The phase tensor analysis of the Nyalindung segment, Cimandiri fault zone, West Java, Indonesia

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Abstract. Dimensionality and regional strike in Nyalindung segment, Cimandiri fault zone, Wes Java, Indonesia is determined using phase tensor analysis from audio frequency magnetotelluric (AMT) data. The AMT data acquisition has been carried out along 26 km profile with 24 AMT observation points. The result presents that the skew angle is $-3^\circ \leq \beta \leq 3^\circ$. The skew angle can be applied to determine the dimensionality of the study area. Besides, the rose diagrams of the phase tensor analysis show that geoelectrical strike of the study area dominated to be northeast-southwest direction with N80° E. It indicates the regional structure of the study area could be assumed as two dimensional and the calculated regional strike agree well with the previous studies.

1. Introduction

Indonesia is a geologically complex region situated at the southeastern edge of the Eurasian continent. It is located within the boundaries of three significant plates: Eurasia, Indian-Australia, and Pacific-Philippine Sea. The boundary between the Eurasian and Indian plates in the western of Indonesia is the Sunda trench [1]. The convergent motion of the Indian-Australian and the Eurasian plate occurs along nearly a N-S direction result. The convergent motion results in oblique direction in Sumatera and almost perpendicular in Java [2]. Four distinct morphological and structural units can be distinguished in West Java: (1) the northern coastal plain of West Java, (2) the folded mountains of Bogor, (3) the Bandung zone mostly covered by recent volcanic product, and (4) the southern mountain of West Java [3]. The boundary between the Bandung zone and the southern mountains has the trend of N70° - 80° E from the Gulf of Pelabuhan Ratu to the Bandung area.

The Cimandiri fault zone elongated about SW-NE, from Pelabuhan Ratu to Padalarang. The length of the Cimandiri fault zone is about 100 km [4]. The previous studies suggested that the fault has been either strike-slip fault or thrust fault [4-6]. It was also revealed that Cimandiri fault is divided into six segments; Loji segment, Cidadap segment, Nyalindung segment, Cibeber segment, Saguling segment,
and Padalarang segment [7]. There are some very conductive spots on the surface, indicating the presence of marine sediments, such as in Loji segment. Its geoelectrical strike was dominated by northeast-southwest direction (N80° E) and the dimensionality analysis show it can be assumed as 2-D [8]. In the Cibeber segment, Cimandiri fault zone is about N70 - N80° E and its dimensionality analysis was possibly 2-D [9].

Magnetotellurics (MT) is a passive exploration technique that utilises a broad spectrum of naturally occurring geomagnetic variations as a power source for electromagnetic induction in the Earth [10]. The MT method is divided into five steps to produce accurate subsurface information. The first step is data acquisition that is useful to know the variation of the electromagnetic field. The second step is MT data processing. The purpose of the MT data processing is to estimate the transfer function between the electric field and the magnetic field in the frequency domain containing information of subsurface resistivity distribution. In the study, we use the AMT for analysis phase tensor. The AMT data have frequency range 0.1 Hz to 10,000 Hz.

The third step is the dimensionality analysis of the data. In this step, we can determine the regional structure as well as the dimension of the research area. The fourth step is data modeling which aims to investigate the subsurface structure of the study area. The fifth step is interpretation of the modeling results. In this research our focus is the dimensionality analysis of the magnetotelluric data. Even though, this step has a very important to determine the dimensions and geoelectrical strike of the study area, it is still rarely done. The existence of some errors in the interpretation of modeling dimensions may result from the inaccuracies of conductivity values subsurface [11]. One method to estimate this information is using phase tensor analysis [12]. Phase tensor analysis in Aluto-Langano geothermal field Ethiopia showed 1-D and 2-D dimensionality at the shallow depth and detected the 3-D effects at deeper depth which was characterized by the high skew angle [13]. The analysis of high skew angle

![Figure 1. Physiographic map of Western Java (after Febriani et al., 2013). (1) quaternary volcanic (2) alluvial plain (3) Bogor zone (4) dome and ridge in Bandung zone (5) Bandung-Cimandiri zone (6) southern mountains (7) trace of the Cimandiri fault.](image-url)
also presented that the 3-D inversion was the best choice to reproduce subsurface structures of the Sabalan geothermal field Iran, even though some the 2-D models can also be built form the observed data, which may show a preview of the geoelectric structures [14].

Therefore to provide the comprehensive understanding of the Cimandiri fault zone, we focus to investigate the geoelectrical strike and the dimensionality of the Cimandiri fault zone.

2. Data Observation and Methods

This research was carried out on March 11-17th, 2016 at the Nyalindung segment, Sukabumi, West Java, Indonesia. In AMT acquisitions, time-series data of electric and magnetic fields were collected by MTU-5A manufactured by Phoenix Geophysics Ltd. The data were transformed to power spectra by Fourier Transform, in a frequency range of 0.35-10400 Hz. Figure 2 shows the 24 AMT observation sites distributed along 26-km profile. The topography map of AMT observation area is dominated by the altitude of 500 – 900 m with the northeast and southeast map have altitude of 1000–1500 m. Lower altitude can be found in west map field, which has the altitude about 500 m. Nyalindung segment is located between Cidadap and Cibeber segment.

In this study, we applied the MT phase tensor to obtain information about the dimensionality of the regional structure and to determine geoelectrical strike of the study area. The MT phase tensor can be written in the form of the singular value decomposition (SVD) of a square matrix, as follows:

$$\varphi = R^{T} \left( \alpha - \beta \right) \begin{bmatrix} \varphi_{\text{max}} & 0 \\ 0 & \varphi_{\text{min}} \end{bmatrix} R \left( \alpha + \beta \right)$$

is the transposed or inverse rotation matrix, while $\alpha$ and $\beta$ can be expressed by

$$\alpha = \frac{1}{2} \arctan \left( \frac{\varphi_{32} + \varphi_{13}}{\varphi_{11} + \varphi_{22}} \right) ; \quad \beta = \frac{1}{2} \arctan \left( \frac{\varphi_{32} - \varphi_{13}}{\varphi_{11} + \varphi_{22}} \right)$$

![Figure 2](image.png)

**Figure 2.** The map of AMT field investigation. (a) Topographical map of study area. Black square shows the studied area (b) 24 AMT sites topographical map.
MT phase tensor skew angle is defined by the ellipse. In general, the distribution of regional conductivity 3-D, which is the skew angle $\beta$ non zero. If phase tensor symmetry $\beta = 0$, distribution regional conductivity 1-D or 2-D. The information about dimensionality and geoelectrical strike are essential for preliminary analysis before MT data modelling. In addition, the angle $\alpha - \beta$ defines the direction of the major axis of the tensor ellipse in the Cartesian coordinate system which can be used to express the tensor. Orientation of major axis of the ellipse may then be constructed from knowledge of the lengths of the major and minor axes. The angle $\alpha - \beta$ defines the direction geoelectrical strike [12].

3. Results and Discussion
First, the AMT raw data transformed to power spectra using Fourier Transform. This step aims to change the data from time domain to frequency domain. The apparent resistivity and impedance phase were calculated from the AMT impedance, which was derived from the power spectra at each frequency at each site. In this analysis, we used the data with coherency more than 0.5. Next, we analyzed phase tensor to investigate resistivity structure dimensionality and to determine the regional strike of the study area.

To determine the regional structure, the MT phase tensor was applied for all the profiles. The dimensionality is indicated by the skew angle of the phase tensor ($\beta$). For idealized condition, dimensionality either 1-D or 2-D when $\beta = 0$ [12]. Figure 3 shows the skew angle $\beta$ plot of the observation points for all frequency ranges. The results show that most of the $\beta$ values are distributed within $-3^0 \leq \beta \leq 3^0$. Our results are consistent with dimensionality analysis at Loji and Cibeber segments [8, 9]. It indicates dimensionality at the study area can be assumed 2-D. Therefore, it is safe to perform 2-D modeling for the MT data with the frequency range of 0.35 – 10,000 Hz.

Geoelectrical strike of the study area was estimated by calculating the major axes of the phase

![Figure 3. Phase tensor skew angle.](image-url)
Figure 4. Rose diagrams for frequency ranges of (a) 0.1–1 Hz. (b) 1–10 Hz. (c) 10–100 Hz. (d) 100–1,000 Hz. (e) 1,000–10000 Hz, and (f) all frequency.

tensor \((\alpha - \beta)\). Figure 4 shows rose diagram of the \((\alpha - \beta)\) value for various frequency ranges. The rose diagram values have bias ±90°. In this study, the geoelectrical strike of the Nyalindung segment is estimated about N80°E.

The result also is consistent with geological data as well as results of the previous studies, that Cimandiri fault and the Loji segment have the geoelectrical strike of the N70° - N80°E [4, 8, 9]. After obtaining the geoelectrical strike value, the power spectra is performed a rotation by angle of N80° E. By applying this step, the measurement mode is adjusted to the structure direction.

4. Conclusions
Information of regional structure dimensionality and geoelectrical strike were obtained by applying phase tensor as the preliminary analysis before modelling of the Nyalindung segment, Cimandiri fault zone. The result shows that the resistivity structure of the Nyalindung segment, Cimandiri fault zone, can be assumed as 2-D and the geoelectrical strikes are dominated by the NE-SW directions for all frequency ranges. Therefore, it is safe to rotate the impedance tensor to the N80° E direction and perform 2-D inversion modeling for the MT data with the frequency range of 0.35 – 10400 Hz.

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