I.B. OSAZUWA*

THE SOUTHERN NIGERIA GRAVIMETER CALIBRATION LINE

Abstract. The Southern Nigeria Gravimeter Calibration Line (SNGCL) is derived from a Series of precise gravity measurements made with three LaCoste and Romberg model G gravity meters in order to establish a primary gravity network for Nigeria. The SNGCL extends from Benin to Abeokuta, thus covering a total distance of about 507 km. Its extreme absolute gravity values are 978042.409 mgal and 978119.857 mGal at Benin and Abeokuta, respectively, yielding a maximum interval gravity value of 77.448 mGal. The five base stations along the line are fairly uniformly spaced both in terms of their spacial separations and the interval gravity values between consecutive base stations. The absolute gravity values along the calibration line are referred to the IGSN 71 datum through a network of gravity stations. The average accuracy of the interval gravity values within the calibration line is ± 13 μGal, with worst and best values of 15 μGal and 11 μGal, respectively. Other calibration lines can be deduced from the distribution of the absolute gravity in southern Nigeria, but the SNGCL provides the largest gravity range in the region, with Benin as the focal point from which all lines radiate. It was concluded that periodic measurements along the calibration line will provide a means of monitoring possible crustal movements within the earth tremor zone of Southern Nigeria.

INTRODUCTION

Efforts have been made in the past to establish gravimeter calibration facilities, due to the inadequacy or non existence of calibration lines at that time (Verheijen and Ajakaiye, 1978). The calibration line established by Verheijen and Ajakaiye (1978) extended from Jos (in central Nigeria) to Sokoto (in northwestern Nigeria) and consisted of ten stations. Some of the sites have since been destroyed during road construction. Besides, the calibration line was far removed from some of the scientists who may need the line. For the purpose of easy reference in subsequent discussions the calibration line shall simply be referred to as VACL.

It has been established that VACL is deficient in some ways (Osazuwa, 1985). Some of the deficiencies which necessitate SNGCL are highlighted as follows: (a) the retrievable stations along VACL are too few to facilitate the extraction of the Southern Nigeria gravity range from it during a calibration exercise; (b) the gravity range covered by VACL (329.807 mGal) is too large for gravimetric surveys in Southern Nigeria where the maximum range is 77.448 mGal; (c) many of its few sites have been destroyed due to road construction work and cannot be recovered; (d) the discrepancy in VACL is estimated to be about 500 ppm (Osazuwa, 1985); that is, an error several times more than the standard deviation can arise if gravimeters are calibrated using VACL.

SOURCE OF DATA

The data for the SNGCL were obtained from the Primary Gravity Network of Nigeria (PGNN),

© Copyright 1992 by OGS, Osservatorio Geofisico Sperimentale. All rights reserved.

Manuscript received December 19, 1991; accepted March 5, 1992.

Department of Geophysics, Uppsala University, Sweden.

* Permanent address; Department of Physics, Ahmadvu Bello University, Zaria, Nigeria.

which was established from a series of precise gravity measurements made in a network of 59 base stations throughout Nigeria (Osazuwa, 1985). Three LaCoste and Romberg model G (Nos 446, 464 and 468) gravimeters were used for the observations, part of which were made using a twin-engined air craft to convey the gravimeters and personnel from one station to another. Most of the measurements in Southern Nigeria were made using air transport (Osazuwa and Ajakaiye, 1987). The network was tied to the International Gravity Bureau (IGB) base (No. 7228 J) at Kano International Airport via a base station established also at Kano Airport (Verheijen and Ajakaiye, 1978). Thus the SNGCL can be said to be effectively tied to the International Gravity Standardization Net, 1971 (IGSN 71) (Morelli et al., 1974). Table 1 shows the number of ties along the links that constitute the SNGCL. Each link was observed at least once in opposite directions. The three gravimeters used were read simultaneously at each site.

DATA SYNTHESIS

All measurements in the Primary Gravity Network were corrected for tidal effect using the Tidal Correction Tables (Service Hydrograghique de la Marine and Companie General de Geophysique, Tidal Corrections for 1979, 1981 and 1983). Further synthesis of the data was carried out by performing a least squares adjustment of the network, (Strang van Hees, 1984; Osazuwa, 1985), from which the adjusted interval gravity values between consecutive stations and absolute gravity values at each base station were obtained. The essence of the least squares synthesis of the data is to remove any loop misclosure from the network, and also to estimate the errors in the final values. Interval gravity values were used as observations during the adjustment, and the general form of the adjustment model is given by eqn. (1) below;

$$-g_i+g_j+\eta_k\Delta t_{ij}+(\lambda_k-1)\Delta g_{ij}=\epsilon_{ij}, \qquad (1)$$

where

g_i and g_j are the unknown absolute gravity values to be determined for base stations i and j respectively;

η_k a drift correction factor to be determined for the set of observations measured with the k^{th} instrument;

Δt_{ij} is the time interval in hours for the relative gravity measurement between bases i and j;

λ_k is a scale correction factor to be determined for the k^{th} instrument;

Δg_{ij} is the observed gravity difference between base stations i and j;

ϵ_{ij} is the unknown correction to the adjusted Δg_{ij} so as to make it equal to g_i minus g_j.

From the investigations carried out by Brien at al. (1977) and Csapo (1979), the atmospheric pressure and magnetic effects on LaCoste and Romberg gravimeters were disregarded because pressure variation between consecutive stations within the network is much less than 100 mbar and hence the anticipated error due to pressure effect would be less than 1 μ Gal. Therefore corrections for them were not included in eqn. (1). In a condensed matrix form, eqn. (1) becomes

$$\mathbf{A}x=b+c, \qquad (2)$$

where **A** is a known coefficient matrix; x is the (m x 1) column vector of the unknown parameters g, η and λ whose values were determined from the least squares adjustment; b is the (n x 1) column vector of the observed Δg_i's, and c is the (n x 1) column vector of the unknown corrections or residuals to the adjusted Δg's. **A**, which is also the design matrix of the parameter equations, was used to generate the variance-covariance matrix used for the error analysis. Thus, eqn. (2) is the mathematical model whose parameters are weighted appropriately.

The weight applied to each observation during the adjustment depends on the time taken to complete the tie and the precision of the reading instruments (Strang van Hees, 1984). Thus,

Table 1 - Links that constitute the southern Nigeria gravimeter calibration line.

Station Interval	No. of Ties by Instrument G446	G464	G468	Total Ties	Interval Value (mGal)	S.D. (mGal)
Benin-Akure	2	2	-	4	7.866	0.013
Akure-Osogbo	2	2	-	4	13.633	0.014
*Benin-Osogbo	2	2	2	6	21.499	0.011
Osogbo-Ibadan	2	2	2	6	25.282	0.012
Ibadan-Abeokuta	2	2	-	4	30.667	0.015

* Links used only for Network Adjustment, not part of Southern Nigeria Gravimeter Calibration Line.
S.D. means Standard Deviation.

the inverse weight Q_k of the k^{th} observation is given by

$$Q_k = \frac{1}{\sigma^2_{\Delta g(1)}} \{\sigma^2_{R(r)} + \Delta t_{ij} [\sigma^2_{\Delta g(r)} - 2\sigma^2_{R(r)}]\}, \tag{3}$$

where $\sigma_{\Delta g(r)}$ and $\sigma_{\Delta g(1)}$ are the a priori standard deviations of the gravity difference between a pair of stations determined with the r^{th} and reference instruments respectively, and $\sigma_{R(r)}$ is the a priori standard deviation of point gravity reading measured with the r^{th} instrument.

The least squares solution of eqn. (2), by minimizing the correction or residual term c, yields the adjusted values of the unknown parameters x.

In order to estimate the error in the adjusted absolute and interval gravity values, a complete variance-covariance matrix σ^2_{xx} of the stochastic vector of the unknown parameters was set up and expanded into equation (4), which is given below:

$$\sigma^2_{xx} = \begin{bmatrix} \sigma^2_{x_1} & \sigma^2_{x_1x_2} & \cdots & \sigma^2_{x_1x_n} \\ \sigma^2_{x_2x_1} & \sigma^2_{x_2} & \cdots & \sigma^2_{x_2x_n} \\ \vdots & \vdots & \ddots & \vdots \\ \sigma^2_{x_nx_1} & \sigma^2_{x_nx_2} & \cdots & \sigma^2_{x_n} \end{bmatrix} \tag{4}$$

The diagonal element $\sigma^2_{x_i}$ of the matrix is the variance of the corresponding vector element x_i. The non-diagonal element $\sigma^2_{x_ix_j}$ is the covariance of the pair x_i and x_j. The variance-covariance matrix of the gravity values at the calibration line base stations was extracted from the variance-covariance matrix of the Primary Gravity Network of Nigeria (PGNN). According to Ashkenazi (1967), two variances and their common covariance satisfy the relation given in eqn. (5) below:

$$\sigma^2_{(x_i \pm x_j)} = \sigma^2_{x_i} + \sigma^2_{x_j} \pm 2\sigma_{x_i x_j} . \tag{5}$$

Hence, the error in the gravity difference between stations i and j is given by

$$\sigma_{(x_i - x_j)} = [\sigma^2_{x_i} + \sigma^2_{x_j} - 2\sigma_{x_i x_j}]^{\frac{1}{2}} . \tag{6}$$

From the upper triangle of the symmetrical variance-covariance matrix set up with eqn. (4), the errors (that is standard deviations) in the interval gravity values (Table 1) and the station point gravity values (Table 2) were estimated using eqn. (6).

CALIBRATION SITES LOCATION

In addition to the general criteria (Osazuwa, 1985) adopted in selecting the gravity base sites for the Primary Gravity Network of Nigeria (PGNN), the following additional criteria were used in selecting the stations and the base sites of the SNGCL: (a) The SNGCL should, as much as possible, cover the entire gravity range in Southern Nigeria. (b) The gravity differences between consecutive base stations along the line should be of the same order of magnitude. (c) Interval distances between the base stations should be such that the average travel time between consecutive stations should be less than two hours. (d) Every site must be free from microseismic disturbances. (e) Every site must be established on a permanent location which is not easily destructible. (f) Every site must be accessible to all users at any time of the day or night. (g) Gravity values at succeeding base stations along the calibration line must vary progressively in a systematic order as indicated by arrows in Fig. 1. (h) There must be at least four stations along the calibration line. Some of the above criteria may not be met exactly, but in selecting the sites care was taken to see that the criteria did not conflict with one another.

Table 2 - Characteristics of the southern Nigeria gravimeter calibration line.

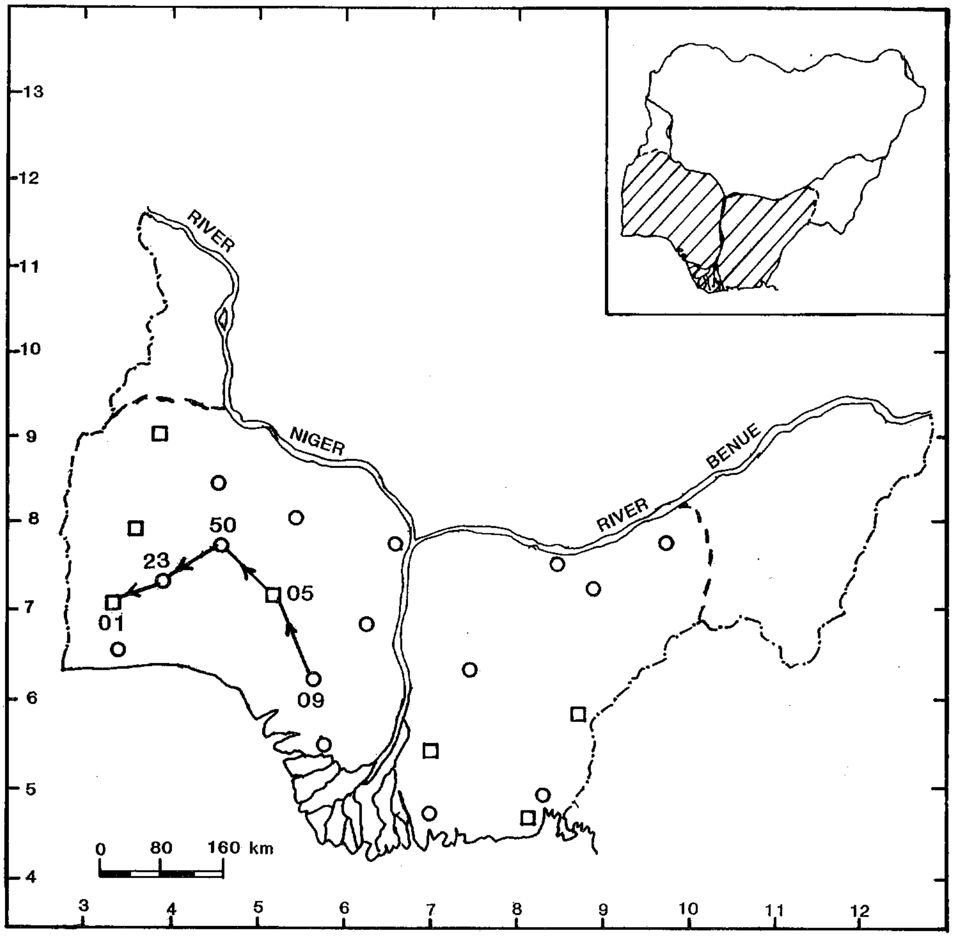
Station No.	Station Name	LAT (°')	LON (°')	ΔS_{INT} (km)	ΔS_{BO} (km)	Δg_{INT} (mGal)	Δg_{BO} (mGal)	g_{ABS} (mGal)	S.D. (mGal)
009	Benin	6 19	5 36		0		0.000	978042.409	0.015
				172		7.866			
005	Akure	7 14	5 11		172		7.866	978050.275	0.018
				113		13.633			
050	Osogbo	7 44	4 29		285		21.499	978063.908	0.016
				138		25.282			
023	Ibadan	7 25	3 35		423		46.781	978089.190	0.018
				84		30.667			
001	Aboekuta	7 08	3 19		507		77.448	978119.857	0.021

ΔS_{INT} Interval distance between consecutive base station.
ΔS_{BO} Distance of the base station from the origin (Benin).
Δg_{INT} Interval gravity difference between consecutive base stations.
Δg_{BO} Gravity difference between a base station and the origin (Benin).
g_{ABS} Absolute gravity value.
S.D. Standard Deviation.

A comprehensive synopsis of the sites along this calibration line are given by Osazuwa (1985), and diagrammatic descriptions of the sites are shown in Fig. 2. With the exception of Abeokuta, the other sites are non-monumented and each of the non-monumented sites can be relocated within a radius of ± 0.5 m. (Fig 2). The monumented site at Abeokuta is marked with an identification pillar carrying the inscription FSN GMSN/55A. A detailed description of the nomenclature of typical site pillars is given by Osazuwa (1985), and Osazuwa and Ajakaiye (1987). In some of the base stations, even though the calibration sites are non-monumented, the excentres are monumented with the same type of pillar as the one at Abeokuta, but with different serial numbers. In order to avoid any conflict, only sites described as main base (Fig. 2) are used as calibration sites.

CHARACTERISTICS OF THE CALIBRATION LINE

The statistics of the SNGCL are given in Table 2. Generally, the distances between the stations can be covered in less than two hours of driving along the usually good highways in the area. With a range of 77.448 mGal (Table 2), and extending from the station of least gravity value (Benin) to the station of highest gravity value (Abeokuta), the SNGCL can be said to cover effectively the Southern Nigeria gravity range. The standard deviations of station gravity values along this line is generally low, being less than 20 μGal, except Abeokuta "absolute" gravity value whose standard deviation is 21 μGal. The SNGCL overall length of about 507



LENGEND

Station No.	Name		
001	Abeokuta	→	Calibration Line and direction of increasing gravity
005	Akure	O 09	Base Station accessible by road and air transport
009	Benin		
023	Ibadan	□ 01	Base Station accessible by road transport only
050	Osogbo		
		— — —	Approximate gravity range

Fig. 1 - Location of the Southern Nigeria Calibration Line (SNGCL).

km makes it attractive to prospective users whose primary consideration is to reduce survey cost and at the same time have a calibration line that fulfils gravimetric conditions as does the SNGCL. Another noticeable characteristic of the SNGCL is that the interval gravity differences (Table 2) increase progressively from the beginning to the end of the line.

DISCUSSION

The final interval gravity values along the SNGCL were determined from the least squares

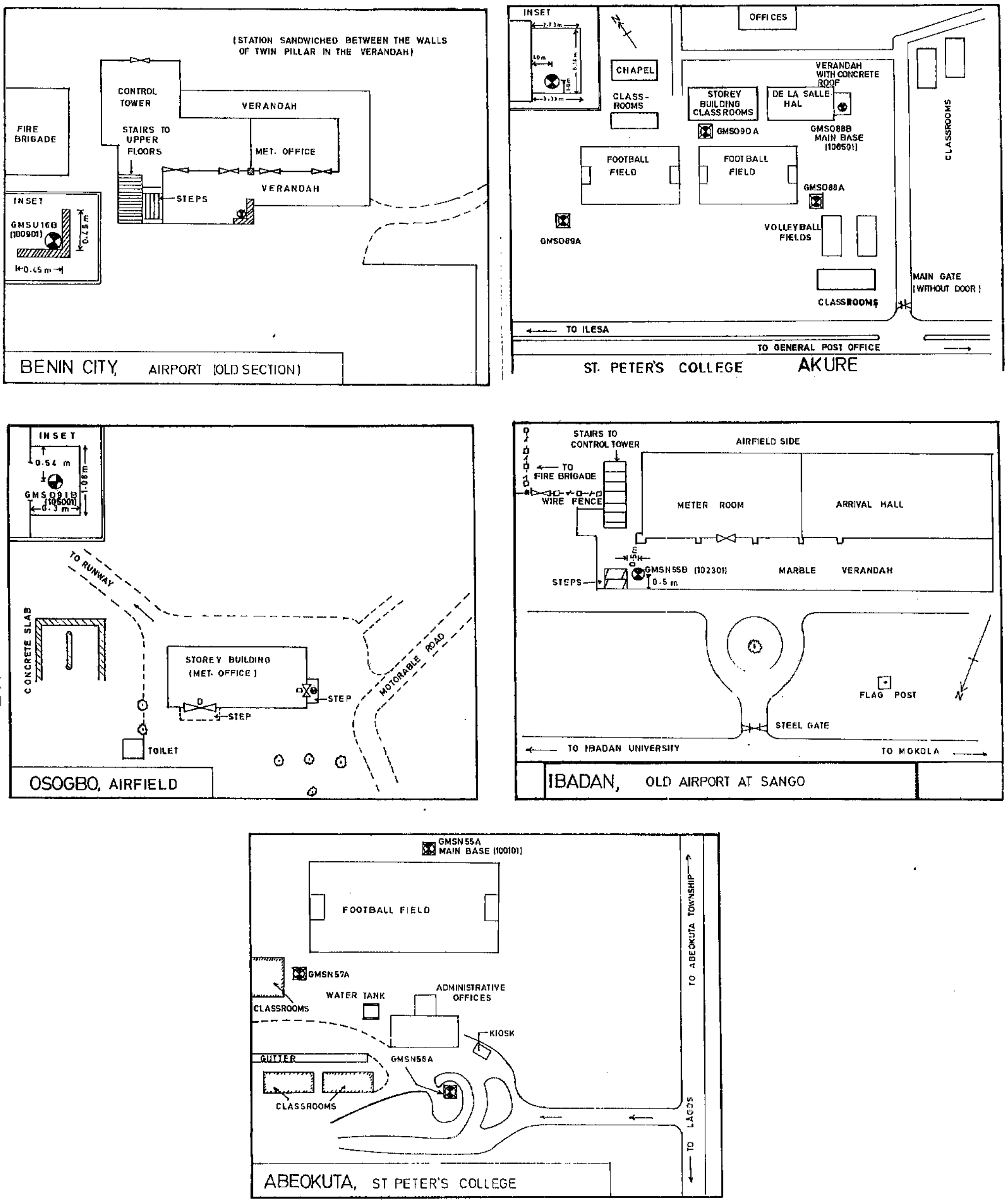


Fig. 2 - Diagrammatic descriptions of the site locations. The calibration sites are those described as main base in the diagrams.

adjustments of the entire data obtained from gravity measurements carried out during the establishment of the Primary Gravity Network of Nigeria (PGNN) by Osazuwa (1985). Apart from Ibadan/Abeokuta interval,(Table 2) the stations are fairly uniformly spaced, thus ensuring uniform interval travel time between consecutive stations during a calibration campaign. Also, apart from the Benin/Akure interval, which has relatively low (7.866 mGal) interval gravity difference, the interval gravity differences (Table 2) between consecutive stations are fairly uniform and regular. These are in good agreement with Uotila (1978), that interval gravity values along a calibration line should be uniform and regular.

Even though the interval gravity differences lie within the same order of magnitude, there is a noticeable systematic increase in their values from the origin of the line (Benin) to the end of the line (Abeokuta). Although it is possible to derive an empirical relation for this phenomenon, no useful geodetic information can be obtained from it. Geologically, however, this could be ascribed to the facies evolution between the thick deltaic sediments in the Benin area and the granitic Abeokuta formation, which is also close to the relatively shallow coastal plain of Lagos with respect to mean sea level. Also, in between these extreme base stations along the calibration line, the stratigraphic sequence is rather complex, thus giving rise to possible complex density variations in the subsurface.

The standard deviations of absolute gravity values along SNGCL (Table 2) are considered low, which is probably an indication of good internal consistency and high quality of observations and data processing of the PGNN. Also, the standard deviations of the interval gravity values (Table 1) are generally less than 15 μGal. The only exception is the Ibadan/Abeokuta interval whose standard deviation is 15 μGal. Similarly, apart from Abeokuta whose absolute gravity value has a standard deviation of 21 μGal, the standard deviations of the remaining absolute gravity values are less than 20 μGal. The high standard deviation of Abeokuta gravity value has been attributed to the fact that Abeokuta lies on the periphery of PGNN and therefore, had fewer links with other stations than those in the interior of PGNN. The same characteristics was noticed for other peripheral sites of PGNN (Osazuwa 1985). It should be noted that the standard deviations were estimated with respect to the absolute gravity at Kano, whose value was fixed during the adjustment of PGNN. Therefore, the standard deviations are a measure of the internal consistency of the adjusted values.

CONCLUSION

From the previous discussion on the suitability of VACL as calibration line, it is concluded that its use for calibrating gravimeters to be used in Southern Nigeria in particular should be discontinued. It should therefore be replaced with the Southern Nigeria Gravimeter Calibration Line (SNGCL).

The SNGCL is well suited for monitoring any crustal movement in the area, particularly as it traverses both the stable and the seismically disturbed areas of Southern Nigeria, where an earth tremor was reported in 1984 (Ajakaiye et al., 1989). In order to enhance the microgravity network which is being established in southwestern Nigeria (Osazuwa and Ajakaiye, 1989; Ajakaiye et al., 1991), periodic assessment of the calibration line will be made.

REFERENCES

Ajakaiye D.E., Ojo S.B., Daniyan M.A. and Abatan A.O.; 1989: *Proceedings of the National Seminars on Earthquakes in Nigeria.* National Technical Committee on Earthquake Phenomena, Federal Ministry of Science and Technology, Lagos, Nigeria, 247 pp.

Ajakaiye D.E., Ojo S.B., Osazuwa I.B. and Ige E.A.; 1991: *Interim Report on: Establishment of a microgravity network at Ibadan/Ijebu-Ode Area of South-Western Nigeria.* Federal Ministry of Science and Technology, Lagos, Nigeria.

Ashkenazi V.; 1967: *Solution and error analysis of large geodetic network.* Part 1: Direct Method. Survey Review, **19**, 166-173.

Brien R., Gerstenecker G., Kiviniemi A. and Pettersson L.; 1977: *Report on high precision gravimetry.* Professional Papers, National Land Survey of Sweden, Gavle, 26 pp.

Csapo G.; 1979: *Geodetic gravimetry.* In: Hungarian IAG Report for the General Assembly of IUGG, Canberra, Australia, Section III, 23 - 27.

Morelli C., Gantar C., Honkasalo T., McConnel R.K., Tanner J.C., Szabo G., Uotila U. and Whalen C.T.; 1974: *The International Gravity Standardization Net 1971 (IGSN71).* Special Publication 4, International Association of Geodesy, I.U.G.G., 196 pp.

Osazuwa I.B.; 1985: *The establishment of a primary gravity network for Nigeria.* Ph.D. Thesis, Ahmadu Bello University, Zaria, Nigeria, 320 pp.

Osazuwa I.B. and Ajakaiye D.E.; 1987: *Gravity control metwork at airports in Nigeria.* Journal of Geodynamics, **7**, 307-317.

Osazuwa I.B. and Ajakaiye D.E.; 1989: *On the application of microgravity techniques for the monitoring of possible erthquakes occurrences in Nigeria.* In: Ajakaiye D.E., Ojo S.B., Daniyan M.A. and Abatan A.O. (eds), Proceedings of the National Seminars on Earthquakes in Nigeria. National Technical Committee on Earthquake Phenomena, Federal Ministry of Science and Technology, Lagos, Nigeria, pp. 63 - 76.

Service Hydrograghique de la Marine and Companie General de Geophysique, Tidal Corrections for 1979, 1981 and 1983. European Association of Exploration Geophysicists, 53 pp.

Strang van Hees G.L.; 1984: *Adjustment Gravity Net.* Unpublished Program, Department of Geodesy, University of Technology, Delft, The Netherlands.

Uotila U.A.; 1978: *Studies in gravimetric geodesy.* Department of Geodetic Sciences, The Ohio State University, Columbus, Report No. 281, 65 pp.

Verheijen P.J.T. and Ajakaiye D.E., 1978: *A gravimetric calibration line, Nigeria.* Survey Review, **24**, 373-380.