[1]The nontidal gravity change at Xiangshan seismostation in Beijing

Jia Minyu① Guo Youguang② Gao Rongsheng③ Huang Dalun② Liu Shaoming① Fang Yongyuan② Xu Jinyi②

①Institute of Seismology, China Seismological Bureau, Wuhan 430071, China

②National Institute of Metrology, Beijing 100013,China

③Department of Monitoring and Predicting, China Seismological Bureau, Beijing 100006, China

Abstract

From March 1988 to March 2001, 58 absolute gravimetric station determinations have been carried out by National Institute of Metrology cooperating with China Seismological Bureau with the NIM－II Absolute Gravimeter at Xiangshan seismostation among which 44 groundwater level observations have been carried out simultaneously. This paper studies the mechanism of gravity change at Xiangshan seismostation from various point of view. The main conclusions include: (1) the groundwater activity is the main local interferential source, the groundwater levels correlate with gravity observation values by segments and its effect on gravity can be corrected by a 5^{th} polynomial; (2) the effect of local crustal deformation is very small, thus it can be ignored; (3) the earthquake activity can result in short - term change of the gravity field and its maximum magnitude comes to $0.333\,\mu ms^{-2}$; (4) the gravity value approximately drops linearly by $0.191\,\mu ms^{-2}$ from 1988 to 2001, the average decrease is $0.0147\,\mu ms^{-2}$ per year, and this gravity change belongs to global or regional gravity change.

Key words: Xiangshan Beijing; absolute gravimetry; nontidal gravity change

Introduction

Since the middle 20^{th} century, nontidal change of gravity field has become one of focal problem which scientists pay the most attention to. Local gravity change is mostly related to earthquake and volcano activity. The period of the change is very short and it used to be observed by relative gravity measurement. There are many achievements about this reportedly. Regional and global gravity change is related to the phenomena of plate movement, earth spin, and core rotation. The period of the change is long and it is usually observed by absolute gravity measurement. So far, there are few achievements about this reportedly. The absolute gravimetric results include not only short-term change but also long-term change. To study it not only has important significance for the study of earthquake prediction and geodynamics but also has important effect on the establishment of the dynamic datum and model of earth gravity field.

1. Measurement and its results

The Xiangshan absolute gravity station is installed in a room of the first floor of west building at Xiangshan seismostation. The pier is set up on bedrock and very stable. There is a groundwater well which is about more than 3m from the gravity station in another room to the west of the station. The Xiangshan seismostation is in a cove to the east of the Xiangshan Park, which locates at the east piedmont of West Mountain, Beijing. Here the surroundings are quiet and tasteful, and the observation condition is very good.

Form Mar. 1988 to Mar. 2001, 58 absolute gravity determinations have been carried out by

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National Institute of Metrology cooperating with China Seismological Bureau among which 44 groundwater level determinations have been carried out simultaneously. The measurement interval was different greatly: there were 11 determinations in 1988 and 1989 each, there was only once in 1998, the number of measurement was between 2 and 5 in other year.

The NIM-Ⅱ free-fall gravimeter which was developed by National Institute of Metrology has been used for absolute measurements. The meter has participated in the International Absolute Gravimeters Comparison held in 1980, 1985, 1989 and 1997. Its observation results were well evaluated in the word and especially its deviation from median of all meters is relatively small in 1997. In 1995 the meter was partially improved. Its uncertain range was further reduced to 0.04-0.06 μms^{-2}.

Around 16 consecutive drops are combined to one set, about 30 sets have been generally performed on each determination and distributed over 12-24 hours.

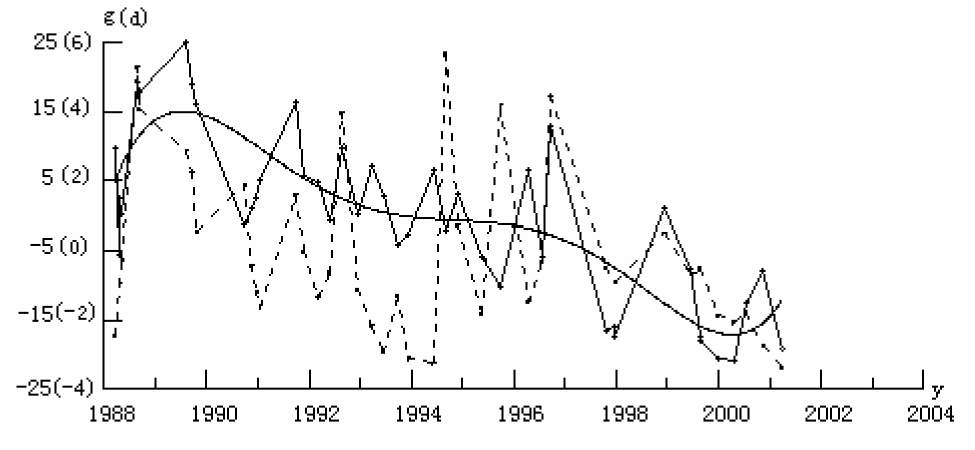

Fig.1 Absolute gravity and groundwater level measurements at Xiangshan station,

Real line is gravity, unit for g-axes is $10^{-8}ms^{-2}$; broken line is water level, unit for d axes is meter,

g or d is the differences between the observation values and their mean.

In observation the effects of some factors, such as electron circuit delay, the limited light velocity, electromagnetic field, vertical level of beams and vacuum level of falling-body cabin etc, were corrected or under strict control. The observation results were corrected with solid tide, air pressure, gravity vertical gradient and polar motion. The gravity and groundwater level changes obtained by the measurements are showed in Fig.1. The smooth curve in Fig.1 represents a fitting 5^{th} polynomial of the g values.

2. The effect of groundwater activity and its correction

Groundwater activity is a most active factor resulting in gravity nontidal change. Not only its effect on the gravity field is large and ubiquitous, but also water level change is fast and the relation between the level and gravity is complicated. However, for the studies of many geoscience problems, it is only an interferential factor and must be separated from observation data. The ground water can be divided into many types, such as vadose water, phreatic water, confined water, fissure water and karstic water etc. Different types of groundwater have different effects on the gravity value of observation station. The phreatic water of them has a great effect on gravity field because it is free aquifer. Above all, we study what type of groundwater the

Xiangshan well water level represents.

In order to find an annual law of water level changes, Fig.2 is drawn, where d-axes is water level, m-axes is measured time overlooked years. It is clear that from January till May the water levels are low, by June the level begins to rise, in August and September they reach their maximum value, then, it begins to drop. This is the typical character of phreatic water changes. It originates from the effects of rainfall and evaporation. Some relatively big fluctuations in the Fig.2 result from difference between years; in other words, it results from long-term change of groundwater level. For example, some obvious lows appear in the years of 1993 and 1994 when the groundwater levels are generally on the low side (see Fig.1).

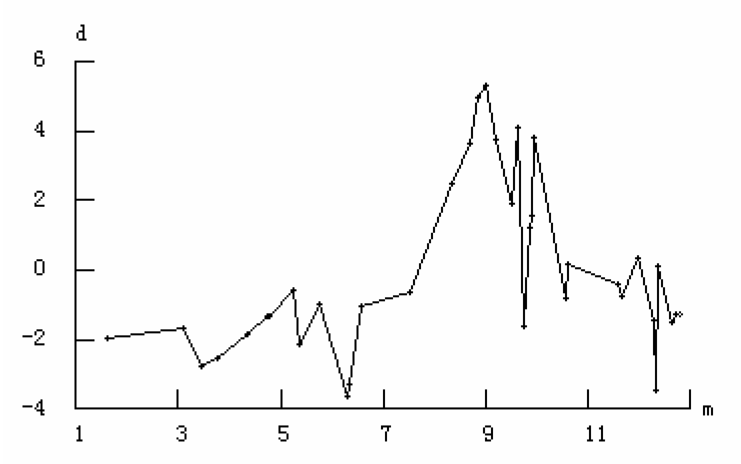

Fig.2 The characters of yearly changes of
Well water level at Xiangshan station
d is the same with Fig.1

In many cases there lies a linear relation between phreatic water changes and their gravity effects, for example, there is $g = 42\delta\rho\delta d$ in North China Plain (Jia et al 1983). However, from Fig.1 it can be roughly seen that the relation in Xiangshan point is more complicated. It seems that the gravity changes and the water level changes both represent a tendency to long-term decrease, but the latter also occurred a bigger jump in 1994. In order to prospect for the relation between both of them Fig.3 is drawn. The fitting curve in Fig.3 is a 5th polynomial, its equation is

$$\hat{g} = -2.1793 + 6.5079d + 2.5211d^2 - 0.6482d^3 - 0.1672d^4 + 0.0318d^5 \qquad (1)$$

Fig.3 and equation (1) show the curved correlation between groundwater levels and gravity values. In the two segments where d is -2.68~-1.03(low water level) and 2.87~5.05(high water level) respectively, gravity values negatively correlate with water levels, but in the segment where d is –1.03~2.87(medium water level), both of them have positive correlation. The bends at the both ends result from the cut of gravity data, a mathematical factor, so it has no physical meaning and it will not be considered. From the gravitational formula it can be known that if a water stratum is above gravity station, its gravity effect negatively correlates with the level change, and otherwise, the gravity effect positively correlates with one. Combining the characters of topography and stratum as well as the conditions of water source around Xiangshan station, the phenomenon of correlation in segments can be explained.

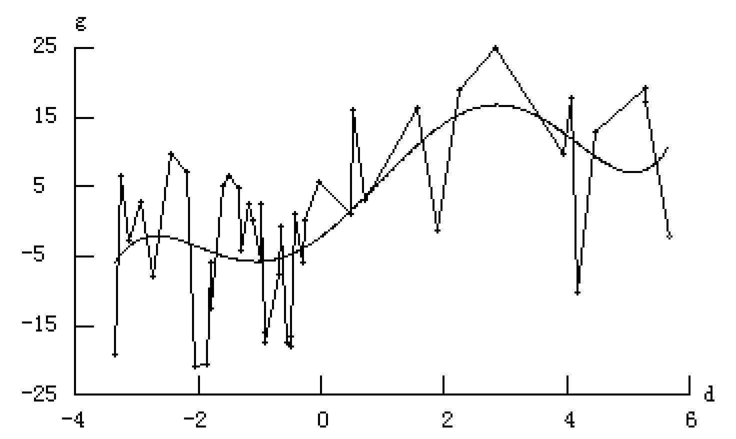

Fig.3 The relation between gravity and well water level observation values

g and d are the same with Fig.1 and Fig.2.

Because the observation station is located at the foot of east of West Mountains, the phreatic aquifer near the station and in its east (PANE) is lower than the pier, but the phreatic aquifer of the western mountainous regions (PAWM) is higher than the pier. Generally the gravity effect of PANE is bigger than PAWM, thus it comes into being that the gravity effect positively correlates with the water level change in the medium level segment. After groundwater level continually drops to the low segment, the water contained in PANE is nearly exhausted; whereas the water in PAWM is relatively abundant because of the supply of water from the mountain. Especially, when the groundwater level would be reaching its nadir in 1993~1994, an artificial pond which is about 200m in the west of the observation station and stores water 500m^3 was built, it provides more water for PAWM. Now, PAWM showed so main effect on gravity that the positive correlation in the low level segment comes into being. As for high water levels，they all occur in rainy season. Here there is plenty more surface water, but the flow velocity in mountains is bigger than plain, therefore PANE could keep being saturated status(the level didn’t almost change) and the level of PAWM could change, and thus the negative correlation in high level segment comes into being. The quantitative calculation by formula (1) shows that if effective porosity of rock stratum and well water level change are the same, the gravity effects of each segment at Xiangshan station are in turn (from low to high) 21%, 55%, 42% of that at most stations in North China Plain(Jia, et al. 1983). This further proves that the aquifers in east and west of the observation station have a function of mutual counteraction and the effect of the flat is greater than the mountain. According to the prospecting on the spot the dip angle of massif rock strata is 70°, the penetration speed of the groundwater will be fast, so that it is possible that the phreatic aquifer in different area controls the well water level in different time. In addition from Fig.3 it also can be seen that the correlativity in low and high segments is weaker than medium. This indicates that the effects of other factors, such as surface water, earthquake activity, are large.

Fig.4 is mapped after the observation values in Fig.1 are corrected with groundwater according to the equation (1). The magnitude of gravity changes becomes smaller and the fitting polynomial curve becomes straighter when comparison with those in Fig.1. From the discussion in the 4th and 5th part of this paper it can be known that the gravity effect of earthquake events and the long-term change of gravity field are more prominent and reasonable, which proves that the groundwater correction is valid.

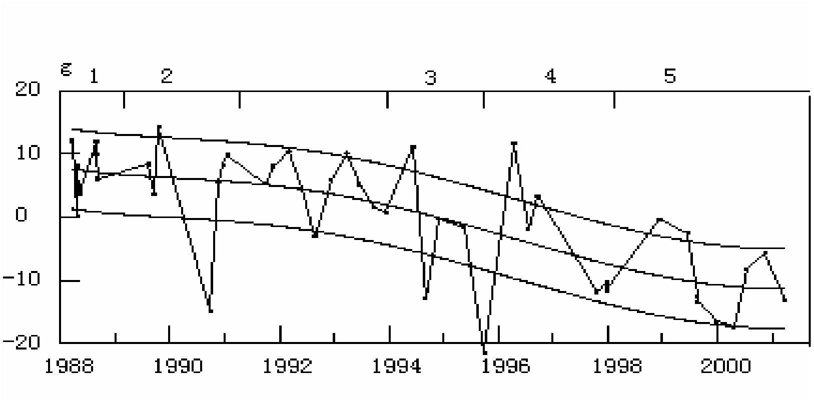

Fig.4 The gravity changes corrected with groundwater

Unit for g-axes: $10^{-8}ms^{-2}$; the numbers on the top are order number of gravity effects from earthquakes.

3. The gravity effect of local crustal deformation

This part discusses the effect of vertical displacement of the observation pier and the gravitational effect of the crustal deformation around the observation station.

In order to monitor the stability of the bedrock, the Beijing Surveying and Mapping Institute distributes a 50km measuring line in northwest Beijing. It includes more than 10 bedrock observation stations, such as Xiangshan, Yuyuantan etc, and 4 times of primary leveling were carried out in 1989, 1992, 1995 and 1998. The results show that the changes of elevation are only few mm, very small, and not continuous. So the gravity effect of elevation changes can be neglected.

At the same time, the Beijing Surveying and Mapping Institute also carried out subsidence observation in the urban area of Beijing and founded two local subsidence areas. One's center is about 22km north by east 50° from the Xiangshan station and its maximum subsidence is 385mm. Another one's center is about 44km south by east 15° from the Xiangshan station and its maximum subsidence is 363mm. When the subsidence area divided into 7 lays, the linear integration method (Talwani et al 1960, Lio, et al. 2002) is used to calculate their effects on Xiangshan absolute station. Their gravity effects are 0.13 and $0.04nms^{-2}$ respectively, which are very small.

In a word, the gravity changes at Xiangshan station absolutely don't result from local crustal deformation.

4. The gravity changes resulting from earthquake activity

The interference of local surroundings factors is removed in the gravity changes in Fig.4. So except the residual measurement errors they should be related to local tectonic activities or the geosciences phenomena in wider range. It is obvious that the gravity changes in Fig.4 can be divided into two parts: one part is a long-term change represented by smooth curve; another part is a short-term change described by the broken line. In this section the latter will be discussed.

The average uncertain region of 58 absolute gravity determinations is $\pm 0.063 \mu ms^{-2}$. When the smooth curve is taken as reference and ± 0.063 is taken as limit (confidence interval), two parallel curves are dropped in Fig.4. The middle part between them is an uncertainty range, and the outside of them is viewed as a region produced the effect of tectonic activity.

Tab.1 provides the earthquakes Ms⩾5.0 which occur within 300km around the Xiangshan station since 1982, and together there are 9 ones. They can be divided into 5 groups according to their occurring time. (See 2nd column of Tab.1.). It is interesting that we can find corresponding gravity changes with them one by one in Fig.4, which are also made signs from 1 to 5 on the top of that. The gravity changes usually appear earlier than earthquakes about 1-2 years, that indicates the former result from gestation of the latter, and so the gravity changes are named an anomaly for portents of earthquake.

Table.1 The earthquakes Ms⩾5.0 within 300km around Xiangshan station

Order number	Group Number	Time	Ms	L	ϕ	Place
1	1	1989.10.18	5.7	113.88	39.94	Datong—Yanggao
2	1	1989.10.19	5.9	113.91	39.92	Datong—Yanggao
3	1	1989.10.19	5.5	113.87	39.92	Datong—Yanggao
4	2	1991.3.26	5.8	113.80	40.00	Datong—Yanggao
5	2	1991.5.30	5.1	118.20	39.50	Fengnan
6	3	1995.10.6	5.0	118.50	39.80	Guye
7	4	1998.1.10	6.2	114.30	41.10	Shangyi
8	5	1999.3.11	5.6	114.60	41.20	Zhangbei
9	5	1999.11.1	5.6	113.90	39.80	Hunyuan—Yangyuan

It looks as if the anomalies of portents have the following characteristics: (1) Every group anomaly contains process: the gravity value first rises, then drops, and then the earthquake occurs; the anomaly of serial number 2 also includes two rising-dropping processes, witch may be caused by 2 earthquakes happened respectively in the east and west of Xiangshang station. (2) The magnitude of the anomalies is related to an intensity of earthquake: the earthquake magnitudes of the 2nd and 4th group are big, so the anomaly magnitudes are also big (up to 0.333 μ ms^{-2}); the earthquake magnitude of the 3rd group is the smallest, so the anomaly magnitude is also the smallest. (3) The effects of earthquake events between which time interval is relatively short on gravity field mutually spliced. The first group of earthquakes is an earthquake swarm and the magnitudes are all relatively big. However, its anomaly form is quite incomplete. The incomplete rising segment is caused by truncation data. The short and small dropping segment results from interference of the 2nd group of earthquakes. Also the short and small rising segment of the 2nd group results from the interference of the dropping segment of the1st group, i.e. the dropping segment of the 1st group and the rising segment of the 2nd group mutually superpose.

5. The long-term changes of the earth gravity field

The smooth curve in Fig.4 is a 5th polynomial. Its equation is:

$$\tilde{g} = 1.7090 - 1.9786t - 0.1980t^2 + 0.0187t^3 - 0.0030t^4 - 0.0002t^5 \qquad (2)$$

Where $\tilde{g}$ is the long-term change of gravity, and t is the time represented by subtracting 1992.8890 from the year corresponding to $\tilde{g}$ (the month and day corresponding to $\tilde{g}$ are reduced to decimal fraction which takes year as unit). The curve in Fig.4 shows the long-term drop process of gravity and this process approximate to linearity. Using Equation (2) we obtained that the gravity decreases by 0.191 μms^{-2} altogether from March 1988 to March 2001 and the average decrease is 0.0147 μms^{-2} per year. This result is consistent with people's theory estimate of gravity long-term change.

Such long-term changes of gravity field have local or global significance. The chief purpose of International Absolute Gravity Basestation Network is monitoring the global gravity long-term changes, especially the gravity changes caused by earth spin and earth core rotation (Boedecker et al 1986, 1993). The observation result at Xiangshan will make contribution to this worldwide concerned study. The author will also further study the mechanism of gravity long-term changes at Xiangshan when there are more results published.

This paper is in agreement with JILAG-3 results (Torge et al. 1999, Jia et al. 1998).

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Reference

Boedecker, G., Th.Fritzer, 1986, International Absolute Gravity Basestation Network, I.A.G—SSG 3.87 Status Report March 1986. Veroff Bayer. Komm, fur die internat. Erdmessnng der Bayer. Akad. d. Wissensch., Astron.—Geod. Ard.,Heft Nr. 47, Munchen.

Boedecker, G. 1993, IAGBN Catalogue of Stations and observation, IAG conference report in Aug 1993 in Beijing.

Jia M., You Z., et al. 1983, Influences of the motion of the underground water on precision measurement of the gravity and the method of eliminating them. Crustal deformation and earthquake, Vol.3, No.1, 50—67.

Jia, M., Xing, C., et al. 1998, Gravity changes with time in Yunnan and Beijing observed by absolute gravimetry, Bur. Grav. Int., Bull. d'Inf., 83, 37-50. Toulouse.

Lio Sh., Gao R., et al. 2002,The Local Crustal Deformation around Xiangshan Absolute Station and Its Effect on the Gravimetric Result, Journal 0f Geodesy and Geodynamics, 22(2), Wuhan (in Chinese).

Talwani, M. And Ewing, M., 1960. Rapid computation of gravitational attraction of three—dimensional bodies of arbitrary shape, Geophysics, 25:203—225.

Torge W., Schnull M., et al. 1999, Absolute and Relative Gravimetry 1990/1992/1995 in the Western Yunnan Earthquake Prediction Experimental Area, Deutsche Geod. Komm., Reihe B, Muenchen.