Comparative Study of Gradient Gravity Method Between Signal Processing and Direct Measurement

Purwaditya Nugraha1*, Wawan Gunawan A. Kadir2, Setianingsih2

1Geophysical Engineering, Institut Teknologi Sumatera
2Faculty of Mining and Petroleum Engineering, Institut Teknologi Bandung, Basic Science Center B 2nd Floor, Jalan Ganesha 10, Bandung 40132, Indonesia.

*corresponding author’s email: purwaditya.nugraha@tg.itera.ac.id

Abstract. The vertical gradient gravity method is one of the developments from the conventional gravity method. The advantage of this method is that it is able to detect the presence of shallow anomalies below the soil surface. In addition, this method is also able to minimize errors resulting from processing and correcting data. This research was conducted by testing the vertical gradient gravity method which is carried out with signal processing or with a vertical gradient gravity filter and the vertical gradient gravity method which is carried out by direct measurement. It was found that the vertical gradient gravity method which was carried out by direct measurements resulted in a clearer pattern in determining the presence of shallow anomaly sources.

Keywords: gravity, vertical gradient, shallow anomaly

1. Introduction
The gravity method is one of the important geophysical methods for solving many problems that involve mapping the subsurface of the earth, besides this method is also the main method in certain geological studies[1], [2]. Currently, several techniques have been developed in the utilization of gravity to determine subsurface density variations with better results, one of these techniques is the vertical gradient gravity technique[3]–[8]. The vertical gradient gravity technique can be used to determine and strengthen the source of gravity anomaly at shallow depths where it is difficult to obtain using the Bouguer gravity method only.

2. Gravity Method
The Bouguer gravity method is a geophysical method that can identify subsurface conditions based on variations in density which is then called the Bouguer anomaly. Bouguer anomaly is defined as the difference between the observed gravity from the measurement results and the theoretical gravity based on the specified earth model. The value of the observed gravity measured at the earth's surface is the total value of the gravity suffered at one measurement point due to various sources. So that to be able to use the gravity data from the measurement results, the data needs to be corrected and reduced to eliminate unwanted values [1], [2]. Mathematically, to get a complete Bouguer anomaly you can use the following equation:
\[ CBA = g_{\text{obs}} - g_N + FAC - BC + TC \]

Where \( CBA, g_{\text{obs}}, g_N, FAC, BC, \) and \( TC \) is Complete Bouguer Anomaly, Observed Gravity, Theoretical Gravity, Free Air Correction, Bouguer Correction, and Terrain Correction respectively.

The vertical gradient gravity method is a development of the Bouguer gravity method where this method can detect local heterogeneity in the distribution of shallow depths\([5], [8]\). One application of the vertical gradient gravity method is to detect the presence of geological formations at shallow depths. In the response to the gravity anomaly of the vertical gradient, an anomaly source in the form of an object with a density contrast at shallow depth is stronger, because this method is very sensitive to anomaly sources with shallow depths. The main factor that influences the measurement of the vertical gradient gravity method is the free air factor because in the measurement process this method requires two measurements at one measurement point location. The first measurement is carried out above the ground or the height of the gravimeter is close to 0 cm, then at the same point the second measurement is carried out by lifting the gravimeter with a tripod at a certain height\([9]\).

The scheme for measuring the gravity of the vertical gradient can be seen in Figure 1.

Where \( h_0 \) is the height of the gravimeter at ground level and \( h_i \) is the height of the gravimeter that is lifted at a certain height of \( i \). Then \( g(h_0) \) and \( g(h_i) \) are the measurement of gravity above the ground and the measurement raised at a certain height, respectively. Mathematically, the calculation of the vertical gradient gravity method can be written as follows:

\[
\frac{\partial g}{\partial z} = \lim_{h \to h_0} \frac{\Delta g}{\Delta h}
\]

\[
g_{zz} = \frac{g(h_0) - g(h_i)}{h_0 - h_i}
\]

So that based on the schematic and mathematical equations it can be concluded that the vertical gradient gravity technique is the difference in the value of gravity at the same point at two different heights where based on the free air correction the value is 0.308 mGal / m \([8], [10]\).

3. Simulation

The vertical gradient gravity method is tested using synthetic data. The test aims to determine the pattern and characteristics of the vertical gradient gravity method. This test is carried out on the vertical gradient gravity method which is carried out by direct measurement and the gravity method which is carried out using the vertical gradient gravity filter.
The test scenario is carried out by making a simple model with several sources of anomaly at a shallow depth, then calculating the gravity of the vertical gradient using a vertical gradient gravity filter and direct calculations. The use of a vertical gradient gravity filter was carried out using Potensoft [11] based on the equation obtained by the potential gravity [12]. anomaly response at different elevations, so that the vertical gradient gravity anomaly can be calculated. The first model is carried out on a model with one anomaly source as shown in Figure 2. The model was made with one source of anomaly with a density contrast of 0.2 g / cc at a depth of 1 meter below the ground surface. Based on this model, the gravity anomaly response is calculated so that it is obtained as shown in Figure 3. The next calculation is carried out by the same process by changing the elevation by one meter so that it is obtained as shown in Figure 4. Based on the gravity anomaly data at an elevation of 0 meters and an elevation of 1 meter, the vertical gradient gravity anomaly is calculated by using the equation to get the gzz, then a direct measurement vertical gradient gravity anomaly map is obtained as shown in Figure 5. The next processing is processing the vertical gradient gravity anomaly using a vertical gradient filter. This process was carried out using Potensoft software[11]. The vertical gradient gravity anomaly is obtained as shown in Figure 6.

4. Result and Discussion
Based on the test results of the vertical gradient gravity method using the direct measurement vertical gradient gravity method and using a vertical gradient gravity filter, it was found that the results of both methods were able to show the presence of anomalous source at shallow depths quite well as in Figure 5 and Figure 6. Only the results based on the
vertical gradient gravity filter, a gross pattern or error around the boundary of the anomaly source is greater than using the direct measurement of the vertical gradient gravity method, so to obtain subsurface anomalies based on the gravity method, we can use the vertical gradient gravity method, but for getting better results is recommended to use the gravity method by taking direct measurements.

5. Conclusion
The vertical gradient gravity method is able to determine the presence of shallow anomalies. The vertical gradient gravity anomaly from the vertical gradient filter results in a larger error value than the vertical gradient gravity anomaly from the direct measurement. The recommended application of the vertical gradient gravity method to get good results can use the vertical gradient gravity method by taking direct measurements.

References
[1] Hinze W J, von Frese R R B and Saad A 2013 Gravity and magnetic exploration: principles, practices and exploration.
[2] Telford W M, Geldart L P and Sheriff R E 2004 Applied Geophysics 2nd Edition_ Telford Geldart Sheriff.pdf.
[3] Ager C A and Liard J O 2002 Vertical gravity gradient surveys: Field results and interpretations in British Columbia, Canada Geophysics 47 no 6 pp 919–925 doi: 10.1190/1.1441358
[4] Butler D K 2002 Microgravimetric and gravity gradient techniques for detection of subsurface cavities Geophysics 49 no 7 pp 1084–1096 doi: 10.1190/1.1441723
[5] Fajklewicz Z, Gliński A and Sliz J 2002 Some applications of the underground tower gravity vertical gradient Geophysics 47 no 12 pp 1688–1692 doi: 10.1190/1.1441318
[6] Hunt T, Sugihara M, Sato T, and Takemura T 2002 Measurement and use of the vertical gravity gradient in correcting repeat microgravity measurements for the effects of ground subsidence in geothermal systems Geothermics 31 no 5 pp 525–543 doi: 10.1016/S0375-6505(02)00010-X
[7] KLINGELÉ E E, MARSON I and KAHLE H-G 1991 Automatic Interpretation of Gravity Gradiometric Data in Two Dimensions: Vertical Gradient Geophys. Prospect. 39 no 3 pp 407–434 doi: 10.1111/j.1365-2478.1991.tb00319.x
[8] Valley T 1976 GRAVITY VERTICAL GRADIENT MEASUREMENTS FOR THE
DETECTION 41 no 5 pp 1016–1030

[9] Wibowo S N E, Mamuaya G E and Djamaluddin R 2018 Land Subsidence Analysis of Reclaimed Land using Time-Lapse Microgravity Anomaly in Manado, Indonesia Forum Geogr. 32 no 1 doi: 10.23917/forgeo.v32i1.5882

[10] Dykowski P 2012 Vertical gravity gradient determination for the needs of contemporary absolute gravity measurements–first results Reports Geod. 92 no 1 pp 23–36 [Online] Available: http://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-50441301-2fc8-4e73-8da2-6853629d193f.

[11] Özgü Arisoy M and Dikmen Ü 2011 Potensoft: MATLAB-based software for potential field data processing, modeling and mapping Comput. Geosci. 37 no 7 pp 935–942 doi: 10.1016/j.cageo.2011.02.008.

[12] R. J. Blakely 1995 Potential Theory in Gravity and Magnetic