Modeling of semarang fault zone using gravity method

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Abstract. A research has been conducted that aims to model the subsurface structure of Semarang Fault, Central Java using gravity method. In this study successfully measured 152 points of measurement of the earth’s gravitational field spread almost evenly in the research area. The measured data were then corrected to obtain a complete Bouguer anomaly value (CBA). CBA data is then performed upward continuation to obtain residual anomaly and local anomaly values. The CBA data local components then can be done gradient analysis using first horizontal gradient. From the results of the method is then correlated with the geological map (overlay) to the location of the Semarang Fault was estimated. CBA local component data then made 3D modeling with inversion method. From the result of first horizontal gradient analysis, it is found that the research area is separated by the weak zone of the east-west. The presence of the northern weak zone is estimated to be lithology contact between the Damar Formation and Alluvium Deposition, while the weak zone in the center of the study area is estimated as Semarang Fault. From 3D modeling which is estimated as the geological structure in the west part of the area and north-south trending direction is Kaligarang Fault with a depth of 2500 m. Semarang Fault is located in the middle of the research area on the east of the relative direction of the south of the north then curved to the west with a depth of 4000 m.

1. Introduction
Semarang is one of the regions in Indonesia which has a very complicated geological structure. This is because the Semarang region is a meeting between the regional structures that developed in Central Java and East Java [1]. One such evolving structure is the fault structure. This developing structure is generally a normal fault, a slip fault, and a reverse fault. For normal faults, the direction is relatively west-east and partially convex to the north. The northerly slip faults of the north-west, south-southeast, and relatively normal faults trending in the east-west direction. These faults are generally in the Kerek Formation, Kalibeng Formation, and the quarterly and tertiary quarter-old resin formation. There are intensive shifts that are often seen between the rocks and the clay, which is evident in the Kalibiuk Formation in Manyaran and Tinjomoyo areas. This fault structure is one of the causes of the area has a "weak" path, so easily porous and ground motion occurs [1,2]

The last tectonic activity in Semarang occurred in Plio-Pleistocene. The faults system mainly develops along the boundary between the Quaternary rocks, the Damar Formation with Kaligetas Formation and Kerek Formation as well as the Middle Miocene [2]. The fault is mainly dominated by reverse fault. For strike-slip fault trending west-southeast develop in the western part of Mijen Sub-district [3]
The gravity method is one of the geophysical methods can be used to describe the subsurface condition based on the density value parameter or the rock mass density under surface in the research area. The gravity method can be used to detect the thickness of a rock layer and can be used to model rock layers both regionally and locally based on their density contrast values [4,5,6].

The existence of the Semarang Fault needs to be modeled so that the physical parameters of the fault can be known, such as the depth of the fault, the width of the fault zone, and the type of fault. It is known that physical parameters are expected to know weak zones that have the potential for disasters such as landslides can be identified. By knowing the potential for disasters that occur, disaster mitigation can be carried out so that they can minimize victims in the event of a disaster, considering that the location of the Semarang Fault is partly used as a place of residence for the community [7].

2. Research method
The data was collected from 2nd to 15th of August 2017 in Semarang area. In this study successfully measured 152 points of gravity field measurements. The gravitational field measurements use the Lacoste Romberg gravity meter G1118 MVR while measuring the location altitude using Differential GPS Trimble 4600 LS. The distribution of the data collection is shown in Figure 1.

![Location of Data Collecting Map](image)

**Figure 1** Location of gravity data collecting in UTM coordinates.

The value of the gravitational field measurements in the field still contains values that are not derived from subsurface conditions. Therefore, before further interpretation is required a reduction process in the form of corrections to the value of the measured gravitational field in the field. Corrections consist of tide correction, drift correction, normal or theoretical gravity field corrections, free air correction, bouguer correction, and terrain correction [4,5,6,8].

Basically bouguer anomaly is the difference between the value of the gravitational field at the measured point of measurement with the theoretical gravity field value in the reference plane.
calculated at a given point. Mathematically the Complete Bouguer Anomaly (CBA) can be calculated using the following formula [4,8]

\[
CBA = (g_0 + FAC - BC + TC) - g_n
\]  

(1)

where \(CBA\) an Bouguer anomaly, \(g_0\) is an observation gravity value (measurement), \(FAC\) is free air correction, \(BC\) is bouguer correction, \(TC\) is terrain correction, \(g_n\) is normal gravity or gravity theoretical value.

In this study used normal gravity values that can be written with equations [4,8]

\[
g_n = 978,0218 \{1 + 0.0053024 (\sin^2 \varphi) - 0.0000058 (\sin^2 \varphi)\}
\]  

(2)

The value of this first horizontal gradient indicates maximum contras density laterally below the surface. This maximum value is associated with a rock lithology boundary or association of a fault structure below the surface. The value of FHG (First Horizontal Gradient) can be calculated by the following equation [8,9]

\[
FHG(x, y) = \sqrt{\left(\frac{\partial \tilde{g}(x, y)}{\partial x}\right)^2 + \left(\frac{\partial \tilde{g}(x, y)}{\partial y}\right)^2}
\]

with \(FHG\) is the first horizontal gradient value, \(\tilde{g}(x, y)\) being the local abl anomaly value, \(\partial x\) is the gradient value toward the x-axis and \(\partial y\) is the value of the gradient toward the y-axis.

3. Geological research area

The geology of the research area is contained in the geological map of Semarang-Magelang sheet shown in Figure 2[2]. The sedimentary rocks groups can be grouped into several rock formations, namely Kerek Formation (Tmk), Kalibeng Formation (Tmpk), Kaligetas Formation (Qpkg), Damar Formation (Qtd) and alluvium deposits (Qa). Rock group results of volcanic activity consist of several units of Kaligesik volcano rock (Qpk), Gadjah Mungkur Volcano rock (Qhg) and Andesite Rock (Tma). [2]
4. Results and discussion
The complete Bouguer anomaly map is shown in Figure 3. This CBA value is in the range of anomalous values of -4.145 to 21,922 mGal shown in the color gradient scale. From Figure 3 we can see a zone with a low CBA value shown in green to blue in the middle of the study area.

For further interpretation, the CBA value needs to be separated which aims to know the distribution of local anomaly and regional anomaly values of the research area. Separation is done by way of upward continuation or commonly called by continuous upwards. In this study, the upward continuation is done with a height of 4000 meters above sea level. Upward continuation results are shown in Figure 4 which shows regional anomalies. Regional anomalies are in the range of values of 6,467 to 12,047 mGal. Where the relatively low anomaly is in the north and high anomalies are in the southern region.

Figure 2 Geological map of the research area [2]
The local anomalies of research areas are the results of total anomaly reduction to the regional anomalies. Map of the local anomaly (residual) is shown in Figure 5. The residual anomaly is in the
range of values from -11,710 to 10,960 mGall. Low anomalous value zones (green to blue) are increasingly apparent, thus further clarifying the existence of a fault system.

![Figure 5 Contour of the residual anomaly of the study area](image)

The distribution of First Horizontal Gradient values is shown in Figure 6. The first horizontal gradient maximum in value indicates rock contact lithology boundary or fault system [8,9]. The first horizontal gradient values in the research area has the distribution of between -0.012 to 0.012 mGall / m.
Figure 6 Map of the first horizontal gradient in the color degradation scale. The black line is thought to be location of the contact rock lithology.

From the geological map (Figure 2), an overlay of the First Horizontal Gradient contour map (Figure 6) is used to compare the position of the structure. The overlay result of the geological map with the first horizontal gradient map is shown in Figure 7. Here it is seen that the straightness of maximum values indicates the lithological contact between the Damar Formation and the Alluvium deposits located in the northern part of the study area. While the indication of a geological structure of the fault located in the southern part of the study area.

Figure 7 A contour of First Horizontal Gradient data which have been done the overlay to Geology map Magelang-Semarang sheet in the research area. Black line (A) indicate the Semarang Fault and black line B indicate the rock lithology contact using gradient analysis.
From Figure 7 it is known that from the geological map of the research area there is a Semarang Fault structure shown by dust white line. While the results of the first horizontal gradient the location of Semarang Fault is shown by the distribution of the first horizontal gradient maximum value indicated by a straight line of black in the southern.

The results of 3D modeling using inversion method is shown in Figure 8. 3D modeling results can show the distribution of rock density contras values toward the lateral direction or towards the depth. The depth that can be estimated in this research is as 4102 meters below the surface.

![3D model sub surface based on gravity data in the research area](image)

**Figure 8** 3D model sub surface based on gravity data in the research area

From the 3D model results, then the cross section to the depth shown in Figure 9 with the result of contour cross section made as much as 4 layers at a depth of 1000 meters, 2000 meters, 3000 meters, and 4000 meters.

![The result of the depth incision of the 3D model](image)

**Figure 9.** The result of the depth incision of the 3D model
From the result of the depth, an cross section is shown the clarity of the weak zone which becomes the maximum anomaly separator. At a depth of 1000 to 2000 meters the weak zone is seen not yet merged well, but in the 3000 meters to 4000 meters of the weak zone already seen together which can then be indicated as a structure of Semarang Fault. Weak zone with density contrast values in the range of -1.08 to - 0.7 g/cm$^3$ located around Quarter's Quarry Formation (QTd) with breccia and volcanic rocks. Zones with high-density contrast, are in the range of -0.01 to 0.79 g/cm$^3$. In the high-density contrast zone to the north lies in the Alluvium Deposition (QA) with the arrangement of sand and clay rocks. As for the high-density contrast zone in the southern part is located in Kaligetas Formation, Kerek Formation, Kalibeng Formation, Andesite and Kaligesik Volcanoes Formation.

Research areas in the south-west pass the Kaligarang Fault. The Kaligarang Fault area is a fault that divides Semarang city which is the north-south direction which is active since the tertiary era until quarter[3]. This is consistent with the modeling results indicating the presence of relatively low-density contrast anomalies (color of blue to green) that lies below the Kaligarang river to a depth of 2500 m below the surface. From 3D modeling results in the east to west, shown in blue to dark blue is a zone of low-density contrast, this is estimated as the Semarang Fault zone. This zone starts from a depth of 1000 m downward getting firm and connected up to a depth of 4000 m. So it can be concluded that the depth of Semarang Fault is more than 4000 m.

Semarang Fault on the surface passes Pengkol River which is located between Kalikayen Village and Jabungan village continue north through Bukit Kencana Jaya, Bulusan Village, Kramas Village, continue north to Jurang Blimbing village and then to Sendang Kenogo village. From Sendang Kenogo turn westward through Trangkil village N, towards the west rather north through Karangrejo village south continent to Ngelosari and Sadeng village. This results in accordance with mapping with magnetic method [7].

The results of this modeling are in accordance with research conducted by Poedjoprajitno et al. which says that in the Semarang region has a fault that trajectory northeast-southwest which is activated again as a reverse fault. Includes the Fault of Pengkol river and the Kreo river Fault, while the west-east trending faults are reactivated as a rising fault [3].

5. Conclusion

From the 3D modeling results can be concluded that in the study area there is two main fault structure that is Kaligarang Fault and Semarang Fault. Kaligarang fault is relatively directional from south to north around Kaligarang. This fault is up to 2500 m depth. Semarang fault is located in the middle of the relatively rounded curved research surface on the eastern side of the south side starting from the Pengkol River in the continuous Kalikayen area towards the north through Bukit Kencana Jaya, Bulusan Village, Kramas, up north to Jurang Blimbing and Sendang Kenogo village. From Sendang Kenogo turn westward through Trangkil Ngesrep Village, towards the north rather north through Karangrejo South village continuous to Ngelosari Sadeng Village. The depth of Semarang fault estimates reaches more than 4000 m below the surface.

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