Abstract—Research on Lasem fault modeling has been carried out to analyze the location of the Lasem fault indication. The Lasem fault is indicated in 3 zones, namely the Rembang zone, Randublatung depression zone and Semarang-Rembang depression zone. Lasem fault is a fault located in the Pati-Rembang area which is an active fault and is close to the Semarang area. This research uses the gravity method as a basic understanding. The data uses obtained through the TOPEX/POSEIDON website. The data obtained were 154 measurement points at coordinates 111000' BT (E) - 111013' BT (E) and 6040' LS (S) - 6050' LS (S). The results obtained on TOPEX/POSEIDON are data of latitude and longitude coordinates, elevation and free air anomaly correction values. After that, further correction is made in the form of bouguer correction and terrain correction so that the complete bouguer anomaly value is obtained. The complete bouguer anomaly data is analyzed by spectrum with the results of depth estimation for the anomaly. Then an upward continuation is carried out to separate regional anomalies and residual anomalies. After that the gradient analysis filter, eulerdeconvolution, 3D and 2D modeling are done. Gradient analysis filter in the form of first horizontal gradient with the results in the form of fault indications and second vertical derivatives to determine the type of fault that is strike-slip fault. Euler deconvolution is used to determine the estimated subsurface depth with yields of up to 5000 m below sea level. 3D modeling is carried out to see fault indications which result that faults can be seen from depths of 1200 m to 4000 m. 2D modeling results show the types of rocks in the form of claystone, sandstone, limestone, and andesite, respectively the rocks have a density of 2.21 gr/cm$^3$, 2.35 gr/cm$^3$, 2.55 gr/cm$^3$ and 2.6 gr/cm$^3$.

Keywords—Lasem fault, gravity method, gradient analysis, euler analysis, 3D and 2D modeling.

I. INTRODUCTION

The gravity method is one of the geophysical methods based on the measurement of small variations in a gravity field. The difference in small variations or deviations in the terrain from point to point above the surface of the earth, is caused by lateral variations [1][2]. The gravity method is a method that studies variations in the gravity field that occur by variations in the density of rock masses below the surface, so that the variation investigated is the difference in the gravity field from an observation point to another point [2][3]. The gravity method can be used in analyzing the presence of the lasem fault by looking for the density variable that is below the surface.

Lasem Fault is a fault with the longest straightness, occupying a depression with axes trending southwest-northeast. In previous research which concluded that by doing inversion modeling from gravity data concluded that the Lasem fault lies in 3 zones, namely the Rembang zone, the Randublatung depression zone and the Semarang-Rembang depression zone. Then the inversion modeling results obtained are depression models in the south and north of the study area with a density in the range of values 2.1 – 2.8 gr/cm$^3$ [4].
The research area is at coordinates 111000' BT (E) - 111013' BT (E) and 6040' LS (S) - 6050' LS (S). In the Pati-Rembang area there was an earthquake known as the Lasem earthquake. The earthquake was caused by the Lasem fault which at the time was an active fault. The last earthquake that occurred due to Lasem Fault activity was the Jepara earthquake which occurred on October 23, 2015 with an earthquake magnitude of 5 SR [5].

This research uses gravity satellite data which is anomalous data from gravity that can be obtained through gravimetric such as Topex / Poseion and Jason. Topex or Ocean Topography Experiment is a joint project between the National Aeronautics and Space Agency (NASA) and the French Space Agency, the National Center d'EtudesSpatiales which aims to explore ocean circulation and interactions with the atmosphere [6]. This study aims to determine the presence of the Lasem fault using several analyzes based on the gravity method and modeled into 3D and 2D modeling.

II. RESEARCH METHOD

The data from satellite data were obtained in July 2019, totaling 154 measurement points. In TOPEX, the data obtained are latitude and longitude coordinates, elevation data and free air anomaly correction. Then the latitude and longitude coordinates data are changed to UTM zone 49 S coordinates using the Surfer software. After that the data is processed using Ms. software. Excel to get bouguer correction values and simple bouguer anomalies. Before getting the bouguer correction value first to find the average density value using the Parasnis method. The average density value is then multiplied by the elevation value and the 0.04193 constant. Then a terrain correction is performed which is processed using the Oasis Montaj software by using the GX load menu and selecting gravity.omn. After that, additional data is needed obtained from the Global Mapper software in the form of a regional and local grid of the study area and then obtained the value of terrain correction. After the terrain correction value is obtained, then the complete bouguer anomaly value is sought by adding a simple bouguer anomaly value with terrain correction.

The results of the complete bouguer anomaly are then processed again using spectrum analysis to obtain depth information in the study area. After that, an upward continuation filter is performed to separate regional anomalies from residual anomalies. The residual anomaly is used in the advanced filter by using a first horizontal gradient and second vertical derivative filter which is then obtained by a contour map of fault indications and rock contact limits. Then the eulerdeconvolution is interpreted to get an anomaly depth estimate. After getting the depth estimation, 3-dimensional and 2-dimensional modeling is done using Oasis Montaj software. 3-dimensional modeling using the VOXI load menu and 2-dimensional modeling using the GYM-SYS load menu. 3-dimensional modeling is used for quantitative identification by correlating geological information in the study area and rock density data, while 2-dimensional modeling is used to identify fault indications and determine the layers of rock formation in the study area.

III. RESULTS AND DISCUSSION

The complete bouguer anomaly value can be obtained after the data is processed by making corrections in the form of bouguer correction and terrain correction. The complete bouguer anomaly value is the anomaly distribution value obtained by adding up the value of a simple bouguer anomaly with terrain correction [1][2][3]. After the complete bouguer anomaly value is obtained, a grid process is carried out using Oasis Montaj software to illustrate the complete bouguer anomaly map so that the contour of the complete bouguer anomaly is obtained. The results of the complete bouguer anomaly contours can be seen in Figure 1.
The contour map has an anomaly range of 18.96 to 25.46 mGal. Low anomaly values are in the range of values of 18.96 to 19.74 mGal, which is shown in blue, which is spread in the southwest, northwest and east of the study area marked with letters L1, L2, and L3. Areas with moderate anomalies have values ranging from 19.83 to 21.56 shown in green to yellow. Anomalies are scattered extending from the northwest to near the northeast of the study area and are also spread in the northwest part close to the lower anomalies, marked with the letters M1, and M2. High anomalies are distributed in the northeast, southeast southeast and M1, and M2 anomalies are shown with red to purple colors. High anomaly has a range of values between 21.70 to 25.46 mGal. High anomaly areas are marked with the letters H1, H2, and H3.

The results obtained in the form of a complete bouguer anomaly map are then performed a spectrum analysis to find the estimated depth of gravity anomalies that exist beneath the surface of the study area. Spectrum analysis processing was performed using the Oasis Montaj software by making 3 incisions on the complete bouguer anomaly map. The incision that has been made will produce anomalous value which is then processed in Ms. software Excel. Spectrum analysis processing uses the basis of the fast fourier transform that is by means of fourier transform on one path. The incision results are then made into the A curve against k. The k value represents the value of the wave number while ln A is the logarithmic result of the fourier transform. The curve A with respect to k on each path can be seen in Figure 2.
Figure 2. The result of spectrum analysis

The results of spectrum analysis on the three trajectories in the form of depth estimates are then carried out on average values to get one value of estimated depth in each zone. The inner zone is at a depth of 6035.5, then the medium zone is at a depth of 352.84 meters, and the shallow zone is at a depth of 138.98 meters. These results can then be used as an estimate of the depth of the upward continuation filter by using the depth of the inner zone as a reference.

Upward continuation is a filter used to separate regional anomalies from residual anomalies on a complete Bouguer anomaly map[7]. Upward continuation is done using Oasis Montaj software. Filtering with upward continuation is carried out until there is no significant change in the anomaly contour. On the complete Bouguer anomaly map, an upward continuation of up to 6000 meters is carried out. The results of upward continuation in the form of regional anomaly maps and residual anomaly maps can be seen in Figure 3.

Figure 3. The result of regional and residual anomaly

The distribution of regional anomaly values is in the range of values of 20.31 to 23.63 mGal, while the distribution of anomaly values is in the range of values from -3.22 to 2.30 mGal. The existence of positive and negative values on the distribution of anomaly values is likely due to the density of the rock or changes in the rock body size that affect the distribution of anomaly values.

Then the gradient analysis is done in the form of first horizontal gradient filter and second vertical derivative. The contact or boundary of anomaly are in maximum of first horizontal gradient or in SVD.
value are zero [8]. The results of the first horizontal gradient and second vertical derivatives can be seen in Figure 4.

![Figure 4. The result of FHG and SVD.](image)

The results obtained in the first horizontal gradient filter range from 0.00010 to 0.00171 mGal / m. The location of fault indications based on the first horizontal gradient is at the maximum FHG located in the 49 S UTM zone with coordinates 500665.2 and 9247005.03 meters up to 519334.9 and 9257640.1 meters indicated by dashed cyan lines. The first low horizontal gradient value (minimum) is indicated on the contour in blue. The first high horizontal gradient value (maximum) is shown in contours in red to purple. The maximum value can indicate a rock contact limit or a fault in the area. The results obtained in the second vertical derivative filter are a map with information on the type of fault in the study area. The distribution of values on the results of the second vertical derivative is in the range of values -0.051 to 0.084 mGal / m. The results of fault indications are shown at zero or minimum values on the SVD value indicated by the dashed cyan line.

To find out the type of fault, an incision was made on the SVD contour. The results obtained in incision 1 in the form of a maximum SVD value with a value of 0.03 and a minimum SVD value with a value of -0.03. Then the minimum SVD value is made an absolute price, so that in the incision the maximum SVD value is equal to the absolute SVD minimum price. In incision 2 the maximum SVD value is 0.05 and the minimum SVD value is -0.05. The results obtained are the same as incision 1 i.e the maximum SVD value is the same as the absolute minimum SVD price. Then it can be concluded that the type of fault in the study area is a sliding fault or strike-slip [9].

The eulerdeconvolution method is one way of interpretation in determining the estimated depth of subsurface structures. Euler deconvolution uses the principle of euler homogeneity in determining the depth of anomalies [10]. The processing process of eulerdeconvolution analysis uses Oasis Montaj software with a complete input anomaly bouguer data which is then obtained the value of depth (depth). The results obtained can be seen in Figure 5.
The results obtained in the eulerdeconvolution analysis are depth values in meters in which the acquisition of depth values ranges from 1133.45 meters to 5703.41 meters. Euler deconvolution analysis can be additional information in mapping the existing fault indications in the study area. The results of fault indications in the first horizontal gradient, second vertical derivatives and eulerdeconvolution are then overlaid into the geological map of the study area, which then indicates faults in the study area. The indication results can be seen in figure 6.

Fault indications met at coordinates 510145.8 m and 9251190.06 meters which resulted in a deflection, this is due to the existence of syncline in the area which continues to suppress the state of rock formations. Based on the results obtained, the gradient analysis method has a match in determining fault indications and the euler de-convolution method can be used as a support for determining fault indications and depth estimates. The depth of fault indication based on eulerdeconvolution ranges from 1000 m to 3000 m. These results can be used in 2-dimensional
modeling with estimated depths of up to 4000 meters and 3 layers of rock formations with varying densities.

3-dimensional modeling of the study area was created using Oasis Montaj software. 3-dimensional modeling is used for quantitative identification by correlating geological information in the study area and rock density data. Then in 3-dimensional modeling an incision is made for the z axis or depth. The incision is carried out from 1000 meters to 4000 meters using the Oasis Montaj software. The incision results can be seen in Figure 7.

![Figure 7. 3D modeling with density of rock](image)

The incision is made into 4 sections with depths of 1000 m, 2000 m, 3000 m and 4000 m. Figure 7 (a) shows an incision at a depth of 1000 meters, with an indication of a fault that has not been seen. Figure 7 (b) shows an incision at a depth of 2000 meters, an indication of a fault is seen in the low anomaly area. Figure 7 (c) shows the incision at a depth of 3000 meters, the fault is clearly visible that is at low contrast marked in blue. Then in Figure 7 (d) shows the location of the fault indication at a depth of 4000 meters, where the fault indication is in the zone between low anomaly contrast and high anomaly. The fault indication is marked by a dashed black line while a straight black line indicates a syncline based on a geological map.

2-dimensional modeling is carried out to determine the approximate subsurface structure of the study area in a 2-dimensional model. Modeling is done by making an incision on the complete Bouguer anomaly map. The incision is made in the area where there is a fault. Depth estimation used is the result of 3-dimensional modeling, which is around 4629.282 meters below sea level. The modeling results are divided into 3 incisions which can be seen in Figure 8.
In the incision there are 3 rock formations, the Muria volcanic rock formation, alluvial rock formation and tongue formation and 1 topographic effect. Muria volcanic rock formation is shown with andesite which has a density of 2.6 gr/cm$^3$ and limestone with a density of 2.55 gr/cm$^3$, then alluvial formation is indicated by sandstones with a density of 2.35 gr/cm$^3$ and tongue formation with clay rocks which have a density value of 2.21 gr/cm$^3$. Then in the modeling results where the fault location is located in the UTM 49 S zone with coordinates at AB 505569.4 m and 9249817.1 m, CD incision at coordinates 513806.9 m and 9253395.04 m and EF incision at coordinates 518840.9 m and 9257596.9 m. The depth of the location is an indication of the average fault at a depth of 1200 to 3600 meters.

**IV. CONCLUSION**

Fault analysis in the study area was carried out using gradient analysis, derivative analysis and Euler de-convolution methods. In the gradient analysis with the first horizontal gradient filter, fault indications look very much in accordance with the map of the Indonesian earthquake zone. Fault locations are in the UTM 49 S zone with coordinates 500665.2 and 9247005.03 m up to 519334.9 and 9257640.1 m. The results of the analysis of derivatives with a second vertical derivative filter obtained the type of fault that existed in the study area that is horizontal fault. Then for Euler de-convolution succeeded in determining the depth of the fault indication area which is at a depth of 5700 m below sea level.

Fault indications in the study area were then carried out in 3-dimensional modeling with the result that the fault location was seen from a depth of 1000 m to very visible at a depth of 3000 m and above. The depth obtained in the 3-dimensional modeling is 4629.3 m below sea level. The results obtained are increasingly in the study area, an indication of the location of the fault will be increasingly visible. 2-dimensional modeling is done by making 3 incisions that are perpendicular to the fault indication. In the incision there are 3 rock formations, Muria volcanic rock formations, alluvial rock formations and tongue formations and 1 topographic effect. Muria volcanic rock formation is shown with andesite which has a density of 2.6 gr/cm$^3$ and limestone with a density of 2.55 gr/cm$^3$, then alluvial formation is indicated by sandstones with a density of 2.35 gr/cm$^3$ and tongue formation with clay rocks which have a density value of 2.21 gr/cm$^3$. Then in the modeling results where the fault location is located in the UTM 49 S zone with coordinates at AB 505569.4 m and 9249817.1 m, CD incision at coordinates 513806.9 m and 9253395.04 m and EF incision at coordinates 518840.9 m and 9257596.9 m. The depth of the location is an indication of the average fault at a depth of 1200 to 3600 meters. The density values obtained are based on the results of 3D modeling which are then correlated with the average density values obtained from the Parasnis method.
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