GNSS Heighting and Its Potential Use in Malaysia

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SUMMARY

A system of vertical control is realised with the establishment of a levelling network whereby the height value of points may be defined. In early 1977, the Department of Survey and Mapping Malaysia (JUPEM) began to undertake definitive steps to prepare for a new vertical control network to replace the old one that had numerous inadequacies. The field operation commenced in 1985 and the Precise Levelling Network (PLN) was completed in 1999.

Nowadays, the widespread use of global navigation satellite system (GNSS), give a great impact to height determination. By improving the geoid in the area, a modern height measurement technique called GNSS heighting can be contemplated as an alternative for practical height applications.

This paper investigates the achievable accuracy of GNSS heighting by comparing GNSS-derived orthometric heights with spirit levelled heights of bench marks. It demonstrates GNSS as a viable technique of transforming GNSS ellipsoidal heights to orthometric heights using a local geoid model. Preliminary results indicate that the accuracy achievable by GNSS heighting in Malaysia can provide second order levelling standard.

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1. INTRODUCTION

The realisation and maintenance of the national reference systems for horizontal and vertical control in Malaysia falls under the jurisdiction of the Department of Survey and Mapping Malaysia (JUPEM). Malaysia still base its geodetic, cadastral, engineering and mapping activities with the production of accurate maps and survey information on networks that were observed during the 1900s. Such systems have been the 2-dimensional triangulation networks and a separate 1-D height networks.

For the past 100 years, traditional spirit levelling has been a technique of choice in the determination of orthometric heights. It is simple, the operation is effective, the method has remained basically unchanged, and yet it can achieve a remarkable accuracy. However, the observational time is too lengthy, making it a slow, labour-intensive, painstaking and costly operation. It is also a line operation whereby points whose heights are required need to be interconnected by a series of levelling lines. This makes levelling operation prone to many systematic errors which are difficult to detect and eliminated. Thus in recent times, many efforts were made to develop alternative techniques and technologies to levelling to suit current needs.

In this paper, three case studies were conducted in Peninsular Malaysia on height determination using global navigation satellite system (GNSS). The purpose of these studies was to compare the height component results of the GNSS heighting with those obtained from levelling.

2. HISTORICAL BACKGROUND

The earliest attempt to establish a vertical datum in Malaysia was carried out by the British Admiralty in 1908 at Port Swettenham, which is now named Port Klang. However, the mean sea level (MSL) was derived from a 5-month tidal observation and was strictly local in nature. It was intended to fulfill the 'surrounding' requirements during the period, and never used as the national vertical datum. The reference bench mark (BM) is no longer in existence today due to the damage caused by heavy development within the vicinity of Port Klang.

It was not until 1912 that the British Admiralty established what has become the first national levelling datum for Peninsular Malaysia with the first line levelled between Port Klang and Kuala Lumpur. It was based on a 8-month tidal observation carried out by the HMS Waterwitch between noon of September 1, 1911 and May 31, 1912, at Port Klang. This datum (LSD12) continued to serve vertical control users in Peninsular Malaysia for more than 80 years.

2.1 The Need for a New Levelling Network

Like most countries around the world, a nation-wide levelling network in Peninsular Malaysia was first established at the turn of the last century. This network is referred to as the First Order Levelling Network of 1967 (FOLN67). This was followed by a second vertical control network called the Precise Levelling Network (PLN).

The FOLN67 network that was built sporadically over 50 years had become obsolete and new levellings are in dire need to meet modern demands. The combined influence of the factors that contributed to the need of a new vertical control network for Peninsular Malaysia can be summarised as follows:

- ad-hoc nature of the levelling operation;
- survey methods, instruments and standards of accuracy were not documented;
- long period of survey to complete the network;
- low coverage of the bench marks;
- LSD12 is based on MSL derived from just 1-year tidal observational data;
- no consistency with levelling networks of neighbouring countries, Thailand and Singapore;
- no single adjustment of the network ever attempted;
- no application of orthometric correction;
- most BMs are either missing or damaged; and
- increasing requirements for accuracy and consistency by modern users.

2.2 Implementation of the New Levelling Network

Realising the weaknesses that were inherent in the old network as outlined above, JUPEM in 1977 performed an extensive inventory of the FOLN67. As a first step towards the realisation of a new levelling network for Peninsular Malaysia, a field inspection on the overall status of the BMs was carried out. The field inspection revealed that out of 2532 BMs in the network, only 1009 BMs or about 40% of the total number of BM was found to be intact, whilst others were reported to be either missing or damaged. As a result, JUPEM has given a serious consideration to the possibility of undertaking a programme of precise levelling over the whole Peninsular Malaysia. A review soon followed, specifying the tasks and requirements to realise a new levelling network.

As a result, a comprehensive plan was outlined that included the following strategies:

- replace all missing or damaged bench marks as well as establish new ones with better designs and specifications;
- establish a network of first order precise levelling lines, known as the Precise Levelling Network (PLN), with accuracy equal or better than 3 millimetres per root kilometre of length ($3mm\sqrt{km}$) that will support second order levelling lines with

accuracies equal or better than 12 millimetres per root kilometre of length ($12mm\sqrt{km}$);
- set up a network of tidal observations at selected sites along the coast of Peninsular Malaysia for the redefinition of the vertical datum;
- perform gravity measurements on bench marks to derive orthometric corrections for the levelling network; and
- explore into the use of motorised levelling and digital levelling techniques in order to expedite the completion of the levelling network.

2.3 Peninsular Malaysia Geodetic Vertical Datum (PMGVD)

The LSD12 has remained unchanged since it was established in 1912 and derived from 8-month tidal observational data at Port Klang. In 1983, JUPEM began to redetermine the precise MSL value in conjunction with the establishment of the new PLN for Peninsular Malaysia. This was carried out by the setting-up of a Tidal Observation Network that consists of 12 tidal stations. Subsequently, Port Klang was selected for the adoption as a reference level for the new vertical datum origin, based upon a 10-year tidal observation (1984-93). This new datum is known as the Peninsular Malaysia Geodetic Vertical Datum (PMGVD). The new mean sea level is adopted as 3.624 m above the zero tide gauge. It was found out that PMGVD is lower than LSD12 by 65mm.

In 1994, a monument to signify the establishment of the PMGVD was built within the JUPEM compound in Kuala Lumpur (Figure 1.0). Here, the tidal datum at Port Klang was extended to the new monument via precise levelling and gravity survey.

2.4 Network Configuration of the PLN

Peninsular Malaysia, especially the western portion has benefited greatly from heavy development of the road and rail systems and has provided the necessary infrastructure on which the levelling network was based. Hence, it is only logical that the configuration of PLN is predominantly dictated by its land transportation pattern.

During the planning stage, the first priority was to improve the old network of FOLN67 by extending it to form a stronger framework. Old levelling routes would still be followed if suitable and missing marks were to be replaced accordingly. In the meantime, new routes would also be identified. Priority attention was given to areas of greatest development or having the potential to develop.

Figure 1.0 Monument signifying the establishment of PMGVD

Initially, JUPEM decided that the levelling lines were to follow highways and major roads. However the planned network outgrew the original design to take into account new development. In the north, the levelling loops are much larger due to the presence of difficult terrain and the scarcity of routes that permits running precise levels. The levelling operation commenced in 1985 and it was completed in 1999.

Figure 2.0 shows the final and main levelling frame of PLN. It consists of 113 first order levelling lines with 5443 bench marks, involving a total distance of 5004 km. Twenty-two main loops make up the network that covers a geographical area of about 131, 598 km^2. There also exists within the network an array of second class levelling lines.

2.5 Precise Levelling Field Specifications and Techniques

In Peninsular Malaysia, there exist two classes of levelling being undertaken by JUPEM. These are defined in accordance to the permissible discrepancy between the forward and return levellings as follows:

Class of Levelling	**Permissible Discrepancy (mm)**
1^{st} Order	$0.003 \sqrt{K}$
2^{nd} Order	$0.012 \sqrt{K}$

where K is the distance in kilometers between two successive bench marks along a levelling line.

Figure 2.0 The extent of Precise Levelling Network in Peninsular Malaysia

Figure 3.0 shows the error curves for the two orders of levelling over increasing distance as applied in Peninsular Malaysia. The average distance between standard bench marks (SBMs) is normally about 5 km and this equates to a permissible misclosure of 6.71 mm in first order levelling work and 26.83 mm in second order levelling work.

3. USE OF GNSS IN HEIGHTING

Nowadays, the many benefits offered by Global Navigation Satellite System (GNSS) have made it a suitable alternative over traditional levelling. This has prompted many countries including Malaysia to not only upgrade their existing reference systems to be GNSS-compatible, but also to seriously look into the potential use of GNSS in heighting.

However, there are several problems associated with the use of GNSS in vertical positioning. First GNSS gives elevations above a reference ellipsoid, World Geodetic System 1984

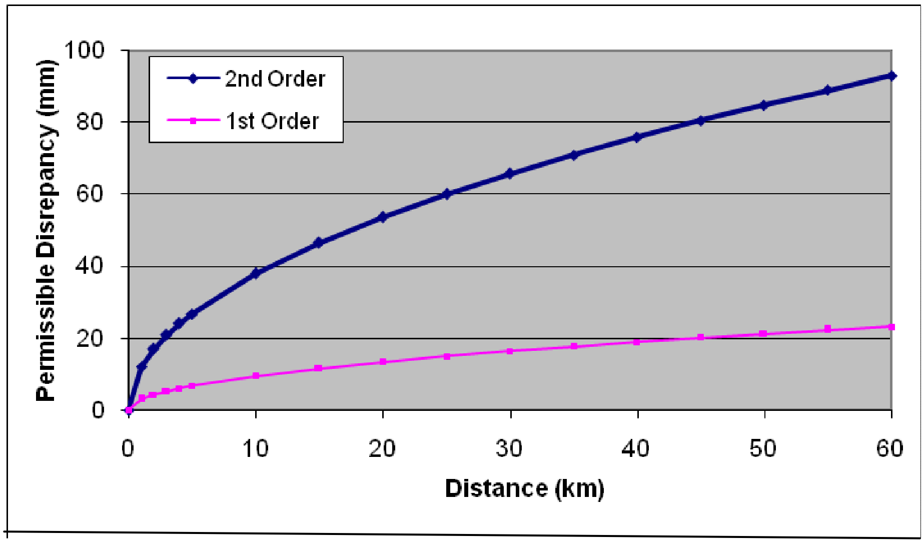

Figure 3.0 Permissible discrepancy curves in levelling

(WGS84). It gives heights that cannot be used directly with traditional orthometric height datums especially in determining the directions of water flow. Neither could the ellipsoidal heights be directly incorporated into the gravity based height systems. Most applications require that orthometric heights to be compatible with the PMGVD.

Therefore, GNSS-based heighting technique need to use ellipsoidal height differences as well as the geoidal height differences in order to obtain orthometric height differences. In order to derive GNSS height with respect to this vertical datum, the geoid-ellipsoid separation needs to be deduced.

As such, orthometric heights can only be obtained from the knowledge of ellipsoidal height from GNSS and geoidal heights from a geoid model.

The basic relationship is represented by the following formulae (Heiskanen & Moritz, 1967):

$$\Delta H = \Delta h - \Delta N$$

where ΔH is the GNSS-derived orthometric height differences, Δh is the ellipsoidal height differences and ΔN is the geoidal height differences. Thus, orthometric heights derived from GNSS and the geoid model can then be compared to the corresponding values obtained by levelling. As most engineering and mapping activities are referenced to an orthometric height surface, GNSS users requiring orthometric heights need to perform geoid modeling.

3.1 Geoid

The determination of geoid involves the gathering of gravity data over a wide area, mostly through surface and airborne gravity measurements. In order to acquire the data, JUPEM has carried out an Airborne Gravity and Geoid Mapping Project for the Peninsular Malaysia, Sabah and Sarawak in 2001-2005. The objectives of the project are:

(i) To provide a dense gravity data at 2 mGal accuracy of gravity anomaly data at 5 km spacing; and
(ii) To provide relative geoid accuracy of 5 cm and 1-2 ppm for the Malaysian region.

The airborne gravity survey has been carried out in Sabah and Sarawak in 2002, continued in Peninsular Malaysia in 2003 and 2004. The airborne gravity survey, surface, marine and satellite altimetry gravity data have been combined to produce a gravimetric geoid. Later, the geoid is fitted to the local bench marks to produce a gravimetric geoid model which is known as MyGEOID (Figure 4.0) and the accuracy of the model is ±5 cm.

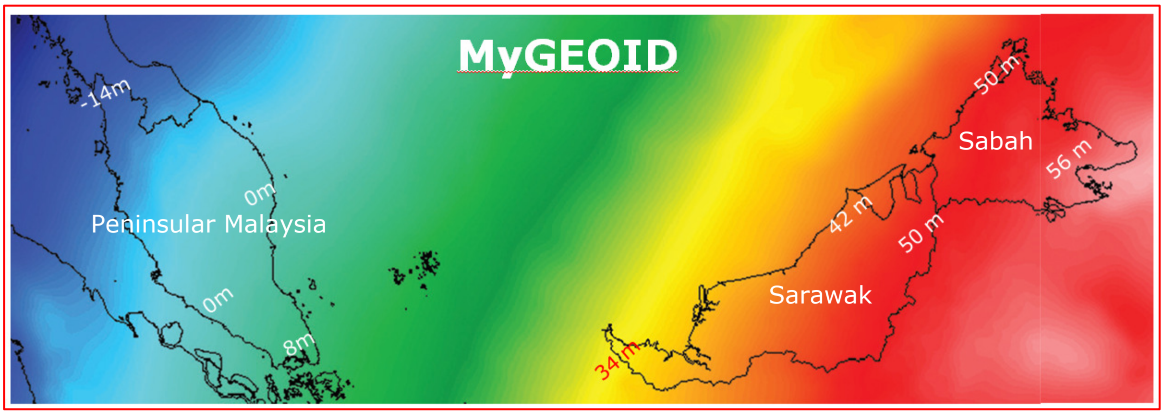

Figure 4.0 : Final output of MyGEOID for Malaysia

MyGEOID is meant to complement and strengthen the existing geodetic infrastructure for Malaysia, consequently enabling the extended use of services rendered by GNSS. MyGEOID consists of the following:

- Peninsular Malaysia : WMGEOID04
- Sarawak and Sabah : EMGEOID05

The geoid models are hybrid ones, combining the gravimetric geoids with datum transformations and GNSS ellipsoid heights on levelled bench marks. The WMGEOID04 geoid model is fitted to the PMGVD in Peninsular Malaysia, which is based on 10 years observation of the Mean Sea Level at Port Klang (1984-1993). The EMGEOID05 geoid model for Sabah and Sarawak is fitted to the Sabah Datum 1997 which is based on 10 years of Mean Sea Level observation at Kota Kinabalu Tide Gauge Station (1988-1997).

3.2 Recommended Procedures for GNSS-Derived Orthometric Height

In order to achieve orthometric height of 5 cm or better accuracy, at least the same level of accuracy must be obtained in GNSS derived ellipsoidal heights. Therefore, it is important to ensure that all components of GNSS observation meet the following requirements:

- Dual-frequency GNSS receivers with full-wavelength are required for all observations of base lines greater than 10 km;
- Geodetic antennas with ground planes or multipath mitigation capability are required;
- All antennas used during a project should be identical; otherwise corrections must be made for antenna phase patterns; and
- Height of antenna must follow manufacturer's specification.

The summary of the recommended guidelines for field and office procedures involved in obtaining GNSS-derived orthometric heights are given in the following Tables 1.0 and 2.0.

Table 1.0 : Guidelines for Field Procedures

Field Procedure		
No.	**Items**	**Parameter**
1.	Observation Technique	Static positioning
2.	GNSS Control	At least 3 stations
3.	Observation Sessions	At least 2 independent sessions
4.	Station Connections	At least 3 independent baselines
5.	VDOP	Less than 6 (90% of the observation session)
6.	Elevation Angle	Above 10°
7.	Satellite Tracking	At least 5 satellites with GDOP of less than 6
8.	Equipment Calibration	As regulated
9.	MyRTKnet Usage	As regulated

Table 2.0 : Guidelines for Office Procedures

Office Procedure		
No.	**Items**	**Parameter**
1.	General Procedure	Prescribed procedures as provided in manufacturer manual must be followed.
2.	Datum	GDM2000
3.	Ephemerides	Short baselines of less than 30 km: Broadcast. Long baselines: precise.
4.	Baseline Processing Quality	RMS less than 2 cm. Maximum data rejection - less than 10 %. Ambiguity fixed solution. Aposteriori variance factor is unity.
5.	Adjustment	Only independent baselines (n-1) should be included in the adjustment. Least square adjustment should be used.
6.	Minimally Constrained Adjustment	1 control station fixed in GDM2000 coordinates.
7.	Quality Indicator	Pass Chi-squares test at 95% confident region. All baselines must pass the local test.
8.	Test on Control Stations	Relative precision must be less than 2 ppm (2D) and 3 ppm on the vertical component.
9.	Over-constrained Adjustment	At least 2 control stations must be fixed in the final adjustment.

4. CASE STUDIES CONDUCTED

The study has been carried out using GNSS in all over Peninsular Malaysia and involved two types of GNSS observation techniques which are real time kinematic (RTK) and static. The studies have been divided into three areas which are:

(i) Penang Bridge
(ii) Peninsular Malaysia
(iii) Tanjung Malim, Perak

Each case study used either RTK or static techniques. With regards to the studies in Penang Bridge and Tanjung Malim, the GNSS observations were carried out using static technique, whilst RTK techniques have been used for the GNSS observation in Peninsular Malaysia.

The observation has been carried out on selected bench marks using Trimble R8 GNSS Receiver. The data has been observed 10 times in 2 epochs. However, the observation using static technique is 5 to 8 hours observation per session. The observational data was downloaded to Trimble Geomatic Office (TGO) to produce final result of GNSS observation data which comprise horizontal positions (i.e. latitude and longitude) and vertical positions (i.e. ellipsoidal height). The N values were obtained from MyGEOID. The GNSS-derived orthometric heights were then compared with levelling heights. Figure 5.0 shows the general overview of the GNSS heighting.

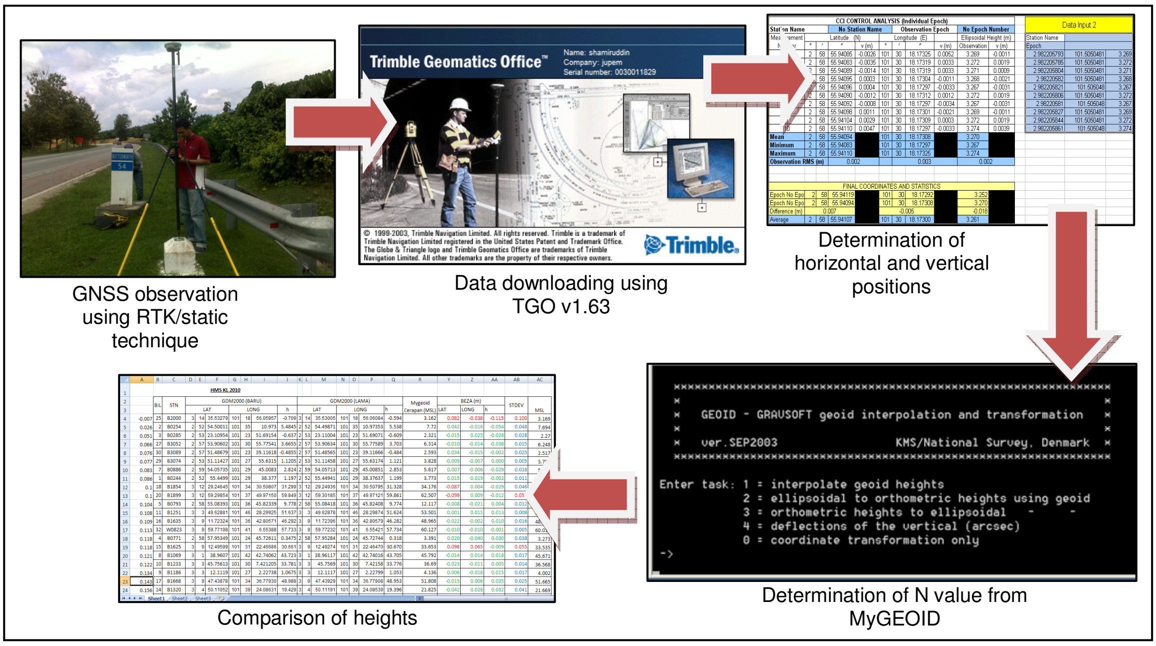

Figure 5.0 : Flowchart of GNSS Heighting

4.1 Penang Bridge

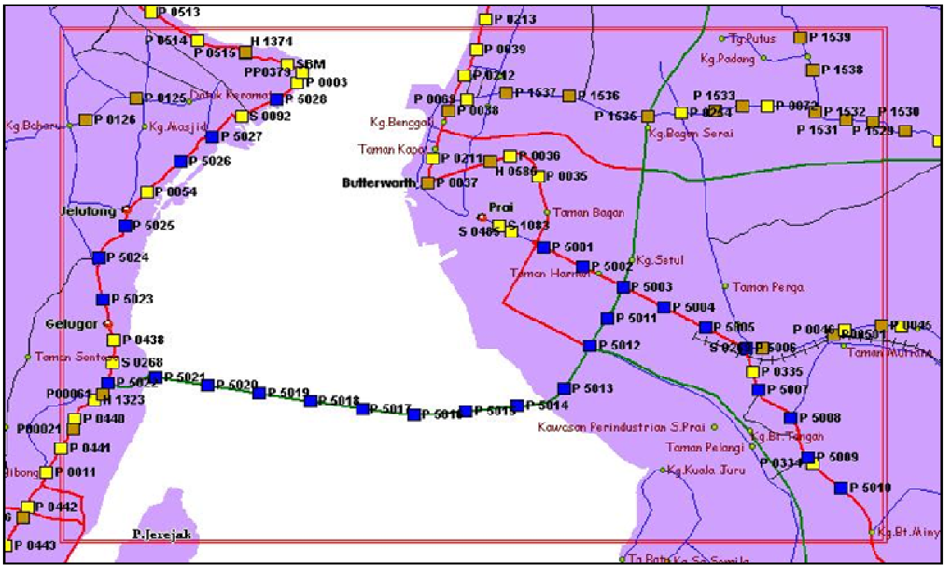

Figure 6.0 : Location of study area in Penang Bridge using static GNSS technique

Based on the study that have been carried out by using static GNSS technique, the difference between GNSS heighting and conventional levelling were less than 1 cm for BM P5009, P5004 and P0431. The results of GNSS heighting at Penang Bridge are shown in Table 3.0.

Table 3.0 : The results of GNSS heighting at Penang Bridge using static technique

STN	GDM2000							N (m)	H_{GNSS} (m)	$H_{Levelling}$ (m)	Diff (m)
	LATITUDE			LONGITUDE			h (m)				
	°	′	″	°	′	″					
P5009	5	22	29. 64183	100	24	19. 55172	-8.431	-11.253	2.822	2.813	0.009
P5004	5	20	50. 01371	100	26	4. 73434	-6.629	-11.114	4.485	4.479	0.006
P0431	5	24	56. 95533	100	20	37. 43134	-9.244	-11.522	2.278	2.275	0.003

4.2 Peninsular Malaysia

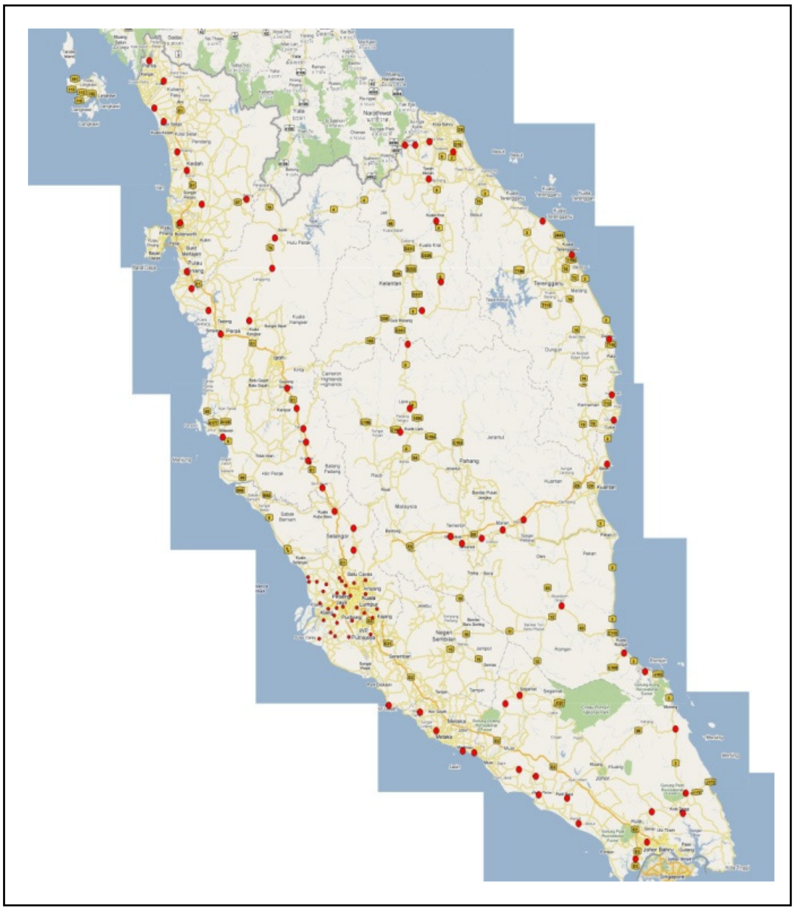

Figure 7.0 : Location of survey area in Peninsular Malaysia using RTK GNSS technique

A study has been carried out in selected parts of Peninsular Malaysia that are categorised by four (4) regions, involving a total number of 77 bench marks (BM) and standard bench marks (SBM), i.e. (i) East Region - 22 BM/SBM; (ii) North Region - 22 BM/SBM; (iii) South Region - 19 BM/SBM; and (iv) Central Region - 14 BM/SBM.

The results are shown in Table 4.0. Figure 8.0 shows the distribution of the difference between orthometric heights as derived from GNSS that has been categorised according to states. Based on the results, there are 59 observations (77%) that give a difference of 10 cm and less and 18 observations (23 %) give a difference between 10 cm to 18.8 cm.

Table 4.0 : The results of GNSS heighting in Peninsular Malaysia using static technique

STN	GDM2000							N (m)	H_{GNSS} (m)	$H_{Levelling}$ (m)	Diff (m)
	LAT			LONG			h (m)				
	°	′	″	°	′	″	°				
C3081	3	4	17.8381	103	4	13.3560	29.303	3.275	26.028	26.022	0.006

C3365	2	46	46.3459	103	29	51.6298	9.739	5.512	4.227	4.290	-0.063
J0291	1	52	8.0409	102	58	46.2029	16.467	4.730	11.737	11.742	-0.005
J1358	1	30	38.5289	103	29	32.3798	19.626	7.358	12.268	12.366	-0.098
J1374	1	41	46.4822	103	6	50.2723	6.953	5.383	1.570	1.478	0.092
J3299	1	33	56.0332	103	36	45.9916	33.115	7.728	25.387	25.416	-0.029
J3418	2	26	27.5438	102	41	5.5994	35.460	2.983	32.477	32.471	0.006
J3736	2	37	24.1799	103	40	34.5558	19.812	6.446	13.366	13.421	-0.055
J3783	2	16	20.3235	103	51	22.2768	25.751	7.631	18.120	18.139	-0.019
J3903	1	59	2.5833	102	52	33.8103	7.469	4.033	3.436	3.301	0.135
J5022	1	44	2.5070	103	42	45.9052	30.546	7.955	22.591	22.631	-0.040
J5352	1	50	55.4423	103	4	32.4083	7.720	5.123	2.597	2.572	0.025
M0872	2	26	49.1414	102	4	13.8250	11.310	0.283	11.027	11.190	-0.163
M5034	2	15	17.2731	102	13	21.9524	11.960	1.067	10.893	11.026	-0.133
M5121	2	8	45.0776	102	24	46.0499	9.738	1.869	7.869	7.903	-0.034
N1580	2	28	14.1765	101	51	29.2393	3.194	-0.658	3.852	3.932	-0.080
S1155	2	30	48.3569	102	48	38.3908	25.087	3.377	21.710	21.741	-0.031
S1157	1	43	24.3026	103	53	54.7369	11.815	8.396	3.419	3.233	0.186
S1165	1	50	48.6709	103	57	14.8943	14.289	8.617	5.672	5.636	0.036
C2193	4	14	34.26344	101	58	49.36640	73.147	-2.210	75.357	75.435	-0.078
C2205	4	20	15.37747	102	1	54.46467	103.111	-2.128	105.239	105.280	-0.041
C2249	4	41	36.01814	102	0	13.35879	152.528	-2.923	155.451	155.419	0.032
C2752	3	37	7.82043	102	48	11.98422	42.697	1.934	40.763	40.951	-0.188
C5197	3	31	58.35132	102	23	44.03667	49.564	0.495	49.069	49.040	0.029
C5204	3	28	42.45596	102	23	38.65620	35.378	0.580	34.798	34.792	0.006
C5290	3	34	7.65056	102	44	10.11232	35.539	1.577	33.962	33.939	0.023
D1061	4	56	22.38679	102	6	17.21499	121.762	-3.198	124.960	124.980	-0.020
D1100	5	26	22.58694	102	14	25.61065	31.161	-4.080	35.241	35.295	-0.054
D1125	5	45	6.86947	102	12	48.65421	26.235	-5.174	31.409	31.423	-0.014
D1142	6	1	22.67900	102	7	3.99242	4.753	-6.189	10.942	11.074	-0.132
D3275	6	2	20.68833	102	11	38.26323	3.988	-5.983	9.971	10.133	-0.162
D3330	5	2	4.98569	102	13	38.95093	118.772	-3.090	121.862	121.816	0.046
S0065	3	24	43.99013	102	2	18.28171	63.136	-0.742	63.878	63.963	-0.085
S0140	3	30	7.70476	102	32	29.89380	42.971	1.127	41.844	41.871	-0.027
S0200	4	45	7.22608	103	24	54.10676	7.657	1.470	6.187	6.223	-0.036
S0283	5	15	50.88208	103	11	3.77234	1.979	-0.625	2.604	2.618	-0.014

S1020	4	25	38.07150	103	27	9.90627	8.315	2.114	6.201	6.190	0.011
S1026	5	53	43.47893	102	20	3.18208	3.191	-5.166	8.357	8.369	-0.012
S5227	5	31	37.19018	102	56	47.41338	2.629	-2.232	4.861	4.827	0.034
S9000	6	2	46.60731	102	8	34.11334	3.455	-6.314	9.769	9.778	-0.009
T3134	4	14	11.56123	103	25	1.54217	8.868	2.504	6.364	6.503	-0.139
A1399	4	8	0.2706	100	44	14.7504	-3.443	-7.543	4.100	4.104	-0.004
S0096	4	49	29.60639	100	42	14.9078	-1.886	-8.900	7.014	7.083	-0.069
S0483	4	56	59.9835	100	37	44.45265	-7.083	-9.496	2.413	2.422	-0.009
A0692	5	4	24.12581	100	30	8.07058	-8.442	-10.106	1.664	1.784	-0.120
S1084	5	7	57.62413	100	28	13.98112	-9.025	-10.453	1.428	1.471	-0.043
S0263	5	29	14.932	100	23	1.73208	-7.691	-11.434	3.743	3.729	0.014
S0501	6	33	20.11833	100	13	44.40812	9.140	-14.384	23.524	23.442	0.082
S0504	6	25	48.63484	100	16	14.36657	-6.814	-13.992	7.178	7.049	0.129
R0433	6	20	22.79337	100	11	34.20657	-10.937	-14.016	3.079	3.020	0.059
S0499	6	10	14.93046	100	18	21.54152	-10.882	-13.144	2.262	2.248	0.014
K5178	5	47	10.01085	100	29	2.73632	37.493	-11.588	49.081	49.069	0.012
K5060	5	39	57.84742	100	32	4.74548	8.306	-11.140	19.446	19.438	0.008
K1538	5	39	35.34173	100	54	8.43215	43.109	-9.640	52.749	52.763	-0.014
A1897	5	23	5.72651	101	3	16.39424	199.747	-8.165	207.912	207.929	-0.017
A3242	5	11	48.39486	101	3	36.02013	83.053	-7.817	90.870	90.846	0.024
A2746	4	49	12.89608	100	53	39.9036	60.108	-8.031	68.139	68.198	-0.059
A2558	4	25	47.33808	101	9	54.56859	36.439	-6.189	42.628	42.639	-0.011
A3766	4	16	16.61183	101	10	9.5367	27.711	-5.915	33.626	33.699	-0.073
A3765	4	6	46.68727	101	17	11.12371	33.598	-5.068	38.666	38.839	-0.173
A3743	3	55	18.95783	101	20	46.09859	48.701	-4.620	53.321	53.344	-0.023
A3723	3	43	24.85438	101	28	16.16937	38.699	-3.606	42.305	42.471	-0.166
B1305	3	38	29.08035	101	33	48.43715	54.551	-3.114	57.665	57.758	-0.093
S1019	3	33	25.93666	101	38	31.69532	69.848	-2.627	72.475	72.626	-0.151
B2000	3	14	35.53279	101	18	56.05957	-0.709	-3.878	3.169	3.162	0.007
B0254	2	52	54.500105	101	35	10.973	5.4845	-2.210	7.694	7.720	-0.026
B0285	2	53	23.10954	101	23	51.69154	-0.637	-2.907	2.270	2.321	-0.051
B3052	2	57	53.90602	101	30	55.77541	3.6655	-2.583	6.248	6.314	-0.066
B3089	2	57	51.48679	101	23	39.116175	-0.4855	-3.003	2.517	2.593	-0.076
B3074	2	53	51.11427	101	27	55.6315	1.1205	-2.631	3.751	3.828	-0.077
B0886	2	59	54.05735	101	29	45.0083	2.824	-2.710	5.534	5.617	-0.083

B0244	2	52	55.4499	101	29	38.377	1.197	-2.490	3.687	3.773	-0.086
B1854	3	12	29.24645	101	34	30.50807	31.299	-2.777	34.076	34.176	-0.100
B1899	3	12	59.29854	101	37	49.97150	59.849	-2.558	62.407	62.507	-0.100
B0793	2	58	55.083925	101	36	45.82339	9.778	-2.235	12.013	12.117	-0.104
B1251	3	3	49.62881	101	46	28.29925	51.637	-1.756	53.393	53.501	-0.108
B1635	3	9	11.72324	101	36	42.80571	46.292	-2.564	48.856	48.965	-0.109

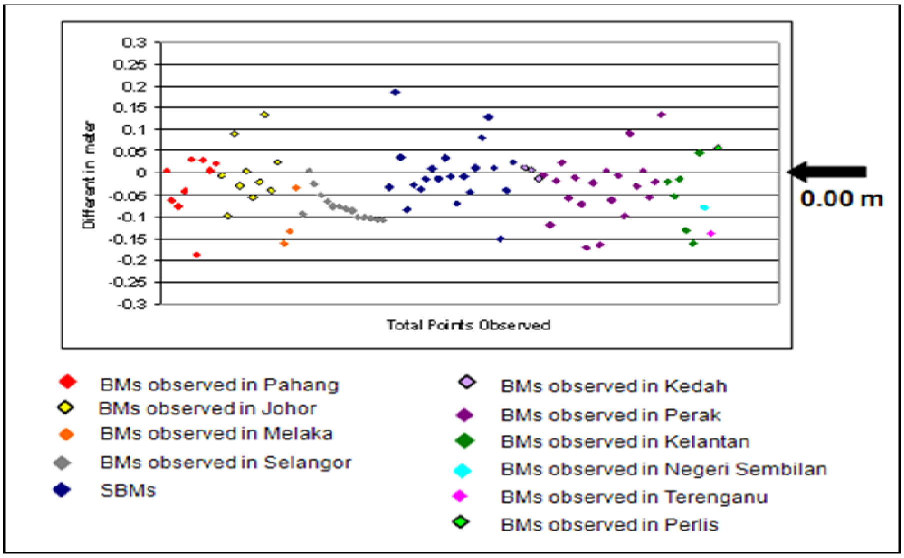

Figure 8.0 : Scatter Plot of the Difference between Orthometric Heights Derived GNSS and Levelling in Peninsular Malaysia

4.3 Tanjung Malim, Perak

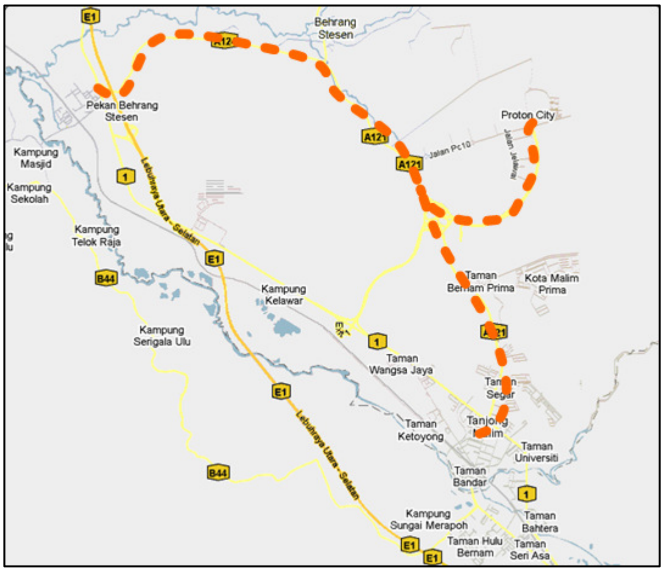

Figure 9.0 : Location of survey area in Tanjung Malim, Perak using static technique

The study has been carried out along a new route in Tanjung Malim, Perak. 11 BMs have been observed using static technique. Table 5.0 shows the results of GNSS heighting that has been carried out in Tanjung Malim. The differences of heights are between 5 mm to 16.2 cm as shown in Figure 10.0.

Table 5.0 : The results of GNSS heighting in Tanjung Malim, Perak using static technique

STN	GDM2000							N (m)	H_{GNSS} (m)	$H_{Levelling}$ (m)	Diff (m)
	LAT			LONG			h (m)				
	°	′	″	°	′	″	°				
A5398	3	45	26.43968	101	27	57.99224	29.740	-3.835	33.575	33.463	0.112
A5399	3	45	25.98052	101	28	26.73695	30.255	-3.789	34.044	34.086	-0.042
A5400	3	45	20.69546	101	29	2.09622	33.492	-3.730	37.222	37.227	-0.005
A5402	3	41	25.61002	101	31	26.07957	40.737	-3.449	44.186	44.269	-0.083
A5403	3	43	34.02441	101	30	57.16137	54.815	-3.508	58.323	58.296	0.027
A5404	3	43	31.99906	101	31	30.53179	61.727	-3.440	65.167	65.078	0.089
A5405	3	43	57.12162	101	31	53.47206	58.339	-3.389	61.728	61.566	0.162
A5406	3	44	29.46193	101	31	51.60500	57.157	-3.385	60.542	60.563	-0.021
A5407	3	44	20.13129	101	31	17.09771	48.198	-3.465	51.663	51.656	0.007
S1186	3	44	48.46105	101	27	19.57006	35.841	-3.879	39.720	39.596	0.124
S5133	3	45	19.52646	101	29	41.97646	32.498	-3.660	36.158	36.041	0.117

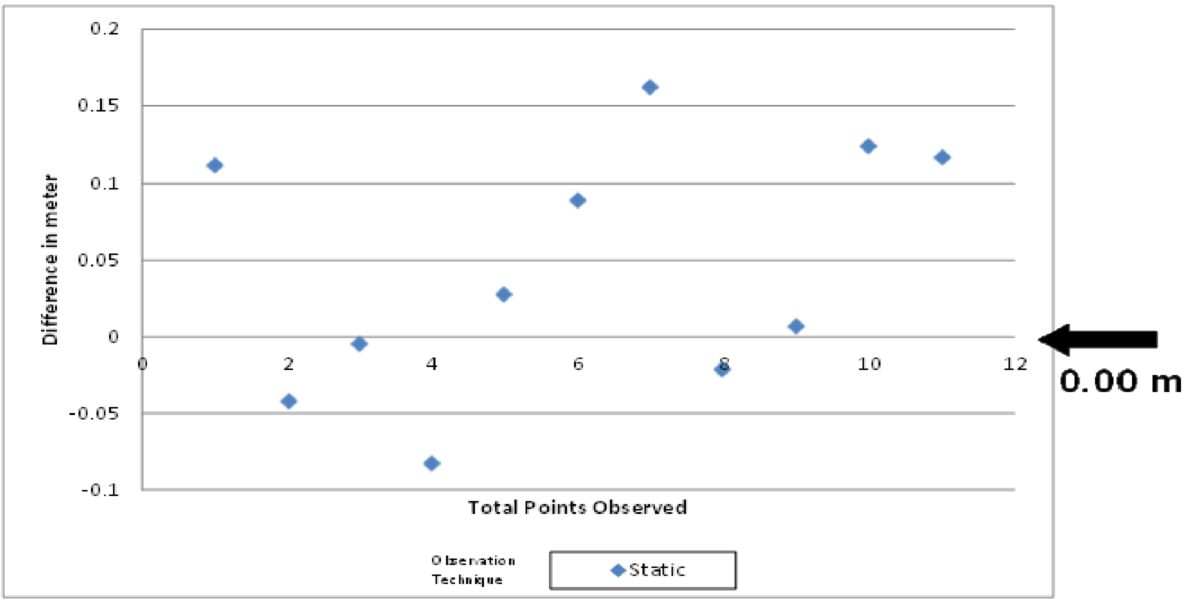

Figure 10.0 : Scatter Plot of Orthometric Heights Derived GNSS Heighting in Tanjung Malim, Perak

5. CONCLUSION

The development of geodetic infrastructures such as MyRTKnet and MyGEOID has given great opportunity in enhancing the determination of heighting using GNSS. The conventional spirit levelling requires a lot of time and is a costly operation as well as involves a lot of manpower as compared to GNSS heighting.

Based on the initial studies that have been carried out, the results indicate that the accuracy achievable by GNSS heighting in Malaysia can provide second order levelling standard. However, more case studies need to be conducted regarding GNSS heighting.

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