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Identification of Kaligarang Semarang Fault Based on GGMplus Gravity Data Using First Horizontal Derivative (FHD) and Second Vertical Derivative (SVD) Analysis

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Abstract. Semarang is located in the northern part of Java Island where two tectonic plates meet, making it seismically active and causing the formation of faults. Kaligarang river valley is estimated to be an active fault. The research used FHD and SVD derivative methods, and FFD as a gravity continuation method in the Semarang City area to determine the structure of the Kaligarang fault based on GGMplus satellite data. The derivative analysis was obtained from the residual anomaly. CBA contour map is performed to obtain regional and residual anomaly contour map with moving average method. Furthermore, 2D forward modeling was carried out to describe the layers of geological structures by determining the depth using spectrum analysis. The subsurface structure in the study area consists of 2 types of formations in each of the Line 1, 2 and 3 models, namely the Kaligetas Formation which has an average density of 1.92-2.40 gr/cm^3. Then in the second layer is the Kalibeng Formation with an average density range of 2.00-2.21 gr/cm^3. Meanwhile, the line 4 modeling is dominated by the Kerek Formation with an average density of 2.21-2.55 gr/cm^3. The fault structure boundaries identified based on FHD analysis are located around coordinates 9215536.4 UTM Y on Line 1, 9217402.4 UTM Y on Line 2, 9220103.6 UTM Y on Line 3, and 9221429.6 UTM Y on Line 4. Based on the SVD analysis, the type of faults that can be identified along Kaligarang River is a thrust fault.

Introduction

Semarang City is one of the most populous cites on the island of Java, located at the meeting point of two tectonic plates The Eurasian Plate and the Indo-Australian Plate. This makes Java Island very seismically active, resulting in many faults. A fault zone is a fracture plane in rock that is subject to displacement. Movement on an active fault will cause earthquakes. Active fault displacements are relatively small or large. Faults can be categorized into several types based on the movement of hanging wall and footwall This makes Java Island very seismically active, resulting in many faults. A fault zone is a fracture plane in rock that is subject to displacement. Movement on an active fault will cause earthquakes. Active fault displacements are relatively small or large. Faults can be categorized into several types based on the movement of hanging wall and footwall [1] that is Thrust fault, Reverse Fault and Strike-Slip Fault Structure.

The geological structure of Semarang city according to the geological map of Magelang-Semarang sheet and its surroundings has a stratigraphic sequence from the oldest to the youngest, that is [2]:

a. Alluvium
   This layer consists of deposits derived from alluvium originating from lakes, rivers, and beaches during the Holocene. Coastal lithology deposits consist of old silt, clay, and sand with a thickness of up to 50 meters or more.
b. Gajah Mungkur and Keligesik Volcanic Rocks
   The rock layer consists of lava and rocks from Kaligesing Volcano in the form of gray-black basaltic lava.

c. Damar Formation
   The Damar Formation layer consists of volcanic breccia, tuff sandstone, and conglomerate. The tuff sandstone is fine-coarse grained and brownish yellow in color.
d. Kaligetas Formation
   The Kaligetas Formation layers are lava and breccia with fine to coarse tuff inserts and lava, at the bottom in the form of claystone containing sandstone tuff and molluscs.
e. Kalibeng Formation
   The layers consist of limestone, marl, and and tuff sandstone.
f. Kerek Formation
   The Kerek Formation consists of interbedded claystone, limestone, marl, tuff, sandstone, conglomerate, and volcanic breccia.

The Kaligarang River through the Semarang City area from north to south. The Kaligarang River valley is thought to have been an active fault since the Tertiary to Quaternary periods [3]. The appearance of faults in the Kaligarang river is characterized by the presence of offset river flows and undulating structures along with fault ridges are some of the evidence that tectonic activity is still active in the region. Semarang City is one of the areas that is rarely affected by earthquakes, because it is located far from the epicenter of the earthquake originating from the southern Java subduction. Relatively small earthquakes usually occur because they originate from deep sources. However, this does not mean that Semarang City will be spared from large earthquakes because the source of earthquakes can be caused by active fault movements with shallow epicenters.

Based on these facts, further research was conducted to describe the subsurface geological structure in the area using the gravity method. Gravity method principle works based on the difference gravity field caused by difference in rock density below the earth's surface. The development of technology on the magnitude of the value of gravity on the earth's surface can be measured using satellites. Satellite gravity anomalies are the result of the development of the relative gravity method. The satellite used in this research is GGMplus 2013. GGMplus (Global Gravity Model Plus) 2013 is an earth gravity model generated from GRACE and GOCE satellite data, EGM 2008, and gravity topography effects with resolution not enough more than 200 meter [4].

Research conducted by Indriana [5] on gravity inversion modeling using satellite data inversion has not been able to prove the existence of the Kaligarang fault. Therefore, research was conducted using the First Horizontal Derivative (FHD), Second Vertical Derivative (SVD) and (Fault Fracture Density) FFD methods as advanced gravity methods to determine the structure of the Kaligarang fault along the Kaligarang river. Further analysis is obtained from Complete Bouguer Anomaly (CBA).

Methodology

The method used in this research is the gravity method using the 2013 GGMplus Gravity field satellite data. Research area on rivers Kaligarang Semarang City which is carried out at UTM coordinates namely 425191–438905 M East and 9214581-9228308 M North with wide area research 196 km^2 and the amount of data obtained was 3969 points.

The initial stage in this research will be a literature study on the regional geology of the area, then data collection is carried out by free access to GGMpuls and DEM data. The data obtained is in the form of G_{obs}, then a gravity correction is carried out to obtain CBA. The existing GGMplus gravity anomaly data corrected tides and corrections float, so for stage continued that is correct normal gravity, correction air free, bouguer correction and correction terrain.

Stages second for obtained a CBA with determination estimation average density of rocks in the area of use Nettleton method. The nettleton method is based on bouguer correction and terrain correction if applied density in accordance with density surface, then profile anomaly its gravity will become more fine[6].

Stage third that is regional anomalies and residual anomalies are separated use method moving average using MVA matrix 33X33 for get regional anomalies. Digitization process done and obtained UTM X and UTM Y coordinates, and CBA values. Furthermore, determine depth of every anomaly with an analysis spectrum in one dimensions and use fourier transform with change signal to summation a number of signals[7]. Analysis method spectrum change to in row fourier distance/space domain become number wave or frequency for get k and Ln A values. The k and Ln A values are plotted to form a curve analysis spectrum so that can determine depth of each zone with a gradient graph. Analysis data spectrum obtained from results slicing on the CBA anomaly map[8].

Stage fourth is determining structural boundaries fault and types fault use FHD and SVD analysis. The FHD method has also been used to identify fault [9, 10]**.** Following equality for determine FHD value:

$$\mathrm{FHD} = \frac{g_{i+1.j} - g_{i-1.j}}{2\Delta x} \quad (1)$$

The SVD method is used for known type structure fault [11, 12, 13, 14]. Equality For determine derived SVD value second is as following:

$$\mathrm{SVD} = \frac{g_{i+1} - 2g_i + g_{i-1}}{\Delta x^2} \quad (2)$$

Structure fault on the resulting SVD graph digitization will show results SVD value is zero or approach zero, while the type of fault will be known from maximum and minimum absolute values. Determination type fault as following:

- Normal fault $= \left|\frac{\partial^2(\Delta g)}{\partial z^2}\right|_{min} < \left|\frac{\partial^2(\Delta g)}{\partial z^2}\right|_{max}$
- Reserves fault or thrust fault $= \left|\frac{\partial^2(\Delta g)}{\partial z^2}\right|_{min} > \left|\frac{\partial^2(\Delta g)}{\partial z^2}\right|_{max}$
- Strike-Slip fault $= \left|\frac{\partial^2(\Delta g)}{\partial z^2}\right|_{min} = \left|\frac{\partial^2(\Delta g)}{\partial z^2}\right|_{max}$

Digitization results residual maps and FHD and SVD graphs are used as input for 2D modeling forward modeling. 2D modeling was carried out on 4 profiles CBA incision with trajectory Same digitization on FHD and SVD. Geosoft oasis montaj software used for enter slice data for do forward modeling using GM-SYS tool.

Results and Discussion

Determining process density in the area research in Table 1, then served graph as in Figure 1 below this:

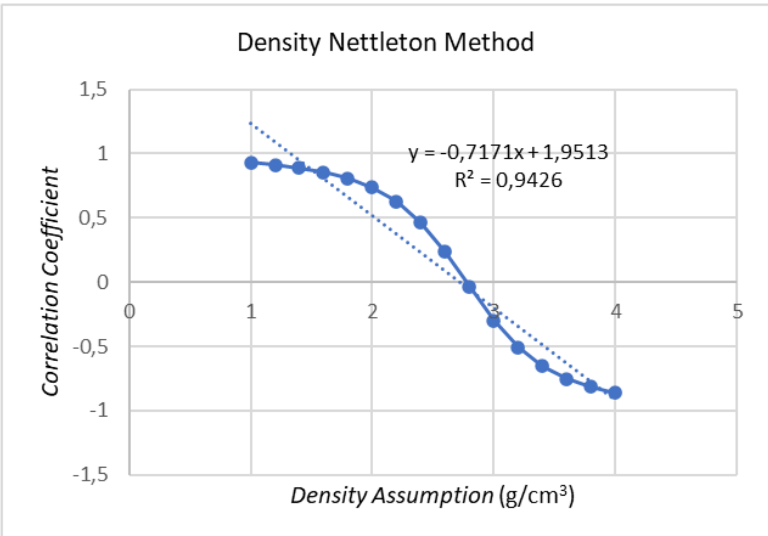

Fig. 1. Density Nettleton method.

Table 1. Coefficient correlation Bouguer anomaly of profile topography.

Density Assumption (g/cm^3)	Correlation Coefficient
1	0.929484
1.2	0.912527
1.4	0.889183
1.6	0.85615
1.8	0.808042
2	0.736122
2.2	0.62698
2.4	0.463687
2.6	0.236309
2.8	-0.0356
3	-0.29878
3.2	-0.50761
3.4	-0.65371
3.6	-0.75093
3.8	-0.81548
4	-0.8592

From Figure 1 it can be seen mark density used as mark average density in the area study of 2.72 g/cm^3, as assumption resulting density mark small correlation can be seen in Table 1. The density values obtained used in the process of processing gravity data for get CBA value.

Gravity data already obtained then done correct normal gravity, correction air free, bouguer correction and correction terrain. Gravity data has been done correct will produce a map CBA contour in Figure 2. CBA contour map in survey gravity is combined to map regional anomalies in Figure 3 and map residual anomaly in Figure 4 located below surface area study with variation level frequency.

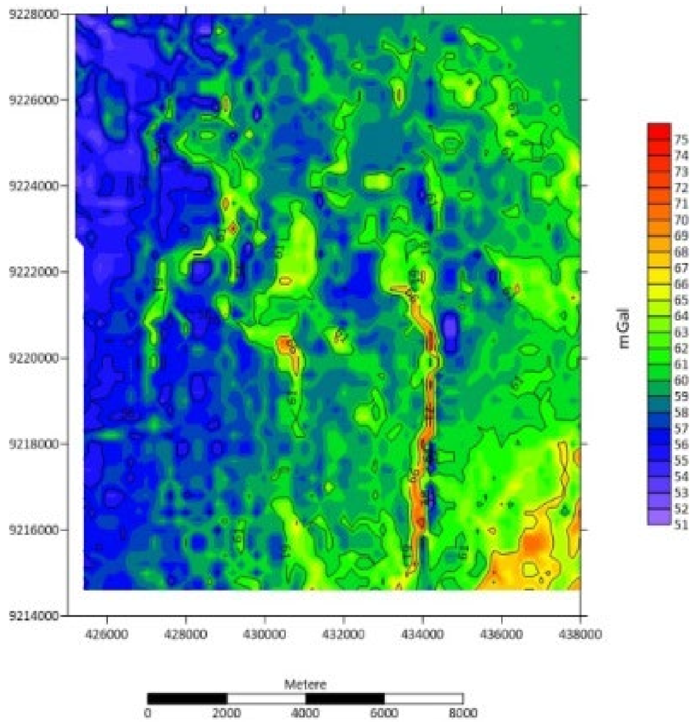

Fig. 2. CBA contour map.

CBA contour map that has been obtained in Figure 2 later made trajectory as many as 6 tracks for represent all areas of the region research, nemely the track A-A' until with F-F' for done calculation analysis spectrum.

Table 2. Depth Use Spectrum Analysis.

Trajectory	Regional Depth (m)	Residual Depth (m)	k cut off	Lamda	Window Width
AA'	1055.900	152.500	0.00145	4323.758	21.619
BB'	1195.600	175.900	0.00077	8201.439	41.007
CC'	1134.000	217.070	0.00067	9342.048	46.710
DD'	631.330	107.540	0.00101	6196.704	30.984
EE'	811.470	212.360	0.00085	7433.490	37.167
FF'	758.200	53.028	0.00132	4765.247	23.826
Average	931.083	153.066	0.00101	6710.448	33.552

In Table 2 it is found the average depth of regional anomalies with depth 931.083 m and depth residual anomaly with depth 153.066 meter. Separation regional anomalies and residual anomalies using a moving average filter use use MVA matrix 33X33 with Surfer software. Separation this aims for know pattern anomalies at each depth. Use of moving average filters for get map contour regional anomalies in Figure 3 and map contour residual anomaly in Figure 4.

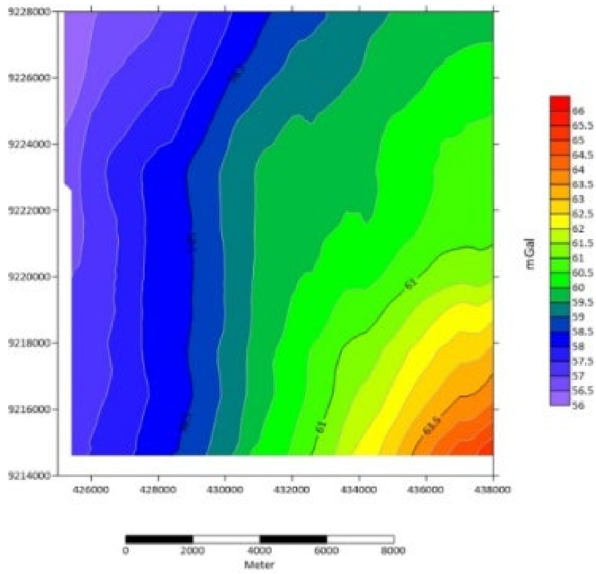

Fig. 3. Regional anomaly map results separation with MVA.

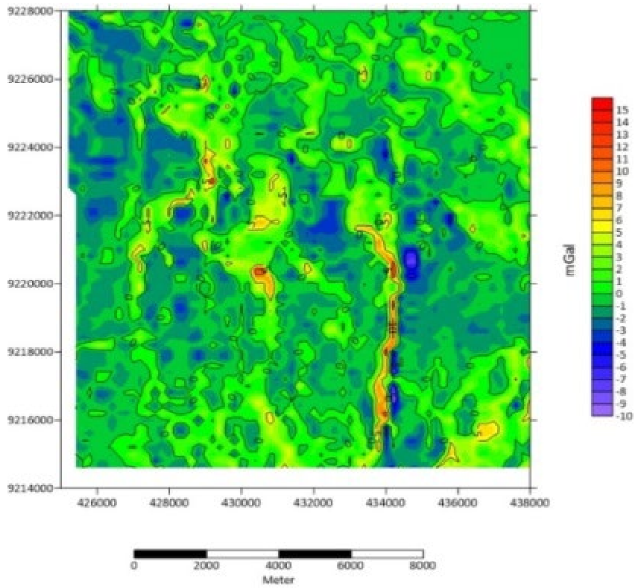

Fig. 4. Residual anomaly map of results separation with MVA.

The next process is carried out after SVD and FHD analysis that is modeling forward modeling 2D using geosoft oasis montaj software using the GM-SYS tool. Trial and error process often used in modeling this. The resulting effect on modeling This with do calculation derived mathematics from condition lower surface, so exists changes in model parameters with level possible correlation accepted based on comparison of residual anomalies. Modeling carried out on the trajectory Lines 1, 2, 3, and 4 on the map contour residual anomaly Figure 4. This direction is digitization, namely west-east, because of the Kaligarang fault location which has the north-south direction of Semarang city.

Analysis determination fault in research this uses FHD analysis and SVD analysis. FHD analysis was used for determinining the boundaries of the structure faults in the research area with digitization of the FHD map is presented in Figure 5. Next A purposeful FHD graphic plot is carried out to determine location fault with the observed mark maximum or highest on FHD graphics. Making FHD graphics based trajectory digitization carried out on the residual grid of the traversed area fault in Figure 4. Trajectory digitizing the map FHD contours have direction transverse to traversed area fault throughout river Kaligarang. In the picture we have done trajectory digitization as many as 4 in the residual map, so obtained UTM X, UTM Y coordinates, value gravity anomaly each residual grid, FHD.

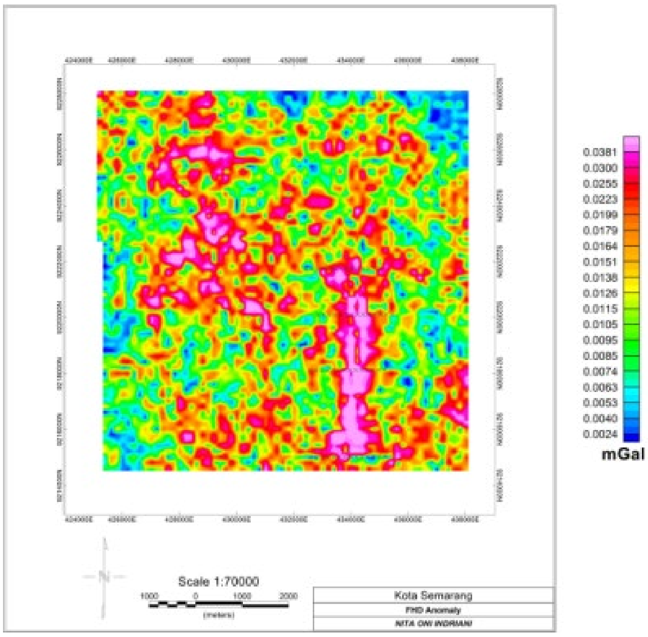

Fig. 5. Contour map FHD anomaly.

Indication exists that structure fault use SVD analysis can be visible in contrast between anomaly high and anomalous low over short distances in the study area. In Figure 6 it is SVD map that performs digitization as many as 4 tracks for known existence fault in the area that. Correlation in research this analysis generated SVD graph from the digitization process. Structure fault on the SVD graph of digitization showing SVD value is zero or approaching zero. Whereas for determine type fault can is known through analysis SVD charts based on mark absolute maximum and value absolute minimum.

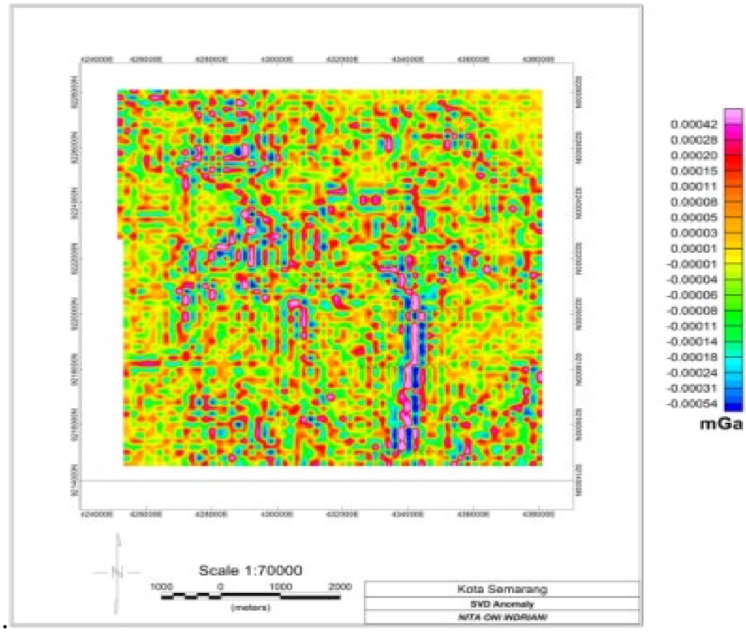

Fig. 6. Contour map SVD anomaly.

Modeling carried out on the trajectory Lines 1, 2, 3, and 4 on the map contour residual anomaly. Position digitization in modeling forward modeling is the same with digitization carried out when analysis faults on the map FHD and SVD contours. Digitization was carried out on the residual anomaly grid in 4 passes so that resulting modeling as many as 4 tracks with direction digitization transverse location fault. This direction digitization namely west-east, because of the Kaligarang fault location which has the north-south direction of Semarang city.

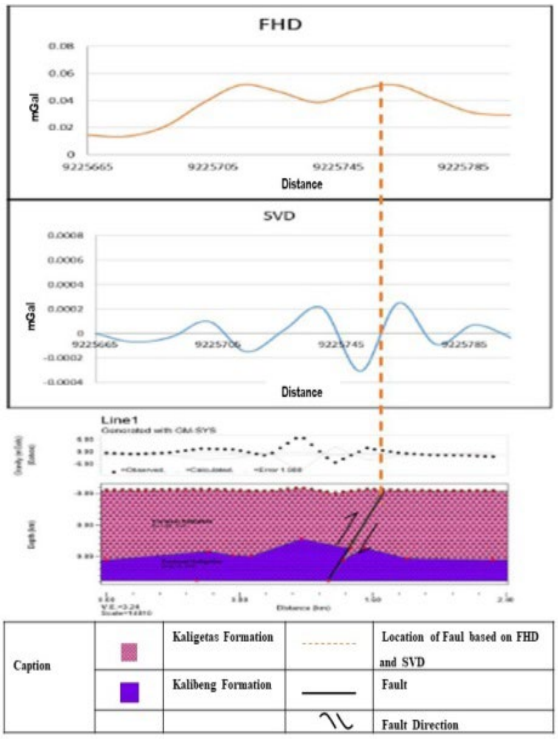

Fig. 7. 2D Forward Modeling on Line 1.

Location of structure boundaries fault on the track digitization Line 1 seen in Figure 7 has a distance 1658.31 meters from the point of digitization. Fault type indicated SVD graph indicated as thrust fault. layer on that is Kaligetas formation. Kaligetas formation arranged from the resulting material results in activity volcanic form lava and lava flows, breccia volcanic and sandstone tuff with range average density of sand tuff 1.92-2.40 gr/cm^3. Second layers is Kalibeng formation consists of gravel, sand, silt and clay with a range the average density is 2.00-2.21 gr/cm^3. Identified faults based on FHD graphics and SVD graphics are available on the track This is located at coordinates between antara 434283.6 UTM X dan 9215536.4 UTM Y. Error obtained on this track is 1.988.

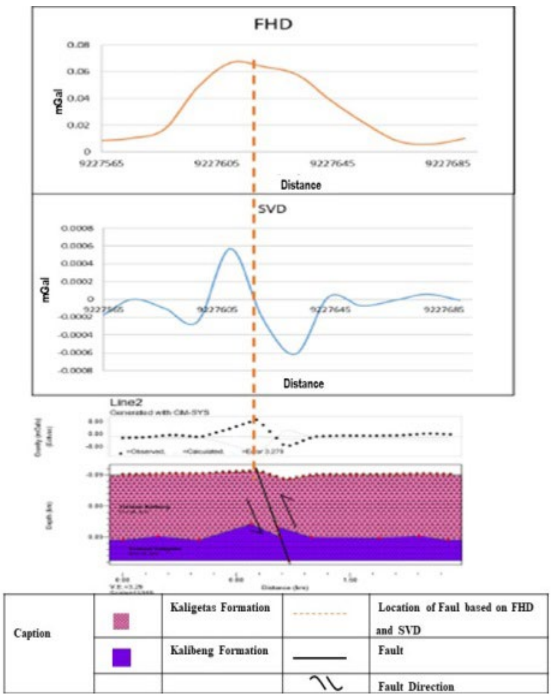

Fig. 8. 2D Forward Modeling on Line 2.

Structure boundaries faults identified on the graph This seen with a marked FHD anomaly on the FHD graph at a distance of 940.44 meters from point did digitization. Thrust faults are identified faults on the track digitized Line 1 is visible in Figure 8. First layers that is Kaligetas formation. Kaligetas formation arranged from the resulting material activity volcanic form lava and lava flows, breccia volcanic and sandstone tuff with range average density of sand tuff 1.92-2.40 gr/cm^3. Lava formation deposits form in the environment. Then on layers second is Kalibeng formation consists of gravel, sand, silt and clay with range the average density is 2.00-2.21 gr/cm^3. Fault location on the track this based on FHD and SVD graphs are at coordinates 433905.6 UTM X dan 9217402.4 UTM Y. Error obtained on this track is 3.279.

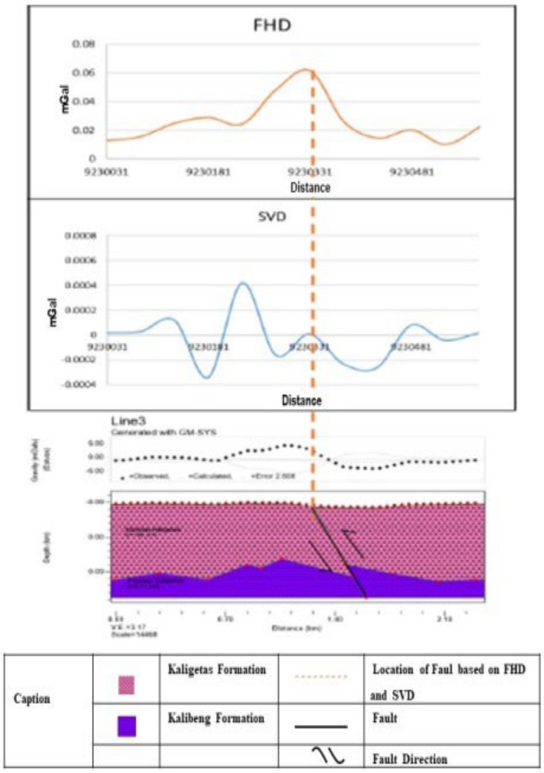

Fig. 9. 2D Forward Modeling on Line 3.

The existence of structural boundaries indicated fault with mark maximum FHD anomaly and zero SVD value or approach zero at a distance of 1266.46 meters from point did digitization. Types of faults identified on the track this is thrust fault. First layrs is Kaligetas formation. Kaligetas formation arranged from the resulting material activity volcanic form lava and lava flows, breccia volcanic and sandstone tuff with range average density of sand tuff 1.92-2.40 gr/cm^3. Formation this is in part lower there are clay stones that contain molluscs. Then on layers second is Formation Kalibeng consists of gravel, sand, silt and clay with range the average density is 2.00-2.21 gr/cm^3. Error obtained on this track is 2.608. Location identified fault on the track Line 3 shown in Figure 9 is at coordinates between 434387.9 UTM X and 9220103.6 UTM Y.

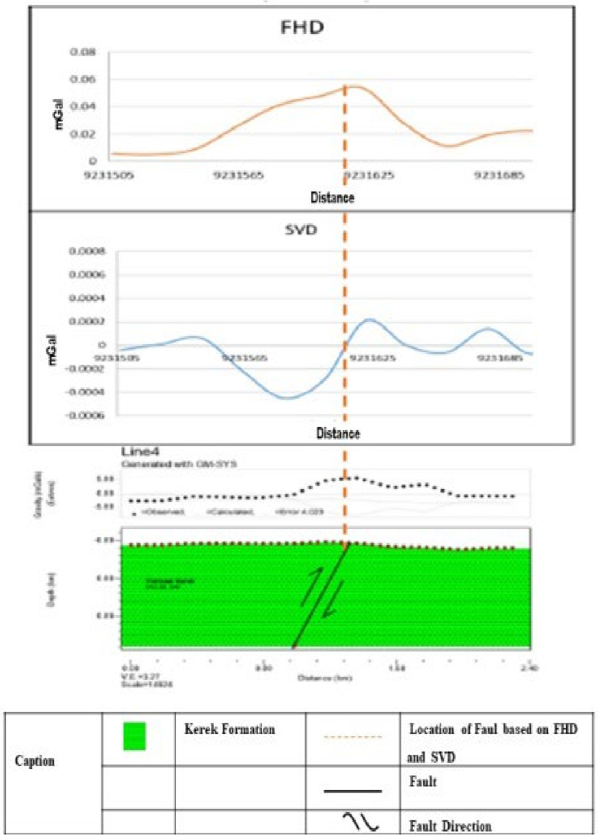

Fig. 10. 2D Forward Modeling on Line 4.

Identified structural boundaries fault trajectory Line 4 in Figure 10 with the maximum FHD value and the SVD value are close to zero or zero at a distance of 1307.21 meters from point digitization. Types of faults identified on the track this is thrust fault. Layer first is the Kerek formation is formation oldest from location research. The Kerek formation consists of mudstone, marl, sandstone tuff, conglomerate, breccia volcanic, and limestone with range the average density is 2.21-2.55 gr/cm^3. Fault location This is at the coordinates between 433676.9 UTM X dan 9221429.6 UTM Y. Error obtained on this track is 4.023, error on the track This is the biggest compared to trajectory others.

Interpretation results obtained showing suitability with study previously carried out by [15] for determine kinematics and dynamics of the Kaligarang fault zone in Semarang and research conducted by [16] which explains studies paleoseismology consequence disaster earthquake earth in the Kaligarang Fault zone in Semarang. Based on research conducted use FHD and SVD methods are proven effective to determine the boundaries of the structure fault and types fault Kaligarang.

Conclusion

FHD and SVD analysis are methods used to determine the types of subsurface structure in the area reseach, which consists of 2 types formation in each modeling. Line 1, 2 and 3 on the top layers is Formation Kaligetas arranged from the resulting material activity volcano like lava and lava flows, breccia volcanic and sandstone tuff with range average density of 1.92-2.40 gr/cm^3. Then on second layers is Formation Kalibeng consists of gravel, sand, silt and clay with a range the average density of 2.00-2.21 gr/cm^3. The modeling Line 4 is dominated by the Kerek Formation with an average density of 2.21-2.55 gr/cm^3. Types of faults that can occur identified throughout river Kaligarang is Thrust fault or Reserves fault.

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