QUALITATIVE INTERPRETATION OF THE GRAVITY CHANGED AROUND LUSI, PORONG, SIDOARJO

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ABSTRACT

In collaboration with Lapindo, BMKG measured the micro-gravity around LUSI. The measurements were conducted at 171 points. Each point was measured 4 times with time interval between two consecutive measurement is 24 days, in average. The measurements were using micro-gravimeter Scientrex CG-5, intended to investigate the gravity changed caused by the hot-mud outflows in LUSI. Authors applied the tide and drift correction before calculating the gravity changed. The gravity changed (Δg) is defined as the difference between the previous and the recent gravity measurement for each point. The pattern of negative Δg are in circular shapes, in which the location of the center is not co-located with the source of hot-mud outflow, but displaced to the west and to the north west. The maximum Δg in this area are -0.311 mgal -0.243 mgal and -0.273 mgal for the first (Δg1), second (Δg2) and third (Δg3), respectively. By comparing the occurrence of subsidence on sites and the value of the Δg, the changed of gravity is caused by both the subsidence and the decrease of density. Therefore, it can be predicted that the subsidence around Porong may be expanded to the West and North west of the mud outflow center.

Key words : gravity, LUSI, hot-mud, outflow

ABSTRAK

Bekerjasama dengan LAPINDO, BMKG melakukan pengukuran gavitasi di sekitar LUSI. Pengukuran dilakukan empat kali di 171 titik, dengan interval waktu rata-rata 24 hari antara dua pengukuran berturutan. Pengukuran dilakukan dengan menggunakan micro-gravimeter Scientrex CG-5, dengan tujuan untuk meneliti perubahan gravitasi disekitar LUSI yang disebabkan oleh keluarnya lumpur panas ke atas permukaan bumi. Untuk itu penulis hanya memperhitungkan koreksi pasang surut dan koreksi drift saja, sebelum menghitung besarnya perubahan untuk tiap-tiap titik. Perubahan gravitasi Δg, didefinisikan sebagai selisih antara pengukuran sebelumnya dengan dengan pengukuran saat itu. Dari 4 kali pengukuran dapat dibuat 3 buah peta distribusi Δg. Pola nilai Δg yang negatif berbentuk hampir bulat, dengan pusatnya tidak berimpit dengan pusat semburan lumpur panas, tetapi tergeser kearah Barat dan Barat Laut. Nilai maksimum Δg nya adalah sekitar -0,311 mgal, -0,243 mgal, dan -0,273 mgal untuk peta perubahan gravitasi pertama (Δg1), kedua (Δg2) dan ketiga (Δg3) berturut-turut. Dengan membandingkan subsiden yang ada di lokasi dan nilai Δg, dapat disimpulkan bahwa perubahan nilai gravitasi tersebut disebabkan oleh dua hal yaitu penurunan elevasi (subsiden) dan juga pengurangan densitas batuan. Sehingga dapat diperkirakan subsiden akan terjadi lagi di sebelah Barat dan Barat Laut dari pusat semburan lumpur panas.

Kata Kunci : gravitasi, LUSI, lumpur panas, semburan

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I. INTRODUCTION

LUSI is a unique natural phenomena in which hot mud is flowing out of the surface continuously at Porong, Sidoarjo. The hot mud out flow is potentially cause a disaster due to the possible subsidence that may occur at any time. Therefore many earth-scientists are trying to contribute in solving the problem by doing mitigation studies

In this paper, the authors present a micro-gravity study around LUSI Porong, Sidoarjo. This study is a collaboration effort between Meteorological, Climatological, and Geophysical Agency (BMKG) with LAPINDO Brantas. The purpose of the study is to explore the gravity change associated with the out flow of LUSI, that likely cause a subsidence around Porong, Sidoarjo.

Previous micro-gravity study[1], using 4D method, indicated that the subsurface mass flowed coming from three directions, those are from North, SW, and NE of the center. It seem that the dominant source of the flow is in line with the trend of the Watukosek fault, south west of the out burst center.

This study provide more data and information regarding the gravity change around LUSI, because we have 4 times gravity measurement for each points around LUSI using high accuracy micro-gravimeter CG-5. The maps of Δg are able to provide clear information regarding the subsidence and the density change around LUSI.

II. METHODS

The value if gravity acceleration at any point in the earth's surface can be expressed as (Telford et al, 1992):

$$g = (G\, M_e/R_e^2\,)r \qquad (1)$$

in which g is gravity acceleration, M_e is Earth mass, R_e is Radius of the Earth and G is universal gravity constant. In SI units the value of $G = 6.672 \times 10^{-11}$ Nm^2/kg^2. The direction of the gravity acceleration vector is downward toward the center of Earth. The gravity acceleration was first measured by Galileo in his famous experiment at Pisa. Therefore the unit of gravity acceleration is Gal, to honor his invention (1 Gal = 1 cm/s^2).[2]

The value of the gravity acceleration at the Earth's surface is about 980 cm/s^2. Because of the Earth's shape is not perfectly sphere, the gravitation value at any point will be depend on the following factors : latitude of the point, elevation, topography, and the density variation of the sub-surface below the point.[3] According to Telford et al[2], the gravitation anomaly caused by variation of density is smaller then the anomaly caused by the difference of latitude and elevation, but larger then earth's tide and topography.

2.1. 4D Microgravity method.

The recent method used in gravity studies is 4D microgravity. This method is applied for very small anomaly (in micro unit), detected from two or more different time of measurements. This forth D is characterized by the time-lapse of the repeated measurements. This method has been applied for variety of studies, such as monitoring hydrocarbon reservoir behavior[4),5)], geothermal reservoir[6)], land subsidence and water level change[7),8)]

The basic idea of this method is measuring the change of gravity value between two measurement at the same point in different time. The discrepancy of the gravity value will be evaluated to investigate the cause of the gravity changed. In this study we applied similar principal with a little modification in defining the gravity changed.

2.2. Gravity measurement at the subsidence area.

Suppose we make the first measurement of the gravity at a point in the subsidence area at t_1. According to equation *(1)* the value of the gravity is:

$$g_{(obs)}\,(t_1) = G\, M_e/R_e^2\,(t_1)$$

It can be simplified as :

$$\boldsymbol{g(t_1)} \sim M/r_1^2 \qquad (2)$$

If at any time at t_2 , the point was subsidized but there is no density changed, the gravitation will be :

$$\boldsymbol{g(t_2)} \sim M/r_1^{\,2} \qquad (3)$$

because the point in where we make the mesurement was subsidized, this mean :

$$r_1 \;>\; r_2$$

and g(t_1) at equation (2) will be smaller then g(t_2) at equation (3).

Therefore : $g(t_1) < g(t_2)$

We define the gravity change is

$$\Delta g_{(obs)} = g(t_1) - g(t_2)$$

And the value of:

$$\Delta g_{(obs)} < 0 \quad (\text{ negative}) \tag{4}$$

Therefore it can be said that the negative changed of the observed gravity, indicate that the point of measurement is subsidized.

2.2. Measurement at a point where the density below the point was changed.

Suppose we make the first measurement of the gravity at a point where the density below the point is changed at t_1. According to equation (1) the value of the gravity is :

$$g_{(obs)}(t_1) = G\,M_e(t_1)/R_e^2$$

It can be simplified as :

$$g(t_1) \sim M_e(t_1)/R_e^2 \tag{5}$$

When the density below the point of measurement is changed, if at any time t_2, we make the second measurement, the gravitation will be :

$$g(t2) \sim M_e(t_2)/R_e^2 \tag{6}$$

The changed of density will affect linearly with Me.(t). In the case of LUSI the density below the point of measurement is decrease, therefore :

$$M_e(t_1) \quad > M_e(t_1)$$

and $g(t_1)$ at equation (5) will be larger then $g(t_2)$ at equation (6).

Therefore : $g(t_1) > g(t_2)$

We define the gravity changed caused by the decreasing density will be :

$$\Delta g_{(obs)} = g(t_1) - g(t_2)$$

And the value of :

$$\Delta g_{(obs)} > 0 \quad (\text{ positive}) \tag{7}$$

Therefore it can be said that the positive changed of the observed gravity, indicate that below the density is decreased below the point of measurement.

At LUSI, the hot mud is flowing all the time, over flows around the area. Around the center of outflow, the surface is always subsidized. The fact, that the density around LUSI, is decreased, but at the same time the subsidence was occurred. Therefore, if we measure the gravity at any point around LUSI two times at different time, the discrepancy of those two gravity observation can be positive or negative. It depend on the value of ?g in the equation (4) and equation (7).

III. DATA COLLECTION AND CORRECTION

3.1. Gravity field measurement.

To map the gravity changed around LUSI, we measured the relative gravitation at 171 points using micro-gravimeter Scientrex CG-5. While for the base point we measured using Scientrex CG-3 continuously for calculation of the tide effect at the base station. The accuracy of of CG-5 and CG-3 is 10^{-3} mgal The distribution of the measurement point is shown at figure 1. For each point we measured 4 times with the time interval about 24 days between two consecutive measurement.

Figure 1. Distribution of the points measurement, shown by black dot.

3.2. Gravity Correction.

The measurements were tight to the main base point at Tretes Geophysical Station. For each trip is corrected to the first measurement, so that we can calculate the Δg in the same reference. We also applied drift and earth tide correction, before calculating the Δg. The latitude, elevation and topography correction is not applied, because in this method we just compare two measurements at the same point, but in different time.

IV. RESULT AND DISCUSSION

4.1. Map of Δg

We define that $\Delta \boldsymbol{g}$ is as in the equation (4) and (7). Figure 2, is the $\Delta \boldsymbol{g}$ maps for the gravity difference between the 1st and the 2nd trip of measurement. Similarly, Figure 3, and 4, the 2nd and the 3rd trip, and the 3rd and the 4th trip respectively. While figure 5 is the gravity difference between the 1st and the 4th trip.

As mention previously, that in LUSI area the subsidence and decreasing density can be occurred at the same time. The total observed gravity changed, between two consecutive measurement, is the sum of $\Delta \boldsymbol{g}$ caused by subsidence and the $\Delta \boldsymbol{g}$ caused by density changed. The condition can be summarized as the following:

- The total observed gravity changed is **negative**, if the gravity changed caused by subsidence is larger then that caused by density changed This means the **subsidence process is dominant**.

- The total gravity changed is **positive**, if the gravity changed caused by subsidence is less then that caused by density changed, In this case **the decreasing density is dominant**.

- The total gravity changed is **zero**, if the gravity changed caused by subsidence is equal to that caused by density changed, or there is **no changed of gravity at all**.

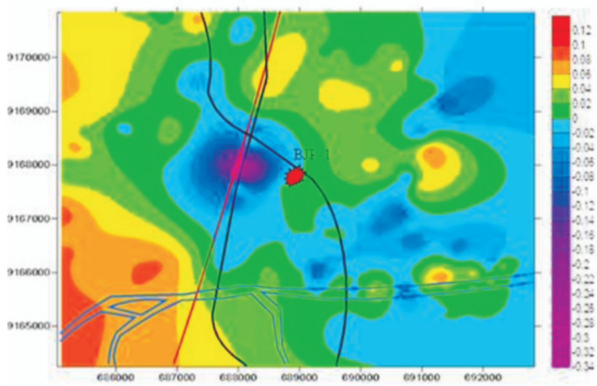

Figure 2. $\Delta g1$= g tripI-trip II, the different between trip I and trip II. The red star indicated the center of mud out flow.

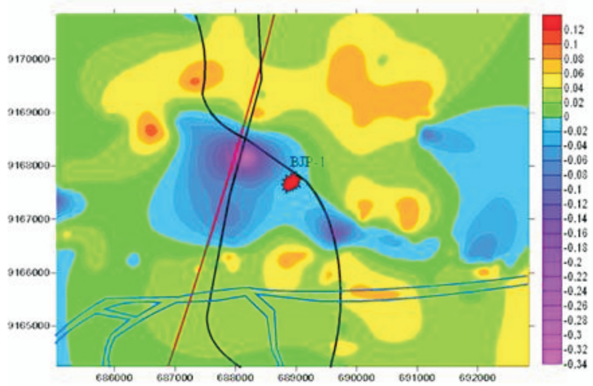

Figure 3. $\Delta g2$= g tripII-trip III, the different between trip II and trip III. The red star indicated the center of mud out flow.

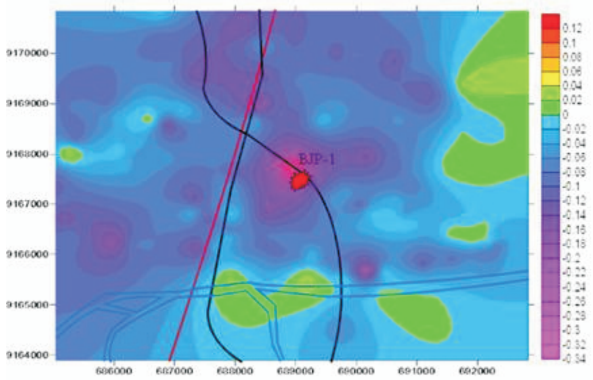

Figure 4. $\Delta g3$= g tripIII-trip IV, the different between trip III and trip IV. The red star indicated the center of mud out flow.

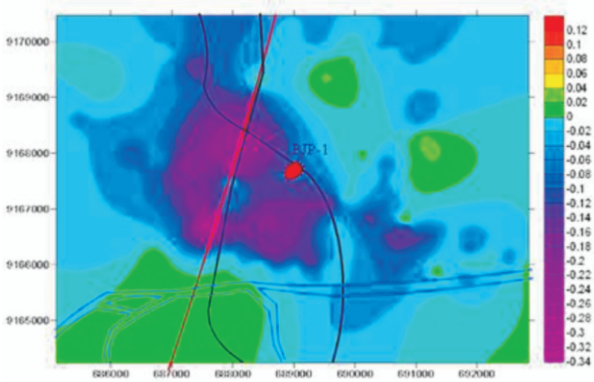

Figure 5. $\Delta g4$= g (trip I-trip IV), the different between trip I and trip IV. The red star indicated the center of mud out flow.

4.2. Subsidence Area

Figure 2 indicate that the negative Δg located just West of the out flow center. This suggests that between the 1st and the 2nd trip the subsidence was mostly occurred in the west of the center. Figure 3 indicates that the subsidence has similar pattern, but the center of subsidence displaced a little bit to the north. While figure 4 indicates that the negative Δg getting larger and spread over to the North, although the negative value is less then the center. In the period of the 3rd and the 4th trip, the center of negative Δg moved and collocated with the center of hot mud out flow. This suggests that during that time period, the subsidence was occurred in almost all area around the out burst center, but not in the South of Porong River.

The total gravity difference (Δg) between the 1st and the 4th trip is shown in figure 5. This figure shows that the negative Δg is almost a circular or round shape. The center is not collocated, rather than located west of the hot-mud outflow center. The subsidence area is much larger than all of each period, covering west and east of railway, north of the Porong River concentrated north. This confirms that the map is indicating the accumulation of all the subsidence in each three period.

4.3. Decreasing Density Area

Figure 2 and figure 3 shows that positive Δg was located in the western part and north part of LUSI respectively. As discussed previously, that the positive gravity changed indicates that the process of decreasing density is dominant. Therefore, this suggests that the source of the mud flows come from the West and the North of the outflow center, but the intensity is changed by time period. The black arrow indicate the possible of direction of the sub surface mudflow. Figure 4 indicates that the subsidence was dominant during that period. It may be said that the source of the hot-mud flow expanded farther to the West and North and not detecting by the measurement in this study.

Similarly the figure 5 shows that between the first and the last gravity measurement, the LUSI area dominated by subsidence, with very clear round shape pattern. The decreasing density was not exist. In fact the outflow of the hot-mud is still continuously happening. It is confirm that the source of the hot-mud flow is expanded to the out of the study area.

Although the total Δg map does not show any decreasing density but the sequence of figure 2, figure 3 and figure 4, suggest that the area with positive Δg finally experienced negative Δg. This suggesting that the density decrease significantly before the area experienced subsidence, Therefore it is suggested the gravity measurement can be used to monitor the dynamics subsurface around LUSI. It makes possible the natural disaster due to the subsidence can be anticipated.

V. CONCLUSSIONS

1. Based on the micro-gravity change maps it can be shown that around LUSI is experiencing subsidence process at least along the time period of field survey.
2. The sequences of Δg map shows the dynamics of the subsurface below LUSI, which suggests that the decreasing density will be followed by the subsidence.
3. The subsidence is getting larger by time, so that can be suggested that monitoring of the subsidence process should be carried out, to anticipate the possible disaster.

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