Identification the Jakarta Fault using MS-SVD (Multi Scale - Second Vertical Derivatives) Method Gravity Data

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Abstract. Jakarta is a metropolitan city in Indonesia with high population. Geologically, its location has the potential to be affected by earthquakes from subduction zones as well as from local faults such as the Cimandiri, Lembang, and Baribis faults. Earthquake history showed that in 1780 and 1834 Jakarta was affected by an earthquake with magnitude Mw 8, destroying existing infrastructure. Several geoscientists believed the source of the fault is located in the south of Jakarta. Study with primary gravity data using the MS-SVD supported by the MS-HDVD method is a good method for identifying faults. From looking at the zero value shift on the MS-SVD graph, a fault zone is visible in the south of Jakarta. It is also confirmed by the CBA map that has contrast gravity between south and north of Jakarta. The faults have parallel-normal and parallel reverse type in East-West direction with dip angle for more than 79°. According to the fault that has been identified, south of Jakarta is evidently crossed by the fault, so the city safety needs to be considered especially for the potential of upcoming natural disasters. However, 2D forward modeling shows that subsurface Jakarta does not have density contrast between rock layers significantly.

1. Introduction

Jakarta is the capital city of Indonesia. From BPS (Badan Pusat Statistika) data online, Jakarta is densely populated reaches up 10.37 million people. The population always increases every year which also leads to infrastructure growth. For that reason, the city safety needs to be considered, such as the safety of potential natural disasters.

Geologically, Jakarta is not just above the fault zone. The conflux of the subduction plate between the Indo-Australian plate and Eurasian plate occurs in the southern part of Java Island [1]. Therefore, Jakarta has the potential to be shaken by the earthquake, especially the events that are generated by local faults around Jakarta.

History said, on January 22, 1780, the southeast of Sumatra and West Java were affected by an earthquake with an estimated strength up Mw 8.5 or larger [2]. Another history said, on October 10, 1834, the earthquake felt in Jakarta, Banten, Lampung, West of Sumatera, Karawang and also Tegal with an estimated strength up Mw 7.0 or larger [3]. Both of them were estimated to be caused by either Baribis Fault, or crustal or intraslab event [3]. Besides, on January 5, 1699, earthquake happened too, but originated from the intraslab or megathrust plates destroyed some of the existing infrastructures in DKI Jakarta with an estimated strength up Mw 7.5 or larger [3]. Talk about the presence of Baribis fault was estimated crosses south of Jakarta through GPS data analysis [4], the traces was estimated extension part of Kendeng fault in East Java [5]. However, the existence of the fault in Jakarta is still debated, so further scientific analysis is still needed. But the potential for its existence can be a concern and threat for Jakarta.
Modeling from Koulali et al. [4] in Figure 1 shows there are fault segments caused by the earthquakes in 1780 and 1834 with magnitude Mw 7.7. The two different segments are namely strike-slip and normal faults. This means, the fault is estimated to be a normal fault but the main segment is strike-slip. The blue and red-colored number in the red box are for the normal fault segment and the strike-slip segment, respectively. The strike-slip segment has a greater speed than the normal segment.

![Figure 1](image)

**Figure 1.** Koulali et al. (2016) modeling of deformation rate of each segment. The strike-slip fault in Jakarta (red number) has greater speed than the normal ones (blue number) [4].

When an earthquake occurs and its waves reach the surface, the vibration has the potential to damage anything on the surface, such as buildings and infrastructure. Potential hazards can be further investigated by looking at an amplification values in the geology area. Amplification is a magnification of soil waves that occurs due to significant rock density contrast, the ground wave will be enlarged when an event propagates from hard (high density) medium to a softer (low density) medium [6]. If the value of rock density contrast is high, then the level of damage is potentially high. If the density contrast between two layers is low, then the level of damage is potentially low as well. The amplification number can vary on the same rock depending on the level of deformation and weathering of the rock. The example, it can cause the phenomenon of the destructive earthquake with a small magnitude, has happened on Banjarnegara earthquakes of 19 April 2013 and 18 April 2018 [7].

One method that can examine the existence of the fault is gravity data. The gravity method can be used to identify and map geological structures by looking at variations in the value of gravity. This value is due to the difference in density values for each rock. The gravity method of processing MS-SVD (Multi Scale-Second Vertical Derivative) can be used to identify the presence fault in Jakarta and its characteristics such as direction and magnitude of dip as well as its strike.

This study is expected to provide information about the existence of a fault that crosses the south of Jakarta as well as the presence of density contrast. The density contrast may have detected by gravity 2D forward modeling. Therefore, it hopefully can help the society to be more aware of hazard potential and may help the local government in composing a city plan, also can help a practitioner to determine the type of building foundation that must be built (earthquake-resistant building).

2. Methodology

The method of this study is carried out by the MS-SVD method to identify the presence of fault structures in Jakarta. Then 2D forward modeling gravity data is made to illustrate the estimation of subsurface appearance and identify the possibility of a subsurface density contrast layer.

The CBA map gravity data were corrected beforehand, specifically the data is corrected by latitude, free air, Bouguer, and terrain correction. The CBA map is then done upward continuation to several
high levels. On each level of upward continuation is carried out FHD and SVD filters to get FHD maps and depth-n SVD maps. The slicing data was done to get a graph of FHD and SVD-n depth.

The slicing data is north-south direction since the predicted fault probably in the relatively east-west orientation. When all maps of FHD and SVD depth-n have been sliced, then we get some combined graph of MS-HDVD and MS-SVD graph to determine the location and characteristics of the fault. The 2D forward modeling is also carried out after interpreting the values of MS-HDVD and MS-SVD.

3. Result and discussion

3.1. Gravity data

The gravity data as primary data has been acquired in 2018. Then it made as the corrected data. The average density of the study area that was obtained from processing is 2.3 g/cc. This number means that rocks below Jakarta are not too dense if compared to other sedimentary rocks [8]. For this map, we made three lines to extract the data from each area. Then, the data from each line are made into a graph. From the graph, we can interpret the fault.

It can be seen that the CBA map in Figure 2 has a gravity anomaly in the range of 39.0 mGal to 60.0 mGal. Low anomalies are dominating in the south and east area of Jakarta. High anomalies are dominating in the North of Jakarta. There may be a rock or anomalous structure that extends in that area [9] which causes a high gravity anomaly in the North of Jakarta. But, another hypothesis said it associated with subsidence and seawater intrusion [8, 10]. Meanwhile, the reduction in the subsurface mass in the southern part of Jakarta results in a low gravity anomaly.

![Figure 2. CBA map with distribution of gravity station is overlaid with satellite images of the Jakarta area.](image)

3.2. Derivative analysis

The correlation graph between MS-SVD and MS-HDVD on line 1 has correlated. Three estimated zones (in axis-X) have a maximum FHD gravity with an SVD gravity has zero values. The result are first fault has 81.78° dip towards the south is a type of normal fault. The second fault has 59.74° dip towards the North with a normal fault type. The third fault has 67.46° dip towards the south with a type of normal fault.

The correlation graph between MS-SVD and MS-HDVD on line 2 (Figure 3), there will be estimated has two faults. Resulting in a first fault with a value of 81.97° dip towards the south with a type of
normal fault. The second fault has $65.71^\circ$ dip towards the North with a normal fault type. Figure 4 shows the plot between depth and location of fault.

The correlation graph between MS-SVD and MS-HDVD on line 3 is estimated to have four possibilities faults. The result are, the first fault has dip $79.47^\circ$ towards the southern and has estimated reverse fault type. The second fault has $80.81^\circ$ dip towards the North with a normal fault type. The third fault dip $77.91^\circ$ towards the North with a normal fault type. The fourth fault has dip $76.65^\circ$ towards the south with a normal fault type.

![Figure 3. MS-SVD graph correlation with MS-HDVD in line 2.](image)
Figure 4. An estimation of two predicted faults conditions in line 2 (depth \(h\) vs UTM).

Table 1 shows a plot of the number taken from the zero point of the SVD graph on line 2. Then, the characteristics can be further analyzed and get the dip value and direction of the dip. Table 2 shows the characteristics of estimated fault in south of Jakarta.

**Table 1.** The parameter values to characterize fault in line 2.

| Upward continuation depth-n | X       | Fault 1          | Fault 2          |
|-----------------------------|---------|------------------|------------------|
| 0                           | 705240.7| 9304368.1        | 9321518.1        |
| 400                         | 705240.7| 9304478.1        | 9321478.1        |
| 800                         | 705240.7| 9304448.1        | 9321598.1        |
| 1200                        | 705240.7| 9304378.1        | 9321808.1        |
| 1600                        | 705240.7| 9304298.1        | 9322238.1        |
| 2000                        | 705240.7| 9304238.1        | 9321518.1        |
| 2400                        | 705240.7| 9304178.1        | 9321598.1        |
| 2800                        | 705240.7| 9304118.1        | 9321808.1        |
| 3200                        | 705240.7| 9304068.1        | 9321808.1        |
| 3600                        | 705240.7| 9304018.1        | 9321808.1        |
| 4000                        | 705240.7| 9303968.1        | 9321808.1        |

|            | Y       | h     | Y     | h     |
|------------|---------|-------|-------|-------|
| 0          | 705240.7| 9304368.1| 9321518.1| 49.3 |
| 400        | 705240.7| 9304478.1| 9321478.1| 354.1 |
| 800        | 705240.7| 9304448.1| 9321598.1| 635.1 |
| 1200       | 705240.7| 9304378.1| 9321808.1| 892.3 |
| 1600       | 705240.7| 9304298.1| 9322238.1| 1125.8|
| 2000       | 705240.7| 9304238.1| 9321518.1| 49.3 |
| 2400       | 705240.7| 9304178.1| 9321598.1| 635.1 |
| 2800       | 705240.7| 9304118.1| 9321808.1| 892.3 |
| 3200       | 705240.7| 9304068.1| 9321808.1| 1125.8|
| 3600       | 705240.7| 9304018.1| 9321808.1| 49.3 |
| 4000       | 705240.7| 9303968.1| 9321808.1| 635.1 |

| Dip         | 81.97°  | 65.71° |
|-------------|---------|--------|
| Dip direction| South  | North |
| \(\frac{d^2 g}{dz^2}\)| Max > Min | Max > Min |
| Fault type   | Normal  | Normal |
3.3. Fault analysis
There are faults identified on three lines. The faults are estimated to extend relatively to East-West direction in the south of Jakarta. The faults can be seen clearly from CBA, SVD and residual maps of Figure 5 that the gravitational value is seen to be the contrast between the high and low gravity values, where this is in accordance with the principle of the gravity method that if there is a contrast of anomaly gravity then there is probably an anomaly body in the zone.

![Figure 5. Plotting faults on 2D gravity maps; (a) CBA map, (b) SVD map, (c) residual map.](image)

| Upward continuation depth-n | Fault 3 | Fault 4 | Fault 5 |
|----------------------------|---------|---------|---------|
| X | Y | h | Y | h | Y | h |
| 0 | 710726.8 | 9302375 | -152.6 | 9296905 | -130.3 | 9300955 | -174.3 |
| 400 | 710726.8 | 9302455 | -436.8 | 9297825 | -418.6 | 9300845 | -454.5 |
| 800 | 710726.8 | 9302615 | -697.1 | 9297745 | -683.1 | 9300785 | -710.9 |
| 1200 | 710726.8 | 9302735 | -933.7 | 9297685 | -923.8 | 9300755 | -943.7 |
| 1600 | 710726.8 | 9302815 | -1146.5 | 9297655 | -1140.8 | 9300735 | -1152.6 |
| 2000 | 710726.8 | 9302855 | -1335.6 | 9297625 | -1334.1 | 9300695 | -1337.8 |
| 2400 | 710726.8 | 9302865 | -1500.9 | 9297615 | -1503.5 | 9300645 | -1499.2 |
| 2800 | 710726.8 | 9302845 | -1642.5 | 9297595 | -1649.2 | 9300585 | -1636.9 |
| 3200 | 710726.8 | 9302805 | -1760.3 | 9297575 | -1771.2 | 9300505 | -1750.7 |
| 3600 | 710726.8 | 9302745 | -1854.3 | 9297555 | -1869.3 | 9300415 | -1840.9 |
| 4000 | 710726.8 | 9302655 | -1924.5 | 9297535 | -1943.7 | 9300295 | -1907.2 |

| Dip | 80.81° | 79.47° | 81.78° |
| Dip direction | South | South | South |
| \([\partial^2 g / \partial z^2]\) | Max > Min | Max < Min | Max < Min |
| Fault type | Normal | Reverse | Reverse |
The fault was estimated (based model) crossed on south of Jakarta is oblique or normal movement with main segment strike-slip because the dip value is above 70°. The estimated the existence of a fault in Jakarta seems clearly from SVD Map of Jakarta (Figure 6) and residual map for supported data.

![Figure 6](image6.png)

**Figure 6.** Estimated of the presence fault in south of Jakarta

The gravity anomaly of Jakarta can be associated to western Java sedimentary basins map shown in Figure 7 [11]. It is shown that Jakarta is the hill area, while the left and right areas are basins. The geology of this area (hill and basin) can potentially cause faults to form.

![Figure 7](image7.png)

**Figure 7.** Map of West Java sedimentary basins [11]

3.4. **2D forward modeling**

The subsurface modeling in Figure 8, to estimate the section of subsurface on the 2nd line of the slicing CBA map. It can also be a potential determination of whether Jakarta is dangerous or not if there is an active fault below the surface.

The modeling refers to geological data and gravity data of Jakarta. There are several formations from bottom to top, there are Bojongmanik, Subang & Parigi, Serpong & Genteng, quaternary volcanic deposits [12]. This formation potential to be a rock basement of Jakarta because it forms in mid miosen
age and it has a higher density because it consists of limestone (dominant) and also sandstone. The second formation are Subang and Parigi Formations consist of sandstone and silt. The third are Serpong & Genteng formation consists of sandstone, silt, conglomerate, and breccia. And the last is the top layer consists of alluvial, tuff and breccia [12].

The estimated density of each layer are estimated by seeing the kind of rock and other possibility. The estimated density of Bojongmanik Formation is 2.75 gr/cc because this formation had already compacted. The estimated density for the second formation is 2.6 gr/cc and the third formation is 2.5 gr/cc because this formation was estimated got the impact of seawater intrusion [8, 10]. The last layer (upper formation) is estimated for 2.0 gr/cc. We can see, high density contrast seems clearly between the third formation (2.5 gr/cc) and the layer above it (2.0 gr/cc). It also showed by Cipta, A. paper (2018) with HVSR and ANT method by looking at shear wave on its figure 11 [13].

In this line, there are two fault was estimated in south and north of Jakarta, and one additional fault in south of Jakarta. The characteristic of first fault is normal, heading to north and has dip 65.71°, the second fault is normal, heading to south and has dip 81.97°, and the additional fault was inferred from estimated fault on line 1 & 3.

We can see that Jakarta has faults and high density contrast. Even though Jakarta never has epicenter and the seismicity in Jakarta is classified as rare or almost nothing [14], but Jakarta has the potential to be affected by earthquake and has the potential hazard that will affect infrastructure in Jakarta. This 2D forward modeling is also needed to be considered and should to be always updated in the future, to make the data more comprehensive and accurate.

4. Conclusion
Based on the results, there is a suspected main fault in the south of Jakarta with East-West strike orientation. The dip of the fault is around >79° heading south. The faults are a normal fault and a reverse fault. Moreover, from the results of 2D forward modeling, Jakarta was estimated has significant density contrast between the third formation (2.5 gr/cc) and the layer above it (2.0 gr/cc). If the fault and density contrast in Jakarta is exist, this will make Jakarta has hazard potential from the earthquake. So, people have still must wary for their own personal and other protection. Besides, it would be nice if the building also began to be considered and built with earthquake-resistant foundations with further geotechnical study, while the existing building foundations are re-evaluated, to prevent if someday the buildings are affected by an earthquake. Especially, the building foundations in the south of Jakarta area. I realize that this research needs to be explore further using another supporting data to make the result more comprehensive and accurate.
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