# **SECTION ONE**

# POSITIONING

### **1.0** INTRODUCTION

Malaysia covers an area of about 329,758 square kilometers, consisting of 12 states in Peninsular Malaysia and 3 states in the Borneo Island. South China Sea separates the two regions by about 540 km. Peninsular Malaysia, covering 131,598 sq. km. has its frontiers with Thailand and Singapore while the states in Borneo Island covering 198,160 sq. km, borders the territory of Indonesia's Kalimantan to the South and The Philippines to the North. Malaysia lies close to the equator between latitudes of 1° and 7°N and longitudes of 100° and 119°E.

DSMM traces its origin back in 1886. The 1880s also marked an important phase with the commencement of more widespread trigonometrical works in various parts of Malaya. The first attempt at triangulation survey was made in Penang in 1832 by Lieutenant Woore of the Royal Navy.

In 1885, H.G. Deanne, a contract surveyor from Ceylon, was appointed by the Public Works Department, Perak, to carry out the Trigonometrical survey of Perak. He measured the 4.6 mile Larut baseline and carried out astronomical determinations for latitude and azimuth near Taiping.

This Trigonometrical Survey in Perak together with the Penang and Province Wellesley triangulations and Malacca Triangulation (1886-1888), laid the foundation of the existing control framework. These foundations were still primitive, progress was frequently sporadic and much of the work was found to be substandard. However, by the end of 1901, the Major Triangulation of Perak and Selangor had been completed and work had been in progress in Negeri Sembilan since 1899.

This period also witnessed the commencement of trigonometrical surveys in various parts of the country. However, the quality of the early works were so inconsistent that it was decided to re-observe the principal triangles of the general triangulation with the object of bringing the work up to modern standards. This triangulation scheme in Peninsular Malaysia was known as the Primary or Repsold Triangulation which was completed in 1916. In 1948, it was replaced by a new system known as the Malayan Revised Triangulation (MRT). This was followed by a lengthy process of additional measurements and recomputation until 1968. As a result, this system is then referred to as MRT68. On the other hand, the geodetic network used in Borneo is called the Borneo Triangulation (BT68).

In the subsequent years, there have been numerous geodetic projects implemented by DSMM on a nation wide scale. Collectively, these projects were and are executed with the final aim of providing horizontal and vertical controls for the development of various infrastructures across the country.



 Table 1.1
 Reference Ellipsoids for MRT and BT68

No.	Parameter	MRT	BT68
1.	Reference Ellipsoid	Modified Everest	Modified Everest
2.	Origin	Kertau, Pahang	Timbalai, Labuan
3.	Semi-major axis ( a )	6 377 304.063	6 377 298.556
4.	Semi-Minor Axis ( b )	6 356 103.039	6 356 097.550
5.	Flattening (f)	1/300.8017	1/300.8017

**Table 1.2** Map Projections for Peninsular Malaysia, Sabah and Sarawak

No.	Parameter	Peninsular Malaysia	Sabah & Sarawak
1.	Projection Name	Malayan RSO	Borneo RSO
2.	Datum	Kertau N 3° 27" 50".71 E 102° 37' 24".55	Timbalai N 5° 17' 03".55 E 115° 10' 56".41
3.	Conversion Factor	1 chain = 20.11678249 m (Chaney & Benoit, 1896)	1 chain= 20.11676512m (Sears, Jolly & Johnson, 1927)
4.	Origin of Projection	N 4° 00' E 102° 15' of Greenwich	N 4° 00' E 115° 00' of Greenwich
5.	Scale Factor (Origin)	0.99 984	0.99 984
6.	Basic or Initial Line Of Projection	Passes through the Skew Origin at an azimuth of Sin (- 0.6) or 323° 01' 32".8458 from North	Passes through the origin in an azimuth of 53° 19' 56".9537 east of True North

#### 1.1.2 East Malaysia Geodetic Network

The geodetic network in Sabah and Sarawak known as Borneo Triangulation, 1968 (BT68) was established with the station at Bukit Timbalai, in the Island of Labuan as the origin. For the vertical control, three different datums were adopted and based on the datums at Pulau Lakei, Kota Kinabalu (1975) and Belfry(1918).

BT68 results from the readjustment of the primary control of East Malaysia (Sabah, Sarawak plus Brunei) made by the Directorate of Overseas Surveys, United Kingdom (DOS). This network consists of the Borneo West Coast Triangulation of Brunei and Sabah (1930-1942), Borneo East Coast Triangulation of Sarawak and extension of the West Coast Triangulation in Sabah (1955-1960) and some new points surveyed between 1961 and 1968. This geodetic network is shown in Figure 1.2. The reference ellipsoid used is given in Table 1.1. The map projection used for mapping and cadastral surveys is RSO and Table 1.2 shows the various parameters used.



**Figure 1.2** Borneo Triangulation 1968 (BT68)

## **1.2 OTHER GEODETIC NETWORKS**

#### 1.2.1 South East Asia Datum

The MRT extends over 700km with connections to the Indonesian triangulation in the south and the Thailand triangulation network in the north. In 1965, the American Mapping Service (AMS) carried out an internal readjustment of the MRT in order to connect to the South-East Asia Datum (SEA Datum). In 1965, AMS readjusted the MRT data in the South East Asia Datum (SEA Datum) using three triangulation points in Thailand held fixed. The network was strengthened by AMS by remeasurement of the 3 original baselines and the measurement of one new baseline using Geodimeter, together with four Laplace Stations. A geoidal profile was determined from the available astrogeodetic data in order to correctly reduce the measured distances. Between 1967- 1969, 1205 points had been computed in geographical and RSO coordinates.

#### 1.2.2 Doppler Observations

In 1978, a British Army Survey group carried out a Doppler campaign in Peninsular, Sabah and Sarawak in order to connect the local networks to the World Geodetic System 1972 (WGS 72). The network consists of 5 points of the MRT and 5 points of BT68. The observations were never used for any readjustment of the MRT and BT68. The given accuracy is of the order of three metres.

# **1.3 EXISTING GPS NETWORKS**

#### 1.3.1 Peninsular Malaysia GPS Campaign



Figure 1.3 Peninsular Malaysia GPS Network (PMGN)

A GPS network of 238 stations as in Figure 1.3 have been observed in Peninsular Malaysia using four Ashtech LX II dual frequency receivers. The acquired data was processed and adjusted in 1993. The main objectives are to establish a new GPS network, analyse the existing geodetic network and obtain transformation parameters between WGS84 of GPS and MRT. In the network adjustment, a minimally constrained adjustment was made with Kertau, Pahang, held fixed. The coordinates of Kertau are in approximate WGS84 and derived from Doppler coordinates of NSWC 9Z-2 reference frame. The Ashtech processing software with broadcast ephemeris was used for the determination of the baseline solutions. The relative accuracy of the network is 1-2 ppm for horizontal coordinates and 3-5 ppm for vertical. Summary of the results of the network adjustment made using Geolab network adjustment software is tabulated in Table 1.3.

Network Adjustment Software Used	Geolab Network Adjustment
Fixed Point in 3D	Kertau, Pahang
Approximate Positions	237
Number of Parameters	711
No. of observations	3594
Redundancy	2883
Weights used	$\sigma_{\text{N}}$ = 5mm $\pm$ 0.5 ppm
	$\sigma_{\text{E}}$ = 5mm $\pm$ 0.7 ppm
	$\sigma_U$ = 7mm ± 1.1 ppm
Variance Factor Used	0.9952
Chi-Square Test	Pass
Station Error Ellipses	Hort: 0.038 – 0.094
	Vert: 0.032 – 0.080
Relative Error Ellipses	Hort: 0.013 – 0.031
	Vert: 0.011 – 0.030
Average Baseline Accuracies	Hort: < 1.5 ppm
	Vert: < 2.0 ppm

 Table 1.3
 Results of Minimally Constrained Adjustment For PMGN

#### 1.3.2 GPS Network in Sabah and Sarawak

In 1994, GPS observations were made using Trimble 4000SSE L1/L2 receivers to establish a new GPS network. In the network adjustment, a constrained adjustment was made with coordinates of STRE fixed. Broadcast ephemeris was used for baseline determinations. The relative accuracy of the network as shown in Figure 1.4 is found to be better than 1 ppm for horizontal coordinates and 2-3 ppm for vertical.



Figure 1.4 Sabah/Sarawak GPS Network (SSGN)

Network Adjustment Software Used	Geolab Network Adjustment
Fixed Point in 3D	Timbalai, Labuan
Approximate Positions	169
Number of Parameters	507
No. of observations	1188
Redundancy	681
Weights used	$\sigma_{\text{N}}$ = 1.7mm $\pm$ 0.2 ppm
	$\sigma_{E}$ = 2.3mm ± 0.4 ppm
	$\sigma_U$ = 1.7mm ± 0.2 ppm
Variance Factor Used	0.9603
Chi-Square Test	Pass
Station Error Ellipses	Hort: 0.030 – 0.074
	Vert: 0.040 – 0.090
Relative Error Ellipses	Hort: 0.010 – 0.033
	Vert: 0.011 – 0.032
Average Baseline Accuracies	Hort: < 1.0 ppm
	Vert: < 1.0 ppm

Table 1.4 Results of Minimally Constrained Adjustment For SSGN

Summary of the results of the network adjustment made using Geolab network adjustment software is tabulated in Table 1.4.

# 1.4 GPS OBSERVATION CAMPAIGNS IN MALAYSIA

#### 1.4.1 GPS Observations By STRE

In November 1993, a group from Squadron of Technical Royal Engineers (STRE) observed with TRIMBLE GPS L1/L2 receivers on 5 existing Doppler points and 9 new GPS stations in Peninsular Malaysia. In Sabah and Sarawak, 7 existing Doppler points and 4 old trigonometric stations were observed. The aim of this project is to establish better transformation parameters from Doppler to WGS84 for the region and to connect Peninsular Malaysia to Sabah and Sarawak. In December 1993, the GPS observations were successfully completed and the results were based on the WGS84 reference frame. Results of STRE adjustments show that the absolute accuracy of WGS84 coordinates is at the 1m level for the X, Y and Z axes respectively.

#### 1.4.2 GEODYSSEA Project

GPS observations at Kuala Trengganu, Peninsular Malaysia and Tawau, Sabah were made from 28 November 1994 to 3 December 1994 continuously with Trimble 4000SSE GPS receivers together with members from other Asian and Asean countries. During the 1994 campaign, 2 additional stations namely Kertau and Timbalai were observed simultaneously for the same duration. In the 1996 campaign, 5 additional stations were observed. The acquired data was processed and the stations were connected to ITRF94. The processing and analysis of the GPS observations was carried out at Institute für Angewandte Geodäsie (IfAG), Frankfurt, Germany using the latest version of the Bernese Software in November 1996. In the adjustment, four GEODYSSEA stations of Kuala Trengganu (KUAL), Brunei (BRUN), Tawau (TAWA) and Tanjung Bajau, Indonesia (TABA) were held fixed. Their coordinates with reference to ITRF94 reference frame are in Table 1.5.

Stn. Name	Latitude D M S	Longitude D M S	Ell. Height m
Brunei (BRUN)	04 57 58.647364	115 01 51.278906	55.8317
Tanjung Bajau (TABA)	00 51 46.047121	108 53 27.088729	32.3656
Kuala Trengganu (KUAL)	05 19 08.003639	103 08 20.922165	55.0154
Tawau (TAWA)	04 15 04.696480	117 58 42.792014	451.9327

**Table 1.5** Fixed Stations for Adjustment

The results show that the final coordinates have a comparatively high relative accuracy of up to 1-3 X  $10^{-8}$  and an absolute accuracy of better than ± 3 cm in the ITRF global reference frame.

#### 1.4.3 Comparison of Coordinates

The STRE results are based on WGS84 and the GEODYSSEA project is based on ITRF94 reference frames. The coordinates of the stations observed in Peninsular Malaysia, Sabah and Sarawak by STRE and GEODYSSEA are tabulated in Tables 1.6 and 1.7 respectively. Their differences shown in Table 1.8 are systematic for the horizontal and not for the vertical.

Stn. Name	Latitude D M S	Longitude D M S	Ell. Height m
Timbalai	05 17 00.432	115 11 07.157	113.5
Kucing W/B	01 35 09.975	110 13 07.365	147.2
Al.Setar S/B	06 08 23.011	100 23 06.578	-10.0
Bkt. Kertau	03 27 49.911	102 37 18.943	269.3
Tg. Kupang	01 22 35.500	103 36 29.494	91.7

 Table 1.6
 Malaysian Network WGS84 Coordinates as from STRE

Table 1.7	Malaysian Network (ITRF 94 Reference Frame, Epoch 1996.3) as from
GEODYSS	SEA

Stn. Name	Latitude D M S	Longitude D M S	Ell. Height m
Timbalai	05 17 00.410	115 11 07.152	113.453
Kucing W/B	01 35 09.956	110 13 07.357	147.188
Al.Setar S/B	06 08 22.990	100 23 06.573	-10.111
Kertau	03 27 49.893	102 37 18.936	269.287
Tg. Kupang	01 22 35.484	103 36 29.486	91.582

Diff in Lat (second)	Diff in Long (second)	Diff in Ellip. Ht (m)		
-0022	-0.005	-0.048		
-0.019	-0.008	-0.012		
-0.021	-0.005	-0.111		
-0.018	-0.007	-0.013		
-0.016	-0.008	-0.118		

#### nces Between GEODYSSEA and STRE Coordinates

ons in Peninsular Malaysia as in paragraph 3.1 above was based S84 reference frame Table 1.9 shows the station coordinates of a in approximate WGS84. As can be seen from Table 1.10 and ces are systematic. Therefore, at the moment, the ITRF94 ODYSSEA are used to upgrade level of the GPS network insular Malaysia, Sabah and Sarawak. Table 1.12 shows the ITRF94 and Pen. Malaysia network coordinates.

#### lar Malaysia Station Coordinates (based on approximate WGS84)

Latitude	Longitude	Ell. Height
DMS	DMS	m
06 08 23.034	100 23 06.536	-10.541
03 27 49.935	102 37 18.904	268.705
01 22 35.522	103 36 29.456	90.906

#### nces Between PMGN and STRE Coordinates

Diff in Lat (sec)	Diff In Long (sec)	Diff in Ellip. Ht m
-0.023	0.042	0.541
-0.024	0.039	0.595
-0.022	0.038	0.794

#### nces Between PMGN and ITRF94 Coordinates

Diff in Lat (sec)	Diff In Long (sec)	Diff in Ellip. Ht m
-0.034	0.037	0.430
-0.032	0.032	0.582

# 1.5 COMPARISON BETWEEN GPS-DERIVED AND PUBLISHED RSO COORDINATES

#### 1.5.1 Peninsular Malaysia

The method of transformation between coordinate system using seven parameter parameters can guarantee transformed results to be quite well consistent with the required coordinate system in a certain and quite large areas. But gaps will still exist between the transformed results and the given results in the required coordinate system.

For Peninsular Malaysia, JUPEM has adopted the Bursa/Wolf model for the purpose of transforming from WGS 84 to the Kertau datum. Later, a plane Helmert transformation was made to get the horizontal coordinates in the mapping plane (RSO). The GPS-derived RSO coordinates were later compared with the published RSO.

From Table 1.13, it was found that the differences are within the 1-2 metres level. The largest difference is 0.865m for northing and easting 1.214m.

Table '	1.13	Difference	between	published	and	derived	RSO	coordinates	in
Peninsu	ilar Mala	ysia		-					

Stn	N-PUB	E-PUB	N-GPS	E-GPS	Diff N	Diff E
					(m)	(m)
DOP1	334820.324	383433.712	19.531	34.464	0.793	-0.752
DOP2	152231.334	623695.652	31.772	94.348	-0.438	1.214
DOP3	383107.943	514236.827	07.142	37.599	0.801	-0.772
DOP4	667860.891	481245.686	61.558	45.130	-0.667	0.556
DOP5	679684.099	267040.530	84.395	40.538	-0.296	-0.008
TG11	339123.709	557392.598	22.844	92.610	0.865	-0.012
TG26	573877.792	314093.535	77.926	93.292	-0.134	0.243
TG58	506477.531	385981.849	77.314	82.089	0.217	-0.240
TG19	162473.562	584561.501	73.953	60.525	-0.391	0.976
TG33	568893.982	284077.270	94.021	77.167	-0.039	0.103
TG56	684099.134	319232.377	99.091	32.338	0.043	0.039
TG42	601722.428	361024.807	22.471	24.991	-0.043	-0.187
TG09	272456.618	627126.226	56.661	25.222	-0.043	1.004
TG03	243266.942	473466.351	67.703	66.607	-0.761	-0.256
TG59	493708.822	381571.828	08.720	72.060	0.102	-0.232

#### 1.5.2 East Malaysia

For East Malaysia, relationship was made to the Timbalai datum and later transformed to RSO. From Table 1.14, it was found that the differences are within the 1-2 metres level. The largest difference is -1.709m for northing and easting -1.609m.

Therefore, it can be concluded that the 7-parameter transformation fits better to the local systems of Kertau and Timbalai.

Stn	N-PUB	E-PUB	N-GPS	E-GPS	Diff N	Diff E
					(m)	(m)
D001	584918.782	610231.015	19.070	30.760	-0.293	-0.261
D002	457859.630	516618.800	59.777	19.330	-0.152	-0.147
D004	472483.392	920690.543	83.330	90.416	0.058	0.012
DOP4	708346.933	753757.238	47.430	57.086	-0.499	-0.486
D006	764387.633	779709.480	87.960	09.546	-0.335	-0.318
T034	178201.060	- 1184.330	02.760	-84.225	-1.709	-1.694
T113	645702.275	754716.371	01.170	16.164	1.104	1.111
J011	25618.200	273065.030	17.400	63.581	0.799	0.792
T001	485837.060	478810.760	37.250	11.383	-0.193	-0.182
T003	620767.493	655744.480	67.250	43.980	0.238	0.258
T005	500352.550	578681.780	53.360	81.747	-0.812	-0.801
T007	466719.430	656313.710	19.940	13.640	-0.514	-0.513
T016	278620.010	239782.410	19.710	82.758	0.294	0.304
T021	218544.700	193188.120	45.030	88.137	-0.337	-0.326
T025	123959.380	169556.300	60.000	55.647	-0.620	-0.619

**Table 1.14** Difference between published and derived RSO coordinates in Sabah/Sarawak

# 1.6 SCALE STUDY FOR PENINSULAR MALAYSIA

By comparing the GPS derived distances and the MRT derived distances, there are discrepancies of between +11ppm and -13ppm as shown in Table 1.15.

FROM	то	Approx. Dist.	Location	Scale
		(KIII)		(ppin)
DOP3	TG10	274.3	Central-South	+ 3
T190	TG13	213.6	Central	- 13
T190	TG18	42.7	Central	- 1
TG13	TG14	32.1	Central	- 6
TG15	DOP3	43.5	Central	- 12
TG01	TG20	17.1	South	- 8
TG06	TG11	36.8	South	+ 11
TG05	TG06	28.9	South	- 11
TG07	TG10	24.1	South	+ 6
TG19	DOP2	40.5	South	- 2

Table 1.15 Comparison between distances derived from GPS and MRT

For the scale study, Peninsular Malaysia was divided into 3 blocks (Figure 1.5) as follows:

Block 1:	N 01° to N 03°( (9 common points)
Block 2:	N 01° to N 03°( (9 common points)
Block 3:	N 05° and above (11 common points)

As seen from Table 1.16, there are differences in scale for the blocks. Only one baseline that is TG19-DOP2 corresponds to the scale of Block 1. In the central part, the 2 baselines namely T190-TG13 and TG15-DOP3 have similar scale of Block 2. There is no comparison made for the scale of Block 3.



Figure 1.5 Transformation Parameters for the three blocks

Block	Dx	Dy	Dz	Rx	Ry	Rz	Scale
	(m)	(m)	(m)	(m)	(m)	(m)	(ppm)
1.	379.947	-770.555	88.069	2.698	1.522	-12.113	-0.791
2.	364.179	-703.220	92.460	2.591	2.064	-12.061	-11.654
3.	369.690	-727.644	88.868	2.453	2.613	-12.039	-7.697

Table 1 16	Transformation	Parameters	for the 3 Blocks
	Transionnation	Falameters	

It can be said that the scale is not uniform in MRT. Even in the same block, the scale varies from baseline to baseline. For further studies, the 3 blocks should be divided into smaller blocks. Smaller blocks could be made for Peninsular Malaysia but the problem is to connect GPS observations to the existing trig points which are either too high on mountain tops or disturbed by developments.

In another study, smaller blocks as in Figure 1.6 were made consisting of state boundaries such as follows:

Johore 1st Block Selangor, Negri Sembilan & Melaka 2nd Block



Figure 1.6 Transformation Parameters for various blocks

Pahang	3rd Block
Kelantan & Trengganu	4th Block
Perak	5th Block
Kedah and Perlis	6th Block

More than one state is made into one block in order to get enough common points for the relationship between WGS84 and MRT. The minimum number of common points for block is four with Pahang having the maximum 6 common points.

As from Table 1.17, it can be seen that Blocks 1 & 2 have similar transformation parameters. Blocks 3 and 4 also have similar parameters. Block 5 and 6 have different parameters and not similar to the other blocks. Thus, uniformity of scale is not present in MRT network. This is mainly due to the fact that few or minimum measured baselines were used for the establishment of MRT.

Block	Dx	Dy	Dz	Rx	Ry	Rz	Scale
	(m)	(m)	(m)	(m)	(m)	(m)	(ppm)
1.	378.697	-765.221	88.442	2.646	1.765	-12.107	-1.651
2.	372.594	-746.019	89.902	2.443	2.834	-11.994	-4.804
3.	365.241	-709.524	91.906	2.616	1.935	-12.062	-10.651
4.	366.245	-708.327	92.162	2.038	4.745	-11.847	-10.808
5.	363.125	-692.749	92.433	2.535	2.203	-12.081	-13.292
6.	371.808	-739.044	88.916	2.828	0.853	-12.227	-5.890

 Table 1.17
 Transformation Parameters for the six blocks