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Preliminary Analysis of Precise Levelling Network for The Southern Peninsular Malaysia

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Abstract

Precise levelling has been planned and implemented by the Department of Surveying and Mapping Malaysia (DSMM) for the provisioning of the levelling framework of the country. The precise levelling network provides the vertical reference datum for mapping and engineering purposes as well as for scientific research work, which includes tectonic movement monitoring and mean sea level studies. At present, twelve loops of precise levelling which cover the southern part of the Peninsular Malaysia were surveyed, processed and adjusted. The precise levelling was made with high precision levelling instruments which are currently used by DSMM, namely, Zeiss NI002A and digital automatic level, Wild NA3000. These instruments are capable of storing data in computer readable form for the purpose of processing and adjustment. Data acquired from the field were processed by RAPC-1 and DELTA processing software. Adjustment and analysis were made using Geolab network adjustment software. For future investigations on Peninsular Malaysia Height Datum, the levelling network has been tied to first order GPS network and tide gauge stations. This paper briefly described the procedures for the acquisition, processing and adjustment of the levelling data for the twelve levelling loops covering the southern half of Peninsular Malaysia.

1.0 INTRODUCTION

The Precise Levelling Project in Peninsular Malaysia was implemented in 1985 and until today 3185 bench marks have been surveyed. These new levelling routes were surveyed by various techniques such as conventional, automatic and motorised levelling. The recent techniques of automatic and motorised levelling allow the use of data loggers instead of levelling field books. From these data loggers, the acquired data can be directly downloaded to microcomputers for processing and adjustment.

With the extensive amount of levelling data, a general adjustment of the results became necessary in order to obtain consistent and accurate elevations for all control points. The levelling network adjustment has been carried out using the Geolab software. In the adjustment, the height datum was referred to the mean sea level as determined at the Pelabuhan Kelang tide gauge station.

This paper briefly described the procedures for the acquisition, processing and adjustment of the levelling data for the twelve levelling loops covering the southern half of Peninsular Malaysia.

2.0 DATA ACQUISITION

2.1 Survey Planning and Monumentation

The planning stage involved the identification of routes for the levelling network. In this precise levelling project, bench marks were planted at a spacing of 1 km throughout the country. A specific period of time is given for the settling process before the actual field observations. The levelling routes followed the main highways or roads and connections were made to all 10 tide gauge stations in Peninsular Malaysia. Since these bench marks are located along the roads, most of them are proned to disturbance due to expansion of roads or other infrastrutural developments projects. In order to overcome this, standard bench marks (SBM) were planted at a spacing of 5-10 km at secured places.

2.2 Levelling Instruments

The current techniques used for the levelling survey are automatic and motorised levelling. With motorised levelling, it is possible to level about 7-8 km a day, while with automatic level 3-4 km a day. The brief descriptions of two techniques are given in the following sub-sections.

2.2.1 Motorised Levelling

Motorised levelling was introduced by the Overseas Agency of the National Land Survey of Sweden (Swedsurvey) on 25 November 1988. With this technique, all observations were made from vehicles except when connecting to the bench marks. The complete motorization of the levelling technique was made possible by the development of the specially designed Carl Zeiss Jena NI002A reversible compensator. According to the manufacturer's specifications, the standard deviation per 1 km of double levelling is ± 0.2 mm.

The forward and reverse levelling are observed at different times of the day and under different meteorological conditions. The observer records the data into a programmable data logger named Micronic M700. These acquired data can be processed either in the field itself or in the office.

2.2.2 Digital Automatic Level

The user programs of the Wild NA3000 which are permanently stored in the digital level make levelling very simple because the operator no longer need to read the values of the staff. This is automatically done by processing the coded measurement signal obtained from the staff in the field-of-view as seen through the telescope of the automatic level.

The microprocessor reads the staff reading and respective horizontal distance between the instrument and the staff are computed and displayed. The measurement are then stored in the REC Module Wild GRM 10 or GRE4. The acquired data are then downloaded to microcomputer for processing. For this instrument, the standard deviation for 1 km double levelling is ± 0.4 mm.

2.2.3 Staff or Levelling Rod

The part of the staff code of Leica NA3000 precise level viewed through the telescope is imaged on the photodiode and converted into a digital measurement signal, which is then correlated with the reference signal stored in the microprocessor. This reference signal relates to the stored image scale (Leica, 1993). This is illustrated in ***Figure 1***. It is possible to obtain the reading of staff at the 0.1 mm level.

For motorised levelling, an invar rods are used and each of them can be set securely and exactly vertical by means of a stand and a base plate. The staff can be read to 5 decimal places or 0.01 mm.

The length of both types of staff is 3 metres and they are calibrated with the Laser Comparator with a precision of 0.001 mm.

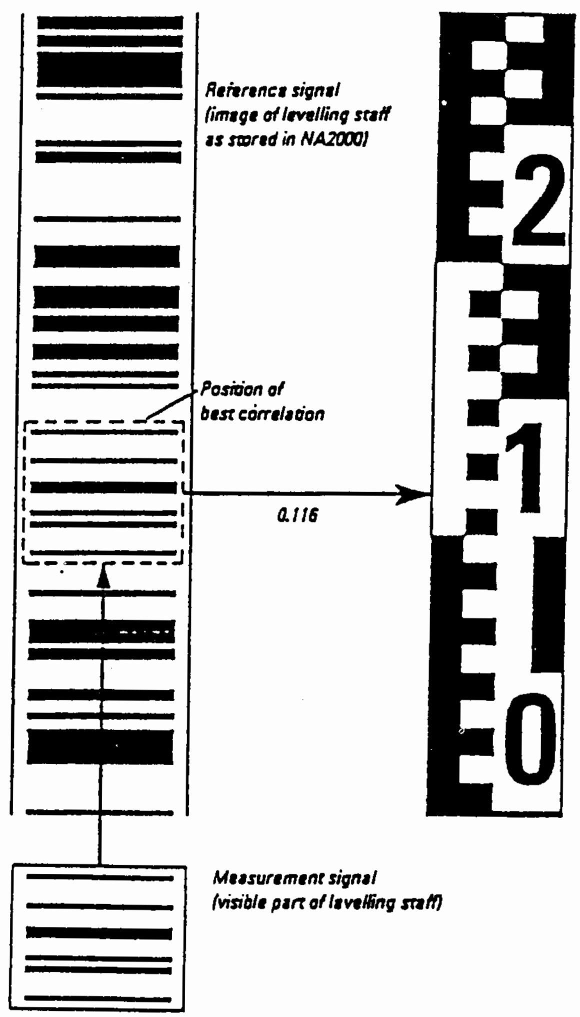

Figure 1: Coded Staff Of Leica NA3000

2.3 Field Procedures

2.3.1 Motorised Levelling

In motorised levelling, six reading were taken to each staff location as shown in ***Figure 2***. The criteria for tolerance, S is

$$S = (b-d) - (f-e) \leq 0.4 \text{ mm} \quad \ldots\ldots(1)$$

The difference in height, ΔH and distance, D are

$$\Delta H_{Mean} = [(b-d) + (f-e)] / 2 \quad \ldots\ldots(2)$$

$$D = [(a-b) \times 2\,] + 0.25 \text{ m} \quad \ldots\ldots(3)$$

where,

0.25m is the instrument constant

For example, if a = 238.300 cm ; b = 218.368 cm ; c = 223.700 cm ; d = 204.735 cm ; e = 508.097 and f = 521.719 then,

$$\Delta H_{Left} = (b-d) = 218.368 - 204.735 = 13.633 \text{ cm}$$

$$\Delta H_{Right} = (b-d) = 521.719 - 508.097 = 13.622 \text{ cm}$$

$$\Delta H_{Mean} = (13.633 + 13.622) / 2 = 13.628 \text{ cm}$$

$$S = 13.633 - 13.622 = 0.011 = < 0.4 \text{ mm}$$

2.3.2 Digital Automatic Level

For this type of level, four readings are taken that consist of two backsight and two foresight readings. The tolerance, S is

$$S = (B_1 - F_1) - (B_2 - F_2) \leq 0.4 \text{ mm} \quad \ldots\ldots(4)$$

where,

B_1 - first backsight reading

B_2 - second backsight reading

F_1 - first foresight reading

F_2 - second foresight reading

The pointing distance, d is checked against the tolerance and the total distance, D as follows :

$$d = 1/2\,[\Sigma\,(D_{B1} + D_{B2}) - \Sigma\,(D_{F1} + D_{F2})] \quad \ldots\ldots(5)$$

$$D = 1/2\,\Sigma\,(D_{B1} + D_{B2} + D_{F1} + D_{F2}) \quad \ldots\ldots(6)$$

where,

D_{B1} - distance computed at first bacsight reading

D_{B2} - distance computed at second backsight reading

D_{F1} - distance computed at first foresight reading

D_{F2} - distance computed at second foresight reading

Three conditions must be satisfied in order to provide reliable elevation differences between points. The conditions are:

- the lines of sight from the instrument to the rods must be level
- the values observed on the scale must accurately indicate heights above the points on which the rods rest
- the point must be stable with respect to the topography

The line of sights cannot be exactly level because of the effects of imperfections in the instrument, refraction, curvature and tidal accelerations. Imperfections of the rods and the turning points restrict the acquisition of quality observed heights above each point. Due to environmental effects, a perfectly stable relationship between the equipment and the topography cannot be maintained.

On the other hand, collimation error occurs when the line of sight is not perpendicular to the direction of gravity at the vertical axis of the instrument. However, this error can be minimised by limiting the sighting distance and a balance sighting distance for each setup (see Figure 3). For geodetic levelling, the average sighting distance should be ≤ 50 metres. Furthermore, the bottom 0.5 metre of the rod should not be used in order to minimise refraction.

3.0 DATA PROCESSING

In motorised levelling, a software called RAPC version 3.1 as shown in ***Figure*** **4** is used for processing which includes matching and editing. The various sub-programs are :

- Dump - downloaded data from data logger to PC
- Matching - checking and editing of the field data
- Correction Program - to compute corrections for temperature, gravity effect, calibration and curvature of the earth.

On the other hand, the digital automatic level data is processed using DELTA software (see ***Figure 5***). The processing includes editing of field data and computation of the difference in heights.

The adopted criteria for the accuracy of double levelling is $\pm 3\sqrt{K}$ mm and K is the distance in kilometres. The loop or curcuit closure limit is $2\sqrt{K}$ mm.

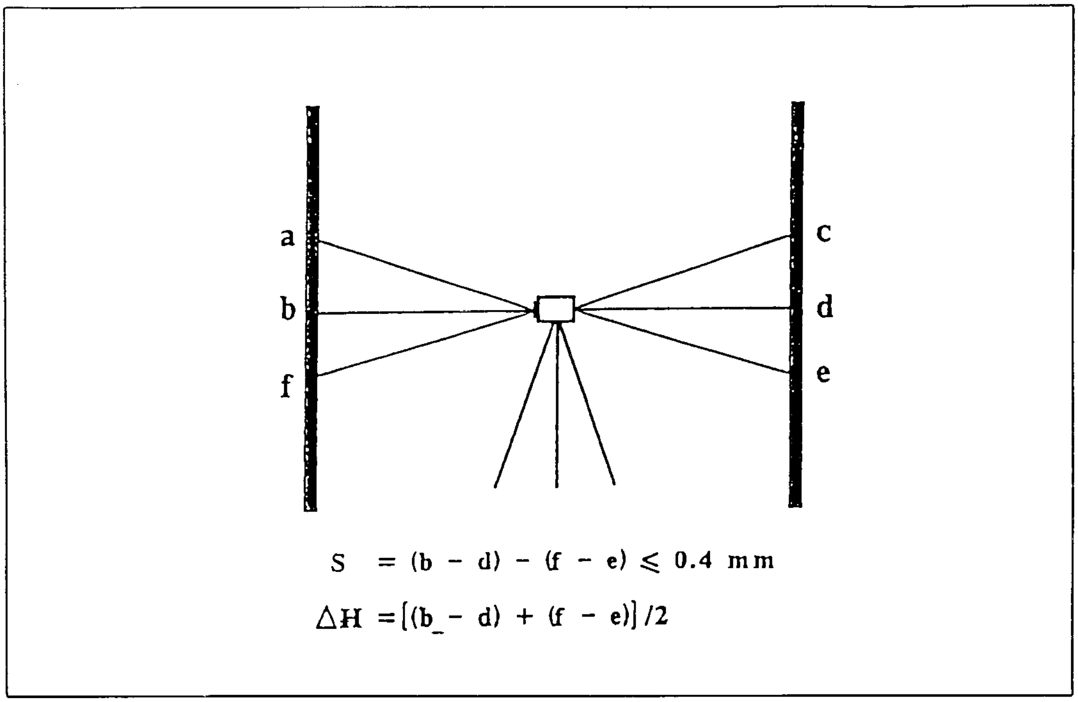

Figure 2: Staff Reading Of Motorised Levelling

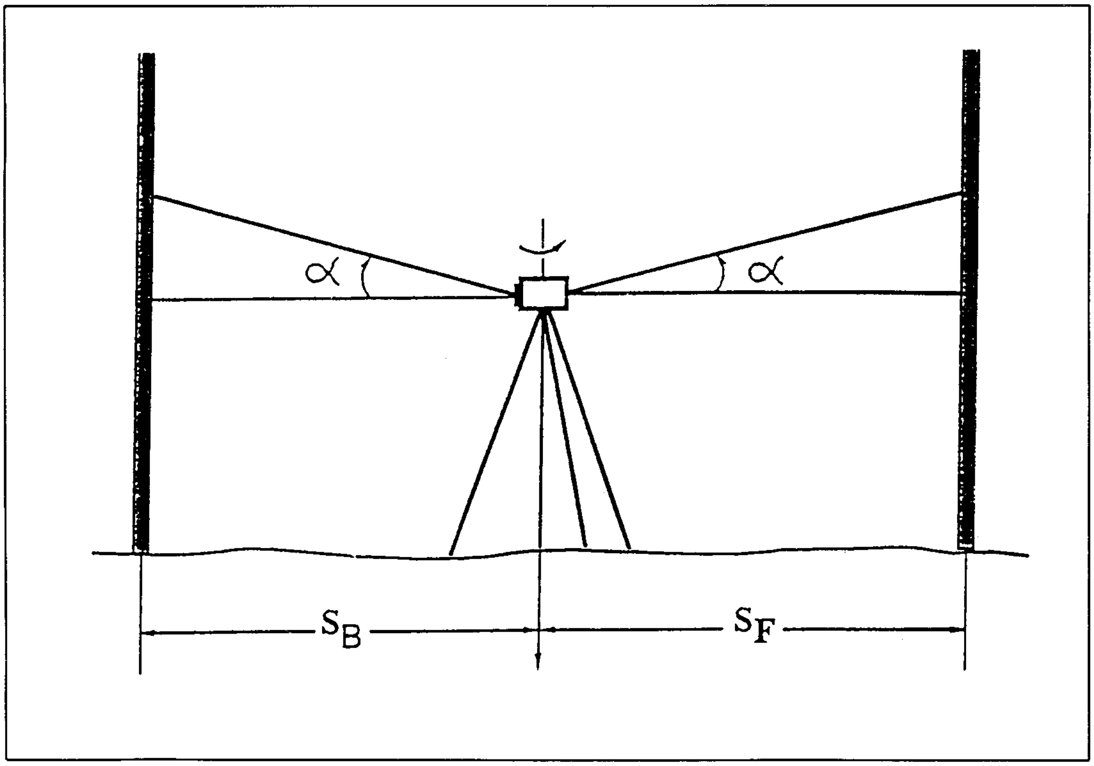

Figure 3: Collimation Error Cancels In A Balanced Setup Since $S_B = S_F$

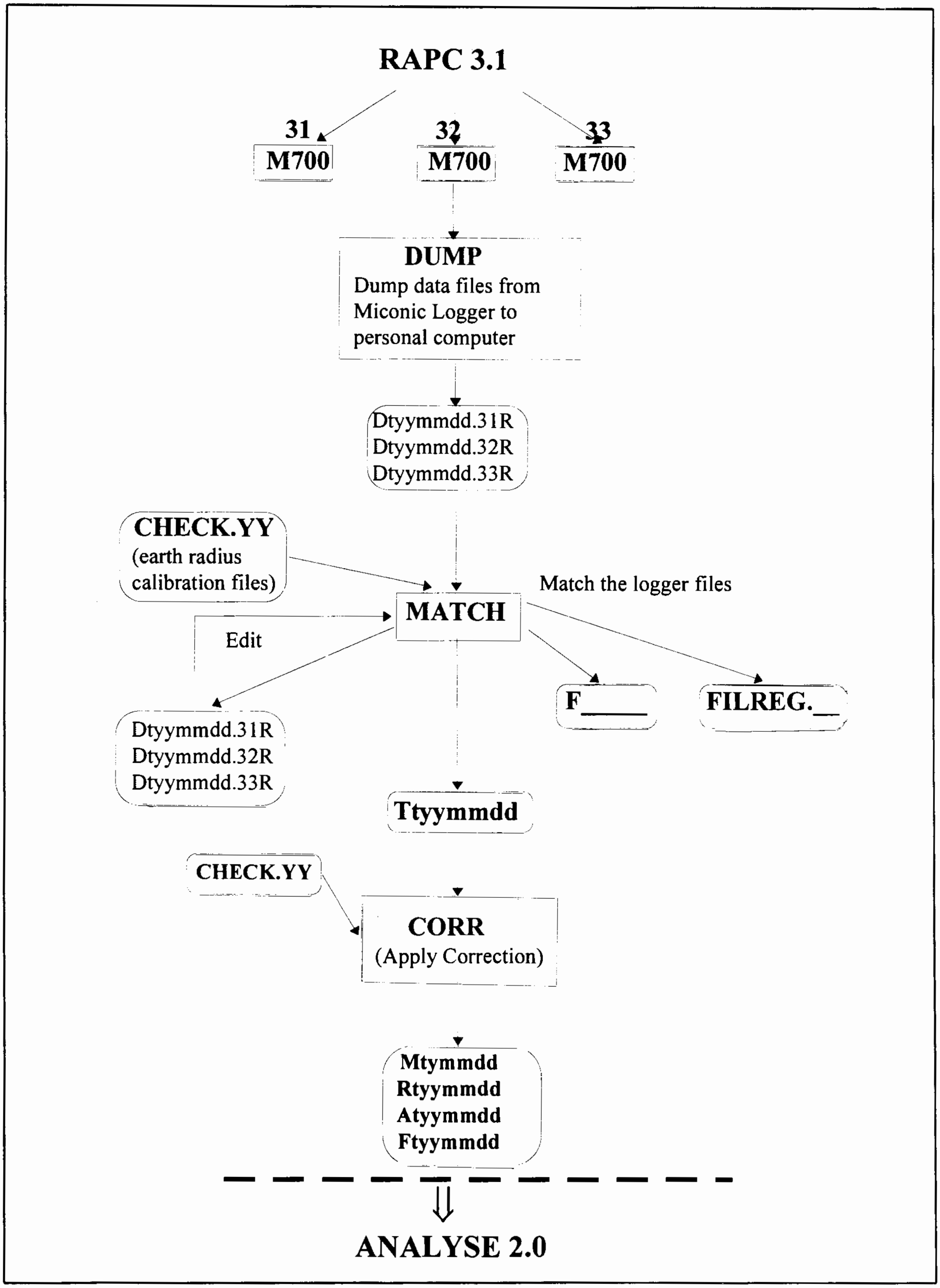

Figure 4: Data Processing Of Motorised Levelling

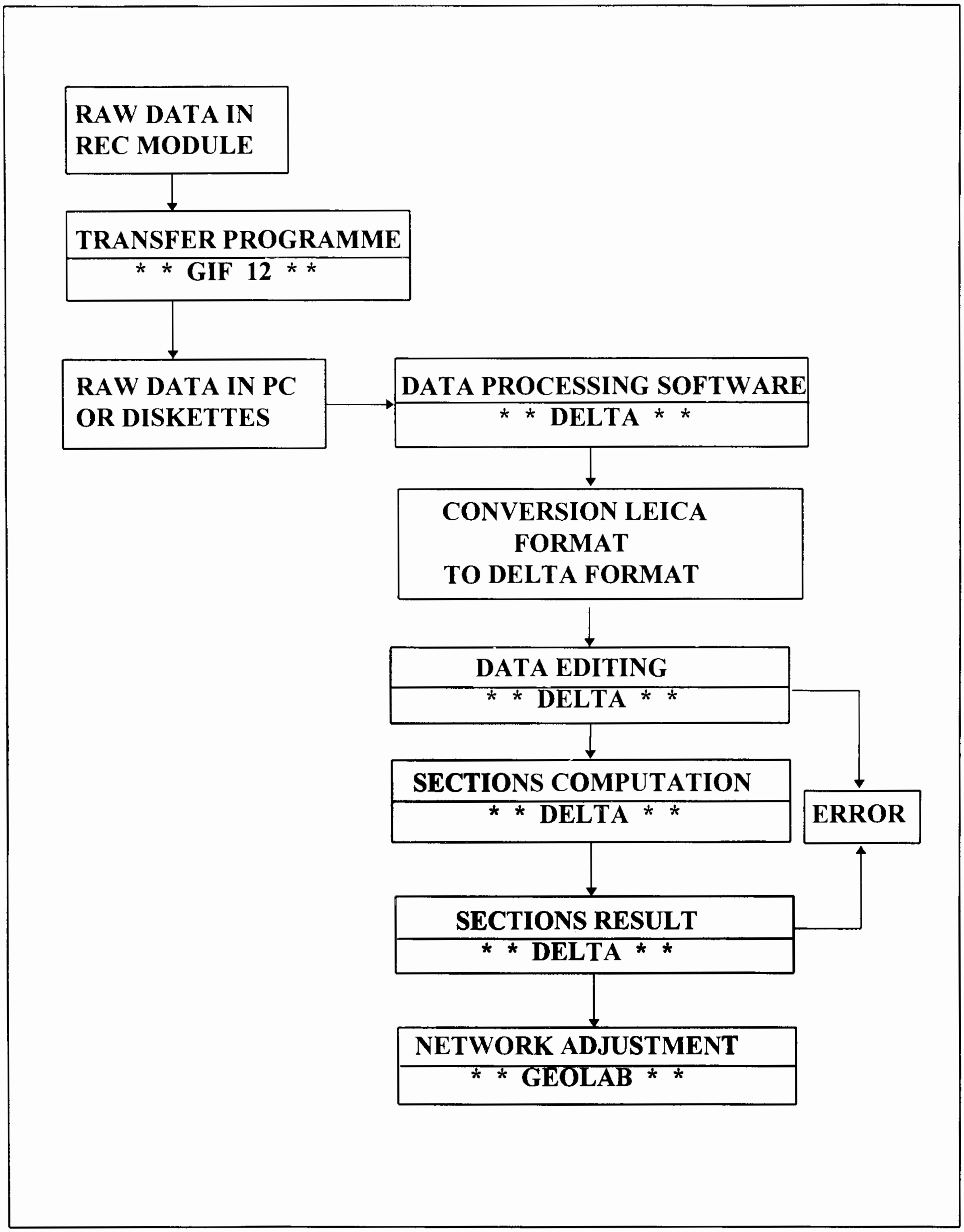

Figure 5: Data Processing Of NA3000 Measurements

4.0 NETWORK ADJUSTMENT

Network adjustment for the levelling network was done using Geolab Network Adjustment Software Version 1.9S. Geolab is a least squares adjustment software which can accept all types of geodetic data to be adjusted in either one-, two- or three-dimension. The automatic and motorised levelling data were combined by Program Analyse 2.0 as shown in ***Figure 6*** in order to obtain the IOB-file which is the format readable by Geolab software.

The unknown parameters in the adjustment are the height of all the stations in the levelling network. The datum of the network is obtained from the height of the fixed point B0169 which is referred to the mean-sea-level (MSL) value at Pelabuhan Kelang. The observations consisted of differences of heights and their standard deviations. The a priori standard deviation for each elevation difference is computed using the following formula :

$$\sigma_L = \sigma_\varepsilon (L/2z)^{1/2} = \sigma_\varepsilon (n)^{1/2} = \sigma_{1\,km} (n)^{1/2} \quad ....(7)$$

where,

σ_L - standard deviation of elevation difference (dependant on distance, L)

σ_ε - standard deviation of elevation difference of a single elevation difference

$\sigma_{1\,km}$ - standard deviation of 1 km spacing of elevation difference

z - average sighting distance

n - number of set-ups

The output of the adjustment are the adjusted heights of levelling bench marks and a posteriori standard deviations. The network adjustment can be analysed with the help of the standard error of unit weight, residuals and standardised residuals. The standard error of unit weight should be closed to unity. The residuals give in absolute figures the estimates of the discrepancies in the network. Standardised residuals are residuals divided by their respective standard deviations. Large standardised residuals indicate gross errors. Measurements with large standardised residuals are removed and network adjustments are repeated with new set of observations.

Minimal constrained network adjustment are also made by fixing five other bench marks which are referred to mean sea levels of Tanjung Keling (Melaka) and Tanjung Gelang (Pelabuhan Kuantan) in order to check for height datum consistency within Peninsular Malaysia. Furthermore a constrained network adjustment was also made with all the bench marks referring to all the above tide stations held fixed. This is done for the purpose of comparison of the results.

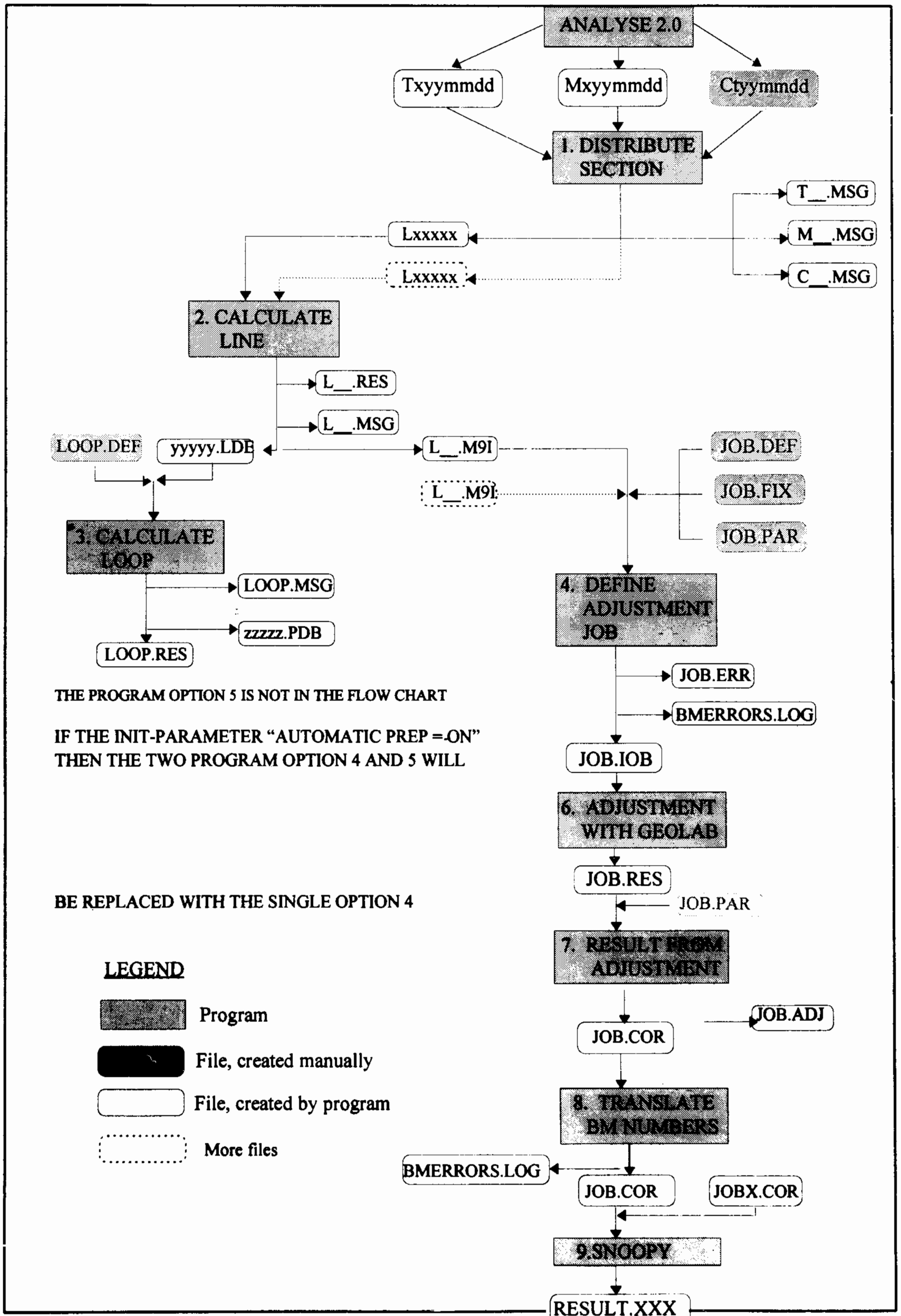

Figure 6: Flow Chart Of Levelling Network Adjustment Process

5.0 RESULTS AND ANALYSIS

Presently, one motorised and two digital automatic levelling teams are doing the precise levelling observations in the field. Until December, 1994, twelve loops of a total of 3185 bench marks had been surveyed, processed and adjusted as shown in ***Figure 7***. The misclosures of each loop are tabulated in ***Table 1*** and are within the permissible limits.

LOOP	Distance (km)	Permissible Misclosure $2(K)^{1/2}$ (mm)	Misclosure (e) (mm)	e^2 (mm^2)
1	509	± 45.14	- 15.19	230.74
2	213	± 29.19	+ 6.08	36.97
3	287	± 33.89	- 0.92	0.85
4	159	± 25.22	- 1.31	1.72
5	286	± 33.83	+ 5.23	27.35
6	566	± 47.60	+36.96	1366.04
7	343	± 37.02	- 4.38	19.18
8	162	± 22.75	+12.71	61.54
9	528	± 36.36	+22.98	528.08
10	371	± 48.07	+19.26	370.95
11	315	± 35.52	+ 22.83	521.21
12	229	± 30.25	- 2.81	7.09
	Σ3698			Σ3272.53

Table 1: Miclosures Of The Southern Peninsular Malaysia Levelling Loop

The computation for the standard error per unit weight from circuit closure is

$$\sigma = (1/m \bullet [\Sigma e^2 / \Sigma L])^{1/2} \quad \ldots\ldots\ldots\ldots (8)$$

where,

m - number of loops
e - summation of misclosure squared
L - total distance of loops

For the above curcuits, the standard error of unit weight for curcuit closure, σ, is

$$\sigma = (1/2 \bullet [3272.53/3968])^{1/2}$$

$$= \pm \mathbf{0.26\ mm}$$

The result of the minimally constrained adjustment with bench marks B0169 at Pelabuhan Kelang held fixed shows that the standard error of unit weight is 1 and the mean error 0.74 mm/km. The results obtained clearly indicate that the accuracy of the precise levelling network is very high.

Constrained adjustments were also made with the following bench marks held fixed.

i] Bench Mark M0331, Tanjung Keling. Melaka

ii] Bench Mark C0331, Tanjung Gelang, Kuantan

The acquired adjusted heights for the respective bench marks were compared and the results are tabulated in ***Table 2*** below. The table indicates that systematic errors do occur by fixing different bench marks. This is true due to the fact that the difference in values of mean sea level at various tide gauges are at the centimetre level.

BM	ADJUSTED HEIGHTS BASED ON P. KELANG (a)	ADJUSTED HEIGHTS BASED ON TG. KELING (b)	ADJUSTED HEIGHTS BASED ON TG. GELANG (c)	b - a (cm)	c - a (cm)	c - b (cm)
B0169	3.8640	3.7796	3.7433	-8.44	-12.07	-3.63
M0331	3.6684	3.5840	3.5477	-8.44	-12.07	-3.63
C0331	3.8357	3.7513	3.7150	-8.44	-12.07	-3.63
A0331	42.5796	42.4953	42.4590	-8.43	-12.06	-3.63
H0653	14.3042	14.2199	14.1836	-8.43	-12.06	-3.63
J0077	18.3229	18.2386	18.2022	-8.43	-12.07	-3.64
M0046	16.7228	16.6384	16.6021	-8.44	-12.07	-3.63
N0177	9.4469	9.3626	9.3262	-8.43	-12.07	-3.64
S0038	25.5216	25.7373	25.4009	-8.43	-12.07	-3.64

Table 2: Comparison Of Adjusted Heights With Difference Height Datum Held Fixed

Furthermore, a constrained network adjustment was made with bench marks M0331, B0169, J1323, C0331, A0401 and J0416 held fixed. The acquired adjusted heights of the respective bench marks were compared as tabulated in ***Table 3.***

	Adjusted Height (in metres) By Fixing Different Height Datum						
BM	Kelang (F) (a)	Melaka (F) (b)	Kuantan (F) (c)	All Held Fixed (d)	b - a (cm)	d - b (cm)	d - c (cm)
A0331	42.5796	42.4953	42.4590	42.5579	-2.17	+6.26	+9.89
H0653	14.3042	14.2199	14.1836	14.2263	-7.79	+0.64	+4.27
J0077	18.3229	18.2386	18.2022	18.1642	-15.87	-7.44	-3.80
H1438	9.4965	9.4121	9.3758	9.3385	-15.80	-7.36	-3.73
M0375	16.0271	16.1228	16.0865	16.1216	-8.55	-0.12	+3.51
M0046	16.7228	16.6384	16.6021	16.6449	-7.79	+0.65	+4.28

... Continued

N0177	9.4469	9.3626	9.3262	9.3778	-6.91	-1.52	+5.16
N0558	44.4662	44.3818	44.3455	44.3977	-6.85	+1.59	+5.22
J1323	3.0113	2.9269	2.8906	2.8970	-11.43	-2.99	+0.64
S0002	22.5795	22.4952	22.4589	22.4215	-15.80	-7.37	-3.74
S0038	25.5216	25.4373	25.4009	25.4215	-10.01	-1.58	+2.06

Table 3: Comparison Of Results Of Minimally and Constrained Adjustment

From the above table, it can be seen that the differences are not systematic. They indicates that with constrained adjustment the network is deformed in order to cater for the fixed heights introduced.

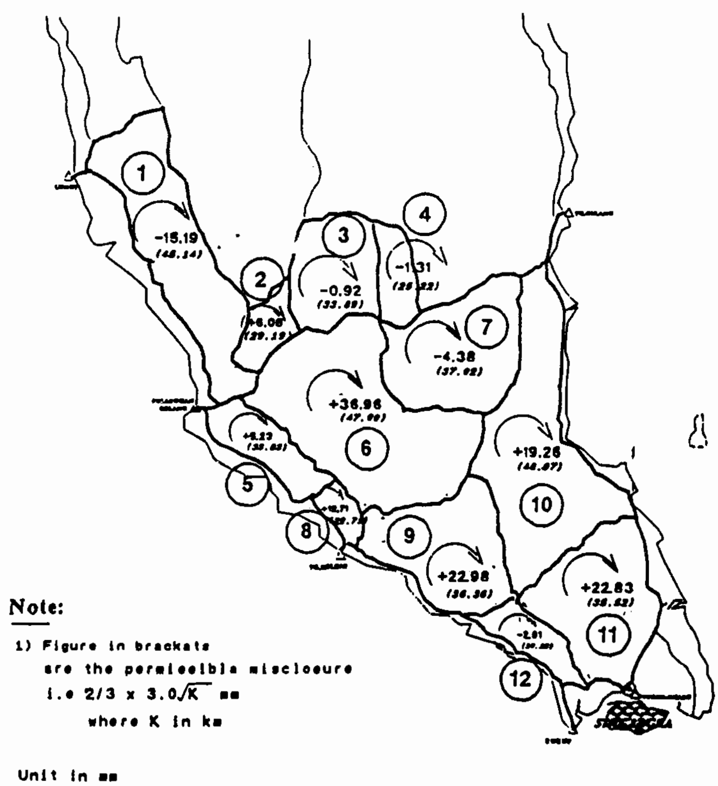

Figure 7: Precise Levelling Network Loop Misclosure

6.0 CONCLUSIONS

The motorised and digital automatic levelling technologies used in the present work have produced levelling data of high quality. This is due to quality control made in data acquisition, processing and adjustment. The adjustment results show that the levelling network is of high accuracy and complies with the geodetic standard. The introduction of motorized levelling is found to be beneficial as the technique produced results comparable to conventional precise levelling and increased the production substantially. The height of the benchmarks in the network was given above MSL at Pelabuhan Kelang. Comparison with heights above local MSL revealed that there is an apparent systematic differences in the vertical datum within the Southern Peninsular region. These systematic differences could be independently quantified in future by means of two techniques, namely, Global Positioning System (GPS) and oceanographic levelling.

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REFERENCES

Becker. J. M.: *The Sweedish Experience with Motorized Levelling - New Techniques and Tests.* NAVD Symposium 1985. Washington. 1985.

DSMM: *Tidal Observation Records.* Technical Report. Dept. of Survey and Mapping Malaysia.

DSMM: *Levelling Network in Peninsular Malaysia.* Internal Report. Dept. of Survey and Mapping Malaysia. 1979.
Kahmen. H. and W. Faig: *Surveying.* Walter de Gruyter & Co. Berlin. 1988.

MIKHAIL E. M.: Observations and Least Squares. IEP-Dun Donnelley. New York. 1976.

NOAA: *Geodetic Levelling,* Manual NOS-NGS3. National Geodetic Survey. USA. 1981.

WILD: *WILD NA3000 Manual,* Switzerland, 1993

ZEISS JENA: *ZEISS JENA NI002A Manual.* 1989