An Absolute / Relative Gravity Base Net in the Emirate of Dubai

Abstract

In order to create an overall reference scenario for planning and surveying information system, the Municipality of Dubai (United Arab Emirate) started the broad “Geodetic Project for Precise Mapping”. Within the framework of this project a new Gravity base has been established in the Emirate of Dubai. First gravity determinations were carried out by the Dubai Municipality Planning Department and the institut fur Erdmessung (ifE), University of Hannover in November 1994. Absolute and relative techniques were applied, employing ifE’s JILAG-3 absolute gravimeter as well as one LaCoste&Romberg (LCR) model D and two LCR model G relative gravimeter.

Introduction

1. Absolute gravity determinations

1.1 Station selection

The gravity base net consists of 9 gravity stations. Absolute gravity determinations were carried out on 3 specially constructed stations, two of them in main land of Dubai area and one in mountainous region of the wadi Hatta. (see map attached). The other six stations are control points of the geodetic network of Dubai and were tied to the absolute datum by relative measurements with 3 LCR-gravimeters.

1.2 Site Construction

Because most part of Dubai are unpopulated desert areas, special gravity stations had to be constructed to match the high quality of absolute gravity determinations,three absolute stations were constructed . A concrete pier of 75 X 75 cm sq. surface and 80 cm depth is constructed separately from the surrounding concrete floor. This enables the best possible protection of the instruments interferometer base from micro seismic disturbances produced by the dropping chamber during the individual drop experiments. The pier is located in an aluminum cabin (Hutte) of nearly 3x3x3 cubic meter. The cabin can be climated to protect the instrument against temperatures higher than 25 degree C, which regularly occur during daytime in desert areas. Electric power for the air-conditioning as well as for the instrument was supplied by a transportable generator, which stayed near the gravity station until the disassembly of the instrument.

1.3 The JILAG-3 absolute gravimeter system

The JILAG-3 gravimeter was developed by prof. J. E. Faller and co-workers at the Joint Institute for Laboratory Astrophysics (JILA), Bolder Colorado U.S.A. (FALLER et al. 1983). It is operated by ifE since 1986 and has been used for more than 140 gravity determinations worldwide. As the instrument as well as the measurement and evaluation

method employed at ifE is well documented (TORGE 1993, RODER 1994, TIMMEN 1994), we here only summarize the main features.
The JILAG-3 gravimeter is a transportable free-fall apparatus, including a Michelson interferometer with a frequency stabilized laser serving for distance measurements to the dropped object and a Rubidium frequency standard for the corresponding measurements of time.
The beam of the frequency-stabilized laser is splitted into a measurement and a reference beam. The reference laser beam is directly led to a "fixed" reference corner cube reflector, whereas the measurement beam is reflected by the dropped object (falling corner cube reflector). After reflection the two laser beams are superimposed, leading to interferences, which are detected by a photodiode.
The falling tube is continuously kept under high vacuum. Additionally the falling body is screened from residual gas molecules by keeping the dropped object inside a co-accelerated drag free chamber. Micro-seismic noise on the reference reflector is strongly absorbed by a so-called "super-spring". The natural period of this spring (1 HZ) is electronically expended to a proper period of 30 s to 40 s.
The falling height in the JILA instrument is 0.25m, corresponding to a falling time of 0.22 s. Per drop occur approximately 800000 interference fringes. Every 4000th fringe is pre-selected leading to a200 fringe counts, which are used to determine the single drop gravity value.
The time interval between the individual drops is 10 s. After 300 drops (1 run) the instrument setup is checked. According to local noise, 1200 to 3000 drop experiments (4 to 10 runs) are performed.

1.4 Applied reductions

The on line adjustment of the 200 position-time pairs per drop is done employing an IMB-compatible personal computer. The derived gravity value is corrected for the finite velocity of light as well as for the temperature dependence and long term drift of the laser frequency.

1.4.1 Air pressure

Air pressure reduction is applied using standard regression model

$\delta g_{air} = 3\ (p-p_n)_{(hpa)}\ nm/s^2$, as proposed by the International Association of Geodesy (IAG) in 1983, with the normal air pressure pn defined after DIN 5450, which is largely compatible to the U.S. standard atmosphere 1962:

$$P_n = 1013.25 \left[\frac{(1-0.0065\ H_{(m)})}{(288.15)}\right]^{5.2559} \text{hpa.}$$

1.4.2 Polar Motion

During on line computation, the effect of polar motion is reduced using predicted pole coordinates, whereas the post-processing is done using the observed pole coordinates given by the weekly delivered Bulletin A of the International Earth Rotation Service (IERS).

1.4.3 Earth Tides

For the reduction of gravity changes due to earth tides, a set of synthetic earth tide parameters, interpolated from a worldwide 1 degree X 1 degree grid by Timmen and Wenzel 1994, was used . The grid has been computed from body tide amplitude factors using the Wahr-Dehant model of an ocean free, elastic, rotating, isotropic and ellipsoidal Earth with liquid outer core, and from ocean tide gravitation and load derived from an 1 degree X 1 degree ocean tide model. During online processing only a simplified model could be used.

1.4.4 Centering to a floor level

The absolute gravity values are from the JILAG-3 reference height (≈0.80 m) to floor level using the vertical gravity γ, which was determined using two LCR gravimeters with built-in SRW-feedback system (LCR-G298F, LCR-G709F),see [RODER et al., 1988]. Assuming a neglect-able non-linear behavior of γ near the ground, the vertical gradient can be easily derived by measuring the gravity difference between the ground point and a corresponding point on a tripod in 1 m height.
The vertical gradients on the three Dubai absolute stations with the corresponding adjustment accuracy are shown in Table 1. From numerous gradient determinations throughout the last years, the absolute accuracy of the derived gradients is estimated to be 0.02-0.03 $\mu m/s^2$

Station	Vertical gradient γ [$\mu ms^{-2}/m$]	Standard deviation [$\mu ms^{-2}/m$]
ET145	322.0	1.0
ET34 a	297.1	1.3
ET152 a	288.5	1.2

Table 1: Vertical gradients and related adjustment accuracies on the Dubai Absolute stations.

1.5 Results

Before and after the Dubai field campaign, JILAG-3 took measurements on ifE's absolute reference station in Clausthal (Harz mountains). The two gravity determinations corresponded within X.XX $\mu m/s^2$

Epoch	g [$\mu m/s^{2}$]	S_g [$\mu m/s^{2}$]
941108	9811157.294	0.004
941216	9811157.313	0.011

Tab X: Results of JILAG-3 calibration measurements in Clausthal before and after
the Dubai campaign.-

The results of the Dubai measurements are shown in table. The formal accuracy of the mean gravity values is 0.02-0.03 $\mu m/s^2$. Although the construction of the three sites is the same, significant differences in the "drop to drop" – scatters were found which are supposed to be caused by the environment.

Station	Epoch	g [$\mu m/s^{2}$]	S_g[$\mu m/s^{2}$]
Et145	941122	9788615.26	0.03
ET34 a	941124	9788467.67	0.02
ET152 a	941128	9788812.66	0.03

Tab: Results of JILAG-3 absolute measurements Dubai 1994

2. Relative Measurements

In addition to the 3 absolute gravity determinations, 6 further stations of the Dubai network were connected to the new absolute datum, employing two of the ifE's LaCoste&Romberg (LCR) model G gravimeters (G298, G709) and one LCR model D gravimeter (D191) of Dubai Municipality.

2.1 Calibration of LCR-instruments

The feed-back systems of the two gravimeters were calibrated before and after the Dubai campaign on the Hannover vertical calibration line. The mean values of both calibrations were used for evaluation of the gradient measurements. The manufacturer calibration of the LCR-D191 has been checked in the Hannover calibration system. Measurements were carried out on the Cuxhaven-Harz calibration line (gravity range ~3000 $\mu m/s^2$)as well as on the Hannover vertical calibration line (gravity range ~200 $\mu m/s^2$. A new calibration function was computed from these observations. The measurements on the Hannover vertical calibration line were also used to compute the short-term periodic errors of the LCR-D191.

For the LCR model G gravimeters, whose calibration functions have shown to be range-dependent, the calibration functions determined in the Wuhan (China) calibration system (RODER 1994) were a-priori applied, as the gravity range of this system is close to the Dubai gravity range.

Period (CU)	Amplitude [nm/s^2]	Phase [^{0}]
1.625	39 +/- 40	44 +/- 15
3.250	37 +/- 14	347 +/- 18

3. Combined adjustment

The combine adjustment was carried out using the program GRAV (WENZEL 1993), kindly provided by the Geodetic Institute of the university of Karlsruhe. This program system consists of two computation steps (GRAVPP, GRAVNA). This processing includes the calibration of observations and corrections resp. reductions for tidal influence, air-pressure effects and instrumental height, while GRAVNA performs the actual least square adjustment.
As the calibration functions of LCR gravimeters have shown to be gravity range-dependent, the relative measurements between the absolute stations were used to derive linear calibration factors fitted to the Dubai gravity range by least square adjustment. These linear factors were introduced in the following combined adjustment of the absolute and relative gravity observations. The absolute gravity determinations were introduced in the stochastic model with a standard deviation of 0,07 $\mu m/s^2$, which has, throughout the last years, shown to be a realistic value for the achievable overall accuracy of JILAG-3 measurements.
The a-priori standard deviation of the LCR gravimeters were set to 200nm/ s^2 and then subsequently approximated to the a-posteriori values. The resulting precision estimates after the final solutions together with the number of usable ties for every gravimeter are listed in table.

Gravimeter	**No of Differences**	**Standard Deviation of single difference [$\mu m/s^2$]**
LCR-D191	27	0.230
LCR-G298	25	0.130
LCR-G709	21	0.131
LCR-G298F	31	0.048
LCR-G709F	29	0.035

The corresponding gravity values together with their standard deviations as listed together with their standard deviations are derived from least square adjustment. The given station coordinates are only preliminary values and need to be replaced as soon as accurate numbers are available. The worst standard deviation (0.09 μm / s^2) is estimated for BTP215 in the south of Dubai. There are mainly two factors that limit the achievable accuracy for this point. On the one hand, the point can't be easily reached (~20 km transportation on desert track). On the other hand, the gravity of this point is not covered by the absolute gravity observation, leading to a forced extrapolation of the gravimeter calibration functions.

Station	**ϕ [^{0}]**	**λ [^{0}]**	**H [m]**	**g [$\mu m/s^2$]**	**Sg [$\mu m/s^2$]**

ET145	24.940	55.234	65.000	9788615.24	0.05
ET34A	24.994	55.659	152.240	9788467.67	0.04
ET152A	24.782	56.141	352.467	9788812.66	.05
ET146	24.973	55.009	10.000	9788841.38	0.08
ET236	24.985	55.480	100.000	9788406.61	0.06
ET92	25.111	55.356	30.000	9788684.91	0.07
ET9	25.222	55.404	25.000	9788721.77	0.07
BP5	25.200	55.625	100.000	9788541.87	0.06
BTP215	24.552	55.458	170.000	9788083.98	0.09

Dubai Gravity base net 1994. Station coordinates and adjusted gravity values.

As the LCR-G298 needed to be repaired since the determination of cycle errors in the Wuhan calibration system, these errors might have changed since then. The periodic errors found for the LCR-D191 on the Hannover vertical calibration line are small and thus not very significant. Besides this, they were determined only over a small range of the gravimeter screw, which was additionally not in the Dubai measurement range. Consequently, the correction of the observations for periodic errors led only for the LCR-G709 to a significant improvement in accuracy.

4. Conclusions

A new fundamental gravity network has been established in the Emirate of Dubai. Three absolute gravity determinations were carried out with a formal accuracy of 0.02 – 0.03 $\mu m/s^2$. *These measurements were the first absolute gravity determinations in the whole South-West Asia.*

Further six of the national Geodetic Network of Dubai could be connected to the absolute datum by relative measurements with LCR gravimeter. Although the height difference between the absolute stations amounts to nearly 350 m, the gravity difference covered by these points is only 350 $\mu m/ s^2$, indicating strong anomalies in the mountainous Hatta region. The gravity difference covers most part of Dubai, except for the extreme southern part of the Emirate. This leads to an unavoidable extrapolation of the LCR gravimeters calibration functions, which means a slight loss in accuracy for for the BTP215 station on the Dubai Abudhabi borderline.

On basis of these 9 relative and absolute gravity stations, a gravity project of whole Dubai Emirate including Hatta, along with leveling and GPS observations was carried out. After computation and adjustment Geoid model for Dubai was established.