

INVESTIGATIONS OF CHARACTERISTICS OF GRAVIMETRIC SITES INTENDED FOR HIGH-ACCURACY MEASUREMENTS

Eugene Krivtsov¹, Alexander Yankovsky²

D. I. Mendeleev Institute for Metrology (VNIIM)
190005, Moskovsky ave. 19, Saint-Petersburg, Russia
Phone: (+7)812-422-1560 Fax: (+7)812-422-4891
e-mail: dep253@vniim.ru

Leonid Vitushkin³

Bureau International des Poids et Mesures (BIPM)
Pavillon de Breteuil 92312 Sevres Cedex FRANCE
tel: +33 (0) 1 45 07 70 81; +33 (0) 1 45 07 70 70
fax: +33 (0) 1 45 34 20 21; +33 (0) 1 45 07 70 49
e-mail: lvitushkin@bipm.org

Olivier Francis⁴

University of Luxembourg
162 A, avenue de la Faïencerie L-1511 Luxembourg
Phone: (+352) 46 66 44 6264; fax: (+352) 46 66 44 6303;
e-mail: olivier.francis@uni.lu

Abstract

Keywords: Absolute gravimetry, metrology, measurement error, gravimetric site.

Quality of high-accuracy measurements completed by absolute ballistic gravimeters considerably depends upon environments and gravimetric site parameters as well. This is confirmed by the results of absolute ballistic gravimeters comparisons, performed in various sites, and by its exploitation experience in approximately in-the-field. The analysis results disclosed that not only natural seismic noise must be taken into account, but dynamic excitement, caused by gravimeters as well. Thus, the subject of special interest is determination of transfer function of gravimeters mechanical systems and that of basements used for the measurements, as well as partial dynamic characteristics: natural frequencies, damping coefficient etc. Investigations were carried out for basements of BIPM (France) and that of VNIIM (Russia) using wideband seismometers. The obtained results allows to state requirements for parameters of basements of gravimetric sites, used for comparison and calibration of gravimeters, and besides, to optimize the procedure of such comparisons and the devices operational mode according to the ambience. Trends for improvement of the gravimeter main systems are determined as well as for reduction of errors due to mechanical excitement of basement – gravimeter system.

The main aim of this investigations was to develop and confirm requirements for the design of gravimetric sites used for precise measurements, in the first place for absolute gravity measurements performed with ballistic gravimeters.

Quality of such measurements considerably depends upon current environment conditions, local gravity field distribution and gravimetric site parameters as well.

Two gravimetric sites were studied – site of Bureau International des Poids et Mesures (BIPM), Sevres, France and site of D. I. Mendeleev Institute for Metrology (VNIIM), Saint-Petersburg, Russia.

Gravity field at the BIPM site is thoroughly studied during several International Comparisons of Absolute Gravimeters (ICAGs) as well as during long term regular measurements with FG-5 № 108 that belongs to the BIPM. The results of ICAGs confirm that this site suites main requirements for the site intended for precise measurements:

- random uncertainty of g measurements can be reduced to 1-2 μ Gal;
- mean value of g is stable between comparisons;
- there are no significant anomalies in local distributions of g and its vertical gradient.

Measurement of g value at the VNIIM site was made in November 2004 with the FG-5 № 216 that belongs to European Center for Geodynamics and Seismology (ECGS), Walferdange, Luxembourg. The results of two sets of measurements, shown in Tab. 1, ensure that VNIIM site also suites the requirement about random uncertainty of measurements.

¹PhD. Head of the Department.

²Deputy Head of the Department.

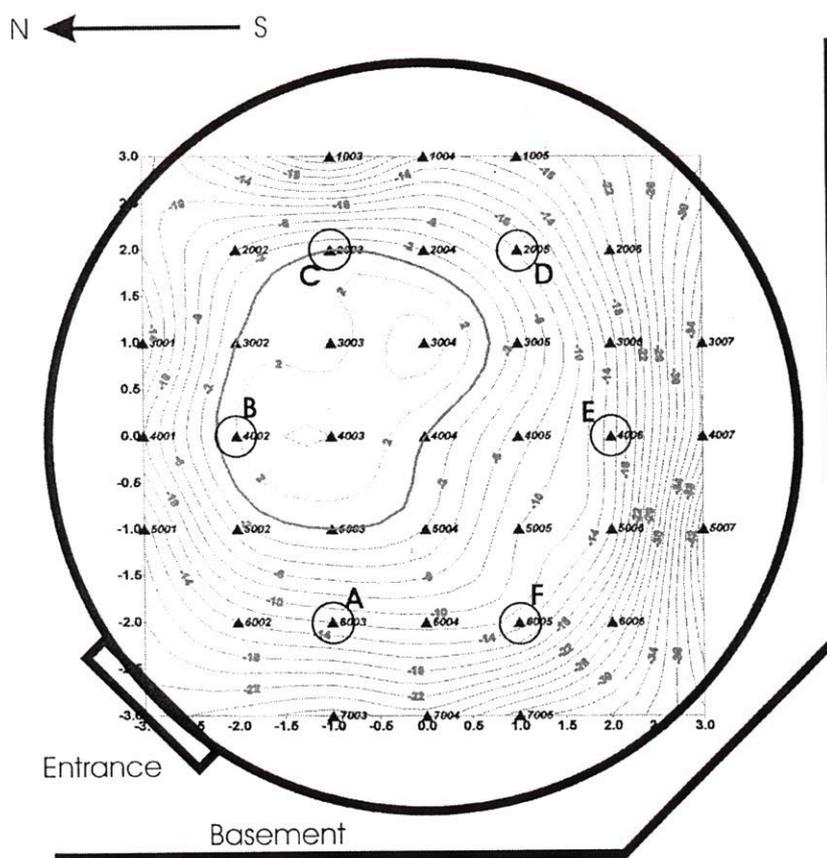
³Doctor of Tech.Sci., Principal research physicist, Section of time, frequency and gravimetry.

⁴Professor, Faculty of Sciences, Technology and Communication.

Summary of the absolute gravity measurements at VNIIM site

Date	Gravity value, μGal	Standard Deviation, μGal	Drop-to-drop Standard Deviation, μGal
4-5 November 2004	981902491.36	2.08	21.03
5-6 November 2004	981902491.45	0.9	21.06
Combined dataset 4-6 November 2004	981902491.45	1.09	21.04

Local distribution of g value was measured with precise relative gravimeters. The summary of these measurements is shown on fig. 1.

Fig. 1. Local g distribution at the VNIIM site. Line step $2 \mu\text{Gal}$

For the site located in a box 7.5 meter in diameter contour lines are shown in the area for gravimeters location. Variations of g value with respect to the center of the box for six key points of this area are shown in Tab. 2.

Table 2

Key points gravity distribution with respect to the center of the box

Point	A	B	C	D	E	F
$\Delta g, \mu\text{Gal}$	-13 ± 4	2 ± 3	0 ± 5	-8 ± 7	-12 ± 4	-12 ± 3

Due to significant differences between constructions of basements at the BIPM site and at the VNIIM site it is interesting to study the mechanical behavior of the system that joins basement and gravimeter. At the BIPM site basements are separate concrete blocks either located on a dry sand bed and connected with the building

(pillars C and E) or surrounded with the layer of special damping material with the thickness of few centimeters. VNIIM site is located on a large massive basement (total mass is about 4000 tons) isolated from the building, mounted on the sand bed with additional damping layer of dry wood. This design is intermediate between BIPM site and site located on the ledge rock egress (e.g. ECGS site at Walferdange, Luxembourg).

Broadband seismic transducers of type ПДГС-18, ПДВС-9 were used to carry out measurements. Such seismic transducers are of diffusion type (seismometer with liquid sensing body) and intended for measurement of low frequency and middle frequency seismic oscillations. Main seismic transducers specifications are given in tab. 3.

Seismic transducers specifications

Table 3

	ПДГС-18	ПДВС-9
Type, orientation of measuring axis	Unicomponent, horizontal	Unicomponent, arbitrary orientation
Max. measured acceleration	$2 \times 10^{-4} \text{ m/s}^2$	10^{-3} m/s^2
Frequency range	Normal: 0.001–30 Hz Extended: 0.001–150 Hz	Normal: 0.01–60 Hz Extended: 0.001–150 Hz
Dynamic range	120 dB	120 dB
Sensitivity on the base frequency	$5 \times 10^4 \text{ Vs}^2/\text{m}$	$5 \times 10^3 \text{ Vs}^2/\text{m}$
Base frequency	0.01 Hz	0.3 Hz
Uncertainty in normal conditions	2-3%	2-3%
Cross sensitivity	<0.3%	<0.3%

During the investigations the measurements have been done to determine the following characteristics of the basements:

- the basement seismic noise level;
- the basement transmission characteristics;
- the basement resonance characteristics (self frequency and damping);
- level of vibro-disturbances taking place during the gravimeters work;
- the basements inclination when asymmetric load takes place (it is so when people move or equipment being moved over the basement surface).

Some differences in seismic noise were found between two sites mainly in low-frequency part of the spectrum where influences of artificial sources and dynamic characteristics of basements are not very significant (Fig. 2).

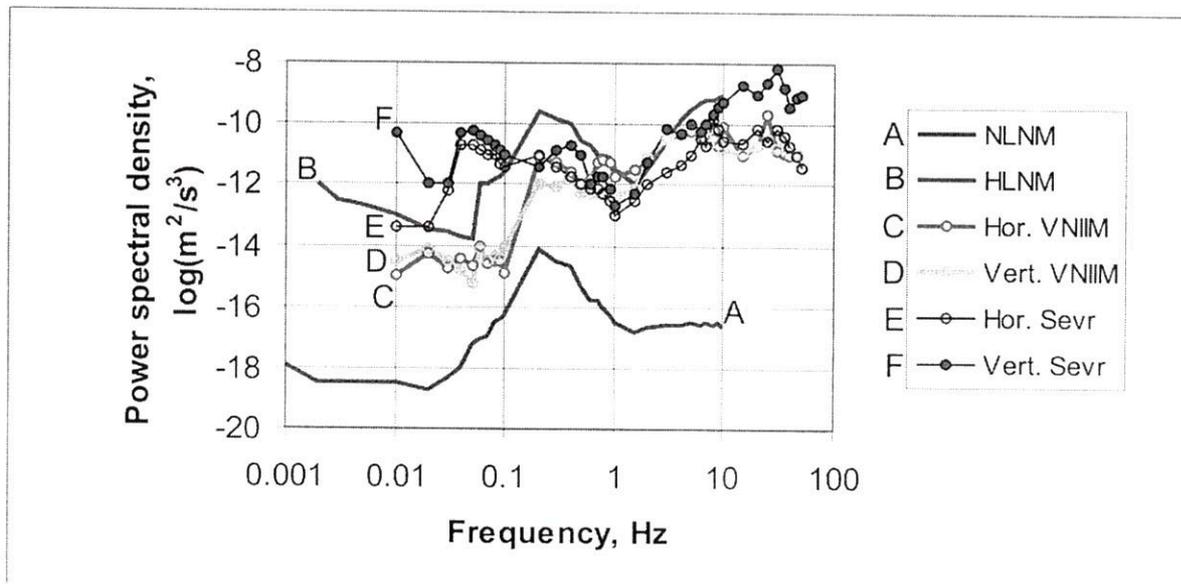


Fig. 2. Power spectrum density at two sites with respect to NHHM and NLNM

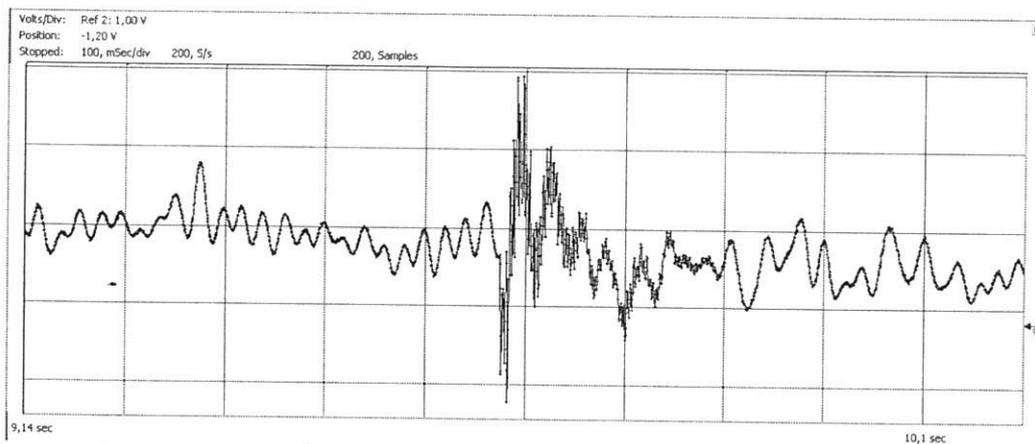
Tab. 4 shows results of determination of dynamic characteristics of the main basements of two sites. Sensitivity to asymmetric loads is presented in the form of “Man’s inclination” - tilt due to 80 kg load as if an average man stepped over the basement.

Dynamic characteristics of main basements at two sites.

Pillar		Self-frequency, Hz	Damping	"Man's inclination", arc.sec
BIPM, pillar C	X	12,4±0,3	0,14	0,03
	Y	36,4±0,3	0,16	0,05
	Z	41,7±0,2	0,05	
BIPM, pillar E	X	15,9±0,3	0,15	0,07
	Y	21,1±0,5	0,26	0,09
	Z	21,3±0,8	0,36	
BIPM, pillar B	X	29,8±0,5	0,23	0,02
	Y	28,7±0,5	0,23	0,03
	Z	33,8±0,2	0,22	
VNIIM	X	8,9±0,3	>0,8	<0,001
	Y	8,6±0,2	>0,8	<0,001
	Z	9,4±0,6	>0,8	

Fig. 3 shows results of modeling the disturbances of the basement due to activity of the ballistic gravimeter.

a)



b)

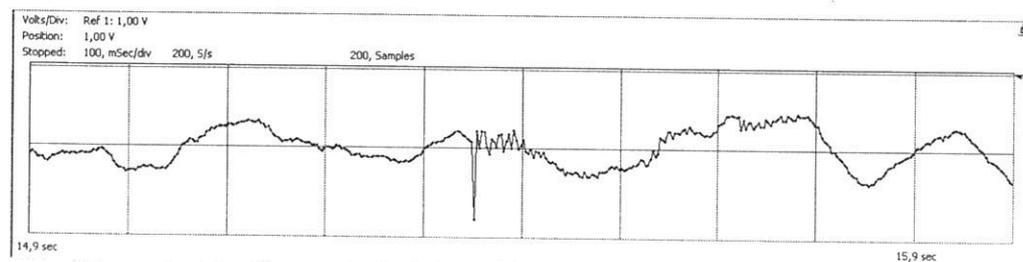


Fig. 3. Excitation of the basement due to activity of ballistic gravimeter:
(a) basement B at the BIPM site; (b) basement of the VNIIM site

Due to the location of pillars C and E at the BIPM there exists a strong interference between them. When some excitation takes place on one of these basements another basement also excites. Pillar E as basement with lower resonance frequencies provides better damping of cross-excitations (up to 5 times less amplitude, depends on frequency excited) while pillar C provide almost no damping of vibrations that originated from pillar E.

Obtained results shows that during concurrent measurements with several ballistic gravimeters the excitation of the basement must be taken into account. Also these results allow optimization of the procedure of simultaneous measurements with ballistic gravimeters in order to reduce the total measurement uncertainty.