Identification of basement and subsurface structure of Depok City by using ESA-MWT gravity data

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Abstract. Basement is a hard layer which has a high-density contrast compare to the above it layer. In geotechnics, this layer is useful for the basement installation of high-rise buildings and other heavy buildings. Rock density contrast is sensitive physical parameter to be detected using gravity data. The study conducted in Depok City is aimed to identify the presence and the depth of the basement. Gravity data has been collected from 87 stations throughout the city of Depok. The average density value of rocks in the study area is 1.73 g/cc which was obtained by using the Parasnis method. The shallow basement layer is mapped using the Energy Spectrum Analysis - Multi Window Test (ESA-MWT) method. This method works by windowing test points from Complete Bouger Anomaly (CBA) values to get the interface depth for each test point. The fault structure can be identified through a residual anomaly map and by the Multi Scale - Second Vertical Derivative (MS-SVD) method whose results correlate with each other. The basement layer was successfully identified among the 3 other horizon layers and was at a depth of 0 - 68 m below the subsurface. Fault structures were also identified in the study area in the North and South part of the study area, where its fault identified as a normal fault.

Keywords: Subsurface structure, Depok, ESA-MWT

1. Introduction
Depok seems as a developing city adjacent to the capital city of Jakarta. Depok needs more development and additional infrastructure. As an effort in setting up the infrastructure, gravity survey was conducted to find out an information about the condition of the basement. Knowledge of the basement information is something that needs to be considered in determining the construction location because it may affect the resistance of subsurface rocks in supporting buildings.

Gravity method is a method commonly used to investigate and identify the bodies of rock or subsurface structure which has density varied laterally [1]. However, the gravity method is not sufficient enough to determine directly the depth of the basement, so it takes Energy Spectrum Analysis - Multi Window Test (ESA-MWT) method to determine the shape of the basement [2] as well as Multi Scale - Second Vertical Derivative (MS-SVD) method to determine the location and type of fracture [3]. Subsurface modelling was made as an interpretation of gravity data.
2. Methodology

2.1. Acquisition
Geographically, Depok City is situated at latitude of 6° 19' 00"–6° 28' 00" South and longitude of 106° 43' 00"–106° 55' 30" East. Depok City is also directly adjacent to the City of Jakarta or are in the area of Jabotabek. The landscape of Depok City which are from South to North is a lowland area - the hills are weakly undulating, with elevations between 50–140 meters above sea level and slopes of less than 15 %. As the youngest district area in West Java, Depok City has a land area of approximately 200 km². The gravity data acquisitions are deployed as many as 87 measurement points at 11 villages in Depok with stations distribution as shown in figure 1.

Data acquisition was carried out on 6–10 April 2018, at 87 measurement points which were distributed with the average distance between stations at approximately 1.5 km. The method used for data acquisition is the looping method. The Scintrex CG-5 gravimeters did not measure directly the absolute gravity, so gravity corrections are needed to correct the gravity data [4]. The result of Complete Bouguer Anomaly (CBA) has been obtained after implemented gravity corrections such as latitude, free air, Bouguer and terrain correction [5].

2.2. ESA-MWT method
ESA-MWT method was applied to obtain an estimation of the basement’s layers’ shape and depth. By doing the Energy Spectrum Analysis–Moving Window (ESA–MW) method in several "points of interest" along the profile, it can produce a depth interface map [2]. The most important thing in applying the Energy Spectral Analysis–Multi Window (ESA–MW) method is determining the correct window width. The width of the small window that does not produce sufficient data to describe the horizon. Whereas a window that is too large will be filled with sources that are too deep [2]. The Multi Window Test (MWT) was conducted to estimate the depth of the addition of the width of the window on the ‘point of interest’. The addition window width interval to determine depth is constant in order to avoid too significant change in depth between two or more the size of the window. Depth plateau indicates the estimated depth of the interface density.

Figure 1. Design of gravity measurement at Depok City.
2.3. MS-SVD method
MS-SVD method is used to identify the location and type of fracture in the study area. Changes in the contour of gravity anomalies are caused by the presence of subsurface geological structures. The fracture position can be determined when the gravitational value on the MS-SVD curve is zero and the fault type can be determined by the value of gravity 0 on an upward scale in the location where the fault is located.

This method uses a process that is the appointment of field measuring upward as if it is above the plane of measurement to get the value of the gravity anomalies on some scale the heights. So that when the results are upward with the 2nd order derivative process from several heights then plotted and form a curve.

3. Results and discussion

3.1. Complete bouguer anomaly
In making the model of the subsurface, 5 lines (as shown in figure 2) were made that would describe the subsurface structure of Depok City. Residual anomaly data used to make the interpretation of the subsurface, it is based on that residual zone is shallow zone as the target depth in this study was a shallow depth. Each line is modeled using the Oasis Montaj software [6].

Complete Bouger Anomaly (CBA) map is an anomaly obtained after the entire correction process was done. CBA is a representation of rock anomaly in the study area. By applying the Surfer 13 software, a CBA contour map is created for the initial interpretation of rock distribution in the study area.

In the study area, the value of CBA anomaly is varied between 40 mGal and 57 mGal. The variation of CBA value shown on a contour map is due to the variety of rock density below the surface. The variations of subsurface rocks might correlate with either rock density that’s mean lithology variations or variations in rock locations that might be associated with the presence of structures. In determining the conditions of rock in the study area, the density value is divided into 2 regions. In the West area the CBA value is high and in the East direction the CBA value is low. So that we obtained high-density rock region is 2.17 g/cc and low region rock density is 1.20 g/cc. Then obtained an average density values for the study area was 1.73 g/cc by averaging the density values divided by the area of the study area. The density rock may represent the alluvium domination as also geologically verified [7]. So, the high density may occur in the region toward the West value of CBA, and a lower density in the region towards the East.

![Figure 2. Complete Bouguer Anomaly map of Depok City.](image-url)
The CBA anomalies values obtained is a combination of regional and residual anomaly so both must be separated. The separation was done using a frequency-based filter after applying Fourier transforms. The value of regional anomalies in the study area ranged from 43 mGal to 55.5 mGal and the residual anomaly values ranged from -2.8 mGal to 2.8 mGal as shown in figure 3 and figure 4. The residual contour resulting from anomaly separation will be used to correlate the depth of the horizon obtained in the ESA-MWT process.

A high value of gravity anomaly on the residual contour indicates the depth of the horizon is getting shallow or closer to the surface. Whereas the low gravity anomaly value on the residual contour indicates a deeper horizon depth compared to the high gravity value on the residual contour.

Figure 3. Regional anomaly map.

Figure 4. Map of residual gravity anomalies.
3.2. ESA-MWT Curve

Energy Spectrum Analysis - Multi Window Test (ESA-MWT) is a method for mapping the horizon by windowing as many \( n \) windows on a test point. The wider number of windows are made, the deeper depth and more regional body results obtained. This window aims to get the depth interface on a test point. The meaning of depth interface here is where the results of the depth on a test point between one window with another window does not change significantly or contrast in depth.

In this study, the used grid is the CBA, because the target depth to be achieved is shallow or local. The residual grid can also be used to find local depth. Here we use a grid from CBA because basically using a grid CBA or residuals will produce the same result because the Multi Window Test method works by windowing the test points where the wider the window gets deeper. However, the use of grid CBA is better because CBA anomalies are consisting of deep and shallow body anomalies.

The window size is made with a width of 20 meters \( \times \) 20 meters for each window. So that in the widest window which is window 10\(^{th}\) the width is 200 meters \( \times \) 200 meters. The window width determination based on the target to be achieved shallow depth so as to be wider window at intervals of 20 meters.

The windowing results of each window are then expanded with the aim that the resulting waveform is periodic. After expansion, the expansion results are filled by dummy data with the aim to keep a wave periodicity which is produced because the Fourier transform works on periodic waves.

On the line 1 of figure 5, there are 3 depth variations with depths ranging from 15 m to 50 m. Horizon that obtained on each line correlates well with residual contours where high residual anomaly indicates shallow depths. It can be seen in test points 4, 5 and 6, the depth interface obtained at the test point is shallow depth of about 17 m to 40 m below the surface. On the line 5 of figure 6, there are 3 depth variations with depths ranging from 15 m to 50 m. Just like on the other lines, the results of the horizon depth obtained can be confirmed by correlating the depth interface results with the residual contour map.

For each line obtained 3 horizons, this is based on the windowing process of each test point on each line that produces 3 depth interfaces for each test point. So, when combined every test point on 1 line will get 3 horizons. The depth obtained in each line is confirmed by correlating it with the residual map where the high residual anomaly values will produce shallow depths, while the low residual anomaly values will produce a deep interface. It seems an anticline structure in the center City of Depok with Northeast – Southwest orientation. In correlating the results of this horizon, the contour map used is the residual contour map instead of the CBA contour map because the CBA contour map is still incorporated from regional anomalies and residual anomalies. Remembering the target to be sought is a shallow depth so that it would be better to correlate it using the residual contour map. The value of residual anomalies in the study area ranged from -2.8 mGal to 3.2 mGal.

![Figure 5. Depth interface in line 1.](image-url)
3.3. MS-SVD result

Multi Scale - Second Vertical Derivative method is a method to identifying faults. The upward continuation process is done by 4 scales at intervals of 20 m, 30 m, 40 m and 50 m. This process is performed on the line 1 and line 5. Then the result of upward for each scale is done by a second order of vertical derivative filter which is then plotted and produces an image shown in figure 7 and figure 8.

For each MS-SVD result on each upward scale, gravity anomaly value of 0 (zero) indicates the existence of a vacancy occurs due to fracture rock mass causes gravity anomaly value to zero (see the red circle sign). Then, to determine the type of fault can be seen through the maximum and minimum SVD values for each fault. On line 1, there is a fault line that is circled in red with the type of fault is normal because the maximum SVD value is greater than the minimum ones. On line 5, there are two identified faults and marked with red circles. The types of faults identified are normal faults as well. The faults seem to form an anticline structure.
3.4. Subsurface model

Subsurface models were created to make it easier to provide interpretation of the subsurface in the study area. In the surface model line 1 and line 5 there are three horizons of alluvium rocks with the densities of them are 1.21 g/cc, 1.22 g/cc, and 1.23 g/cc. Its depth also varies between 18 m to 50 m below the surface for line 1 and line 5.

The indicated fault is also found in the subsurface model, so that the model can provide an interpretation of the subsurface research area more clearly. The results of this subsurface modeling are controlled by residual data. In figure 9 and figure 10 can be seen subsurface models for line 1 and line 5, respectively.

The fault detected by SVD as the SVD method is sensitive to rock density contrast. In figure 9 for the subsurface model 1 there is a normal fault indicated the maximum SVD curve is greater than the minimum SVD curve which can be seen in figure 7, as well as the subsurface model 5 in figure 10 there are 2 normal faults indicated by the SVD curve the maximum is greater than the minimum SVD curve which can be seen in figure 8. In the model of the subsurface, the arrow indicates there is a body of rock that went down and up.

![Figure 8. MS-SVD at line 5 with 4 difference highs of continuation. Two indicated faults are shown in red circles.](image1)

![Figure 9. 2D forward model of the subsurface line 1 with an estimated normal fault.](image2)
Figure 10. 2D forward model of the subsurface line 5 with two indicated normal faults.

MS-SVD is a method that is sensitive to faults which is indicated by the presence of density contrast laterally. In this study, the MS-SVD method detected several faults in which the geological map did not mention any faults. However, the second fault on line 5 were well confirmed by Depok geology map. The density contrast is detected by MS-SVD has three possibilities, including fractures, intrusion, and a large boulder. Due to the geological map, there is no mention of the fault, then the density contrast is detected by MS-SVD cannot be said to be the fault. Then for the possibility of intrusion in Depok is not possible because in Depok City there are no volcanic activity occurred. The most likely thing is the existence of a large boulder which indicated the result of a volcanic eruption from the South toward the area of Bogor leads to the North, namely Depok to Jakarta. Alluvial is a sedimentary rock with a young age, which causes the erupted rocks from eruption to be buried by the alluvium, causing the density contrast between rocks to be detected by the MS-SVD method. The presence of an estimated boulder is also confirmed by Turkandi et al. as Gunugapi Dago basalt [7].

4. Conclusion
From the results of the study, we obtained some conclusions: the lowest density rock value in Depok is 1.20 gr/cc and the highest density is 2.17 gr/cc, so that the average density of the rock in the study area is around 1.73 g/cc. The rocks most likely alluvium. In the study area, it was identified 3 depth horizons with a depth interval of 0 m to 68 m below the surface. In line 5, predicted two faults were detected by MS-SVD method and both confirmed by the geological map. There are also identified some structures on line 1 and line 5 which may represent a boulder resulting from the eruption of a volcano.

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