Chance of time lapse microgravity method survey for subsidence monitoring

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Abstract

Times lapse microgravity method is a development method style. Technically that is developing is looping gravity measurements at the same point by a certain time interval, usually taking the measurements performed in the dry season and rainy season. Based on mathematical modeling is known that micro-gravity anomaly between the time rooted in subsidence and subsurface density changes associated with the dynamics of groundwater and pollution due to human activities, seawater intrusion. This fact can be observed by means of looping gravity by using Gravimeter with precision μGal. Gravimeter with the use of precision is necessary given the gravity anomaly due to pollution (seawater intrusion) small. Modeling of micro gravity anomaly between the time due to sea water intrusion by using software Grav3D The results showed that during the period of September 2002, November 2005, and October 2013 showed that a large subsidence that occurred in Semarang, especially in the port of Tanjung Mas and surrounding 16 cm/year.

Keywords microgravity, time lapse, anomaly, μGal

1. Introduction

Gravity method is one of the oldest methods in geophysics, but its application to the source of the anomaly near the surface and are connected with the environment has not been as intensive as the application for geodynamics studies or exploration in the estimation of the geological structure is relatively large. This is caused by the level of accuracy is still in order mGal anomaly or 103 μGal. In terms of tools gravimeter, 10 μGal accuracy has been achieved in early 1970, but the accuracy of readings is totally dependent on the accuracy of the operator because the gravimeter still use mechanical reading device.

Time lapse Microgravity method is the development of the gravity method with the fourth dimension is time. The principle of the method is the measurement of repeated gravity either daily, weekly, monthly or yearly using a rigorous Gravimeter in order μGal and elevation measurements carefully (Allis and Hunt, 1986). Any changes or differences in the results of the gravity observations in the first period to the next period is called the anomaly microgravity. Observation of gravity changes can be caused by the dynamics around point very, such as changes in the depth of groundwater levels and soil subsidence.

An increase in accuracy gravimeter and the development of digital systems, the application of gravity methods to source anomalies near the surface and are connected with the environment and for the purpose of monitoring is increasingly used, including for

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monitoring geothermal reservoirs, oil and gas (Allis & Hunt, 1986; Andres & Pedersen, 1993; Kamah et al., 2001; Galderen et al., 1999; Eiken et al., 2000; Akasaka & Nakanishi, 2000; Marita, 2000; Nishijima, et al., 2005).

The case study of subsidence in Semarang has been done by previous researchers, such as by Marsudi (1996) have predict subsidence due to a decrease in ground water level using a one-dimensional consolidation. Muhrozi et al., (1996) identify subsidence in Semarang northern research subsidence in many countries is that the more subsidence research conducted by the method Sipat Datar, including in Houston Texas 1973–1987 (Holdahl & Zilkoski, 1991), Flat Sipat method. Wahyudi (1999) Evaluation and Analysis of subsidence in the port of Tanjung Mas Semarang, and Sutanto (2002) with GPS (Global Positioning System) large measure subsidence in Semarang, it appears that the studies that have been conducted using the approach of geology and geodesy.

Research subsidence by using GPS, for example in Western Venezuela (Chrzansowski et al., 1991). Monitoring of subsidence in Salto Caxias Brazil by Santos et al., (2001). In addition, Abidin et al., (2005) using methods Leveling, GPS and techniques INSAR (Interferometric Synthetic Aperture Radar) to monitor subsidence in Jakarta. Based on the research that has been done is given the opportunity to perform subsidence measurements using other methods, one of which is a method of microgravity across time. This method has advantages compared with the method that has been done, for example, enables the measurement of the distribution of the measuring point more and a relatively short time for the measurement period.

2. Materials and methods

Time lapse microgravity anomaly the difference in value between the time of each measurement point Bouguer anomaly at specific time intervals as follows.

\[
\Delta g(x, y, z, \Delta t) = \Delta g(x, y, z, t_2) - \Delta g(x, y, z, t_1)
\]

If the very point elevation changes at two of the measurement period, then Eq. (1) can be written as

\[
\Delta g(x, y, z, \Delta t) = (g_{obs(2)} - g_{obs(1)}) - (g_{obs(2)} - g_{obs(1)}) - (c_1 + c_2 \rho)(h_2 - h_1) + c_3(\Delta h_2 - \Delta h_1) \]

During interval measurements on \( t_1 \) and \( t_2 \) so relatively fixed position point, where \( q_1 = q_2 \), then Eq. (2) can be simplified to

\[
\Delta g(x, y, z, \Delta t) = (g_{obs(2)} - g_{obs(1)}) - (c_1 + c_2 \rho)(h_2 - h_1) + c_3(\Delta h_2 - \Delta h_1)
\]

Kadir (1999) states that for 3-dimensional objects with mass density distribution, time lapse microgravity at the point \( P(x, y, z) \) on the surface is expressed by the following equation.

\[
\Delta g(x, y, z, \Delta t) = \int_{0}^{\infty} \int_{0}^{\infty} \frac{\Delta \rho(\alpha, \beta, \gamma, \Delta t)(z-\gamma)}{(x-\alpha)^2 + (y-\beta)^2 + (z-\gamma)^2} d\alpha d\beta d\gamma
\]

From Eqs. (4) and (5), we obtain

\[
(g_{obs(2)} - g_{obs(1)}) = \left\{ \int_{0}^{\infty} \int_{0}^{\infty} \frac{\Delta \rho(\alpha, \beta, \gamma, \Delta t)(z-\gamma)}{(x-\alpha)^2 + (y-\beta)^2 + (z-\gamma)^2} d\alpha d\beta d\gamma \right\} + (c_1 + c_2 \rho)(h_2 - h_1) - c_3(\Delta h_2 - \Delta h_1)
\]

Based on mathematical modeling and simulation of synthetic data show that the effect of topography does not affect the time lapse microgravity anomalies. Time lapse microgravity anomaly is affected by changes in elevation (subsidence) very point. Consolidation is causing...
subsidence did not cause the soil mass lost so Bouguer correction is not performed. Thus Eq. (6) can be simplified to

\[
(G_{\text{obs}(2)} - G_{\text{obs}(3)}) = \left\{ \left[ G \int \int \int_{0}^{\infty} \int_{-\infty}^{\infty} \frac{\Delta \rho(\alpha, \beta, \gamma, \Delta \alpha)(z - \gamma)}{(x - \alpha)^2 + (y - \beta)^2 + (z - \gamma)^2} \, d\alpha \, d\beta \, d\gamma \right] + c_1 (h_2 - h_1) \right\}.
\]

Eq. (7) shows that the difference between the value of the gravity measurement results caused by changes in the subsurface density associated with groundwater level changes and subsidence.

For survey purposes based on subsidence, the source of the anomaly associated with changes in the depth of the ground water level must be reduced. For the purposes of the reduction can be done in two ways, namely (1) using a specially designed filter adapted to the conditions in the field, and (2) using real data the results of measurements in the field. Especially for (2) in Semarang is not available the data in question. This is due to the measurement of changes in the depth of the ground water level was done continuously for a certain period. To overcome these problems, in this study used a filet MBF (Model Based Filter)


3. Results and discussion

In accordance with the above theory, obtained micro gravity anomaly between the time the initial condition September 2002. Data in the period September 2012 into the data a deduction from the next period to obtain a micro-gravity anomaly over time. Furthermore, this anomaly data corrected by the data reduction in groundwater that occur during periods of measurements to obtain a micro-gravity anomaly between the time due to subsidence. Examples of measurement results period September 2002, November 2005, and October 2013 hereinafter in qualitative analysis with software surfer to get subsidence contour map (see Figure 1).

In general, the value of gravity during the measurement period in Semarang (September 2002, November 2005, and October 2013) indicates that the value of gravity in the northern part is greater than in the south. Results resulting in the northern part of Semarang is lowlands and southern highlands and in accordance with the theory that the value of gravity at a point depends on elevation, where the higher of the surface gravity value decreases and vice versa.

Based on the gravity of each subsequent period calculated micro gravity anomaly between the time that represents the difference between the gravity of the period November 2005 to September 2002 and the period October 2013 to September 2002. Contour micro gravity anomaly between the time as in Figure (2). In the period between the time (September 2002–November 2005) and (September 2002–October 2013) showed three anomalies, namely the positive anomalies that indicate an increase in groundwater levels and subsidence, negative anomalies that indicate a decrease in ground water level, and zero indicates no there is a change.

Time lapse microgravity anomaly value according to the Eq. (7) consists of two sources, namely subsidence and changes in the subsurface density associated with groundwater level changes. To obtain the source of the anomaly due to subsidence, the other anomaly sources
must be reduced by using MBF (*Model Based Filter*) a filter that was built for that purpose. Time lapse microgravity anomaly (see Figure 3(a)). Furthermore, value of this anomaly value is converted to the value of subsidence. Contour subsidence based micro gravity anomaly data across time as in Figure 3(b).

![Figure 1](image1.png)  
**Figure 1.** Gravity contour for each measurement period, (a) September 2002, November 2005, and (c) October 2013.

![Figure 2](image2.png)  
**Figure 2.** Time lapse microgravity anomaly, (a) September 2002–November 2005, (b) September 2002–October 2013.
In that period the subsidence that occurred in North Semarang growing which is 20 to 48 cm in some places, for example: the port of Tanjung Mas, Marina beach area, PRPP, housing Puri Anjasmoro, Lor village Stage and Stage Kidul, Terboyo Kulon, Terboyo Wetan, and housing Tanah Mas. Kaligawe area, Mlatiharjo, Simpang Lima, Miroto, Gabahan, Jagalan, Kauman, Bangunharjo, Karangturi, Pendrikan, Mugas, Pleburan, Lempong Sari, Gayamsari, relative Pedurungan not experienced subsidence compared to the previous period. The new zone of subsidence that appeared in the previous period coverage is more widespread.

Area of subsidence that occurred north Semarang more dominant layer of soil compaction caused by naturally. This is attributed to the fact that the layer of soil in the region is the result of sedimentation and human activity in the form of reclamation.

4. Conclusion and remarks

Time Lapse Microgravity methods can be used for monitoring subsidence. For this purpose, the data processing time lapse micro gravity anomaly must be corrected with the data of decreased water level. For the purposes of correction can be done by using a MBF (Model Based Filter) or by the results of measurements in wells monitored in the study site. For example, a case study in Semarang which indicates that the maximum subsidence during the period 16 cm/year occurred in Tanjung Mas port and its surroundings.

Acknowledgment


References


