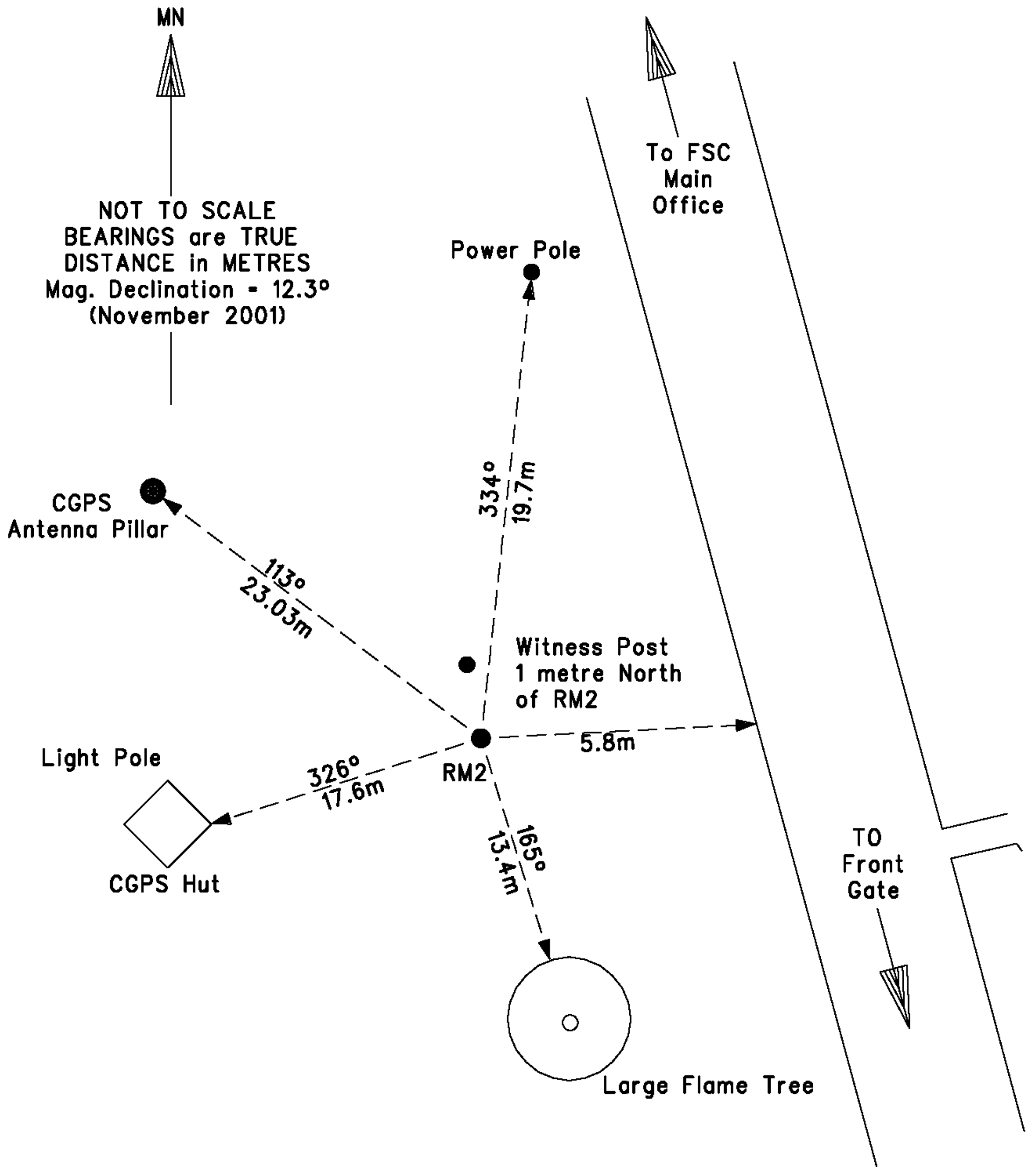
All RM's are capped 20mm stainless steel rods driven to refusal and protected by 150mm PVC pipe within circular poly carbonate valve boxes. the valve box lids are approxomately 150mm below ground level. Treated pine witness posts 150mm in diameter and 1.4n high are located 1 metre to the north of each RM



FIJI GNSS Station, FSC Lautoka - RM 2 Location Diagram

REFERENCE MARKS

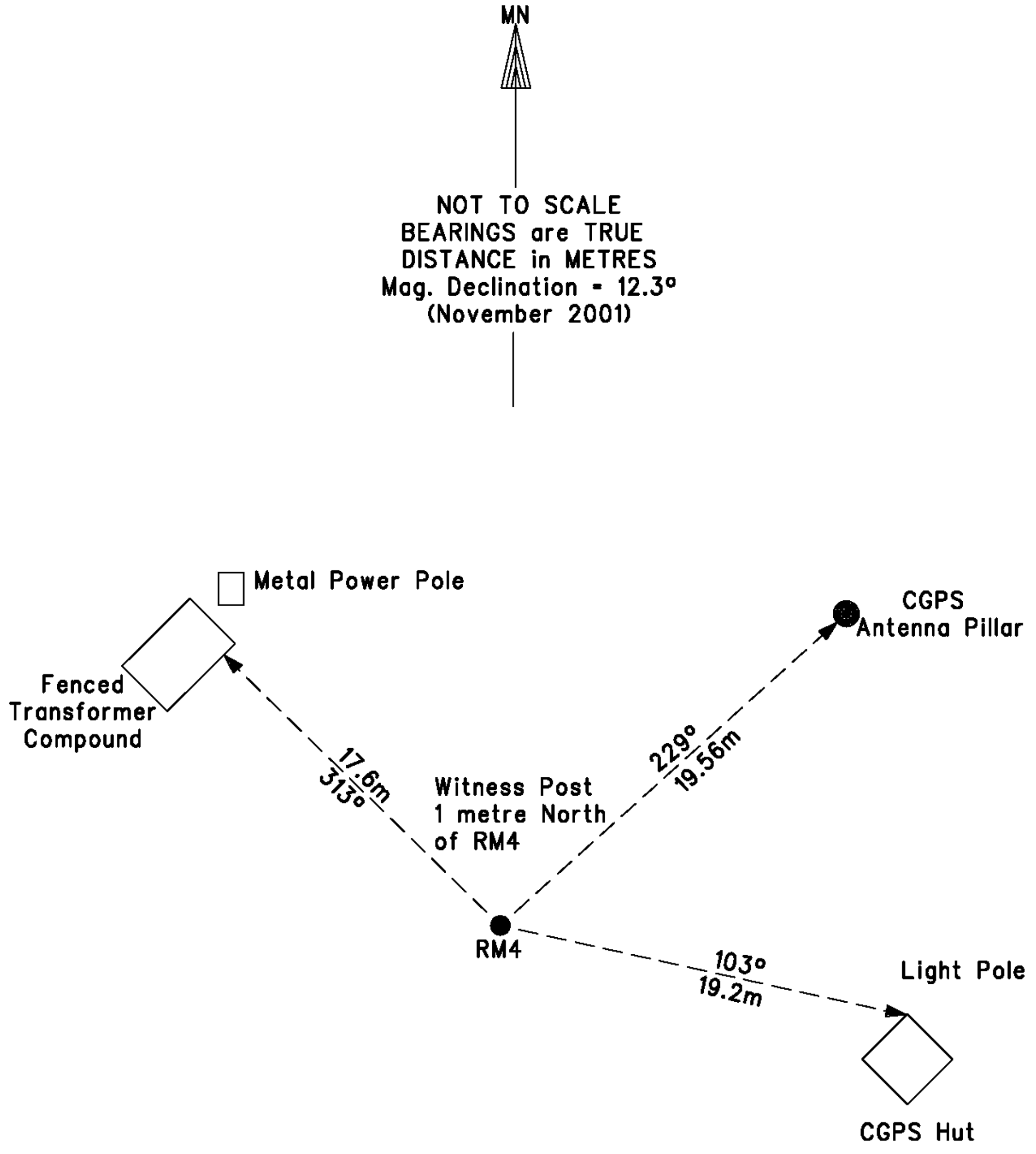
All RM's are capped 20mm stainless steel rods driven to refusal and protected by 150mm PVC pipe within circular poly carbonate valve boxes. the valve box lids are approxomately 150mm below ground level.
Treated pine witness posts 150mm in diameter and 1.4n high are located 1 metre to the north of each RM



FIJI GNSS Station, FSC Lautoka - RM 4 Location Diagram

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 approxomately 150mm below ground level. Treated pine witness posts 150mm in diameter and 1.4n high are located 1 metre to the north of each RM



Appendix B Planning Aspects and Notes

Upon arranging travel to Lautoka, make contact with the project focal point at the Survey Office and the Port Authority at least one month in advance. Also, you will need a valid port user ID card and you will need to attend OHS training before carrying out any work within wharf area

Daily allowance for food and water was provided to Local Surveyor

The GNSS COR Station and the GNSS Pillar was also cleaned.

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

Quantity	Item & description	Locations
1	**Tool Box**	SPC Office Suva
2	*Prism Pole Clamps*	
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 Suva
1	*Aluminium GST6 tripod with Feet*	
1	**PVC Pipe (1.7m)**	SPC Office Suva
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**	SPC Office Suva
1	**Green Bag - Leica GST40 Rigid Tripod**	SPC Office Suva
1	**Spade**	Lautoka GNSS COR Station Hut

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 0.44×10^{-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:

- Septentrio GNSS Receiver SEPT POLARX5 GNSS receiver Firmware Version: 5.5.0 S/N 3025125
- Javad Choke Ring antenna (JAVRINGANT_DM NONE) -S/N 00682