Shallow dipping structure associated to the Cimandiri Fault: evidence from single station teleseismic receiver function analysis

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Abstract. The Cimandiri fault zone is located in the eastern part of the boundary between the oblique subduction of the Indo-Australian plate along Sumatera and the frontal subduction along Java. Even though some geological and geophysical investigations have been conducted and focused on this area, the geometry of the fault zone remains poorly resolved. To provide better constraints on the geometry of the Cimandiri fault zone, we analyze teleseismic receiver functions from single permanent seismic station located in the fault zone. We observe that the computed receiver functions show back azimuthal variation in the amplitude converted waves at the first 2 second of receiver functions providing clear evidence for the presence of complicated shallow structure. We implement forward modelling technique using synthetic seismograms with the same parameters as the observed receiver functions. The modelling reveals at least 2 km thick low velocity zone dipping N-E at 30°, which might be correlated to the Cimandiri fault.

1. Introduction

The seismogram from teleseismic P wave recorded at a seismic station consists of the effects of source, sub-surface structure, path propagation, and instrument response. This waveform thus can be utilized for characterizing the local crustal and mantle structure beneath seismic stations by computing a time series of receiver function. The receiver function is obtained by isolating the response of the Earth structure from the source and propagation effects. The receiver functions are calculated both in radial and transverse components. In receiver function modelling, theoretically, the isotropic laterally homogeneous media may cause zero energy on the transverse receiver function. However, the significant energy on this component may appear due to the presence of lateral heterogeneous structure such as dipping or anisotropy layers (e.g., [1]). On the radial receiver function, these factors may identify as variation in amplitude of Ps conversion waves with the back azimuth of the events (e.g., [2]). Therefore, the objective of this research is to identify the presence of dipping or anisotropic structures using receiver function method beneath a seismic station located in the area where the active fault zone may be exist.
The study area is suggested as the location of the presence of fault zone called as Cimandiri fault. The Cimandiri fault zone is located in the southern part of West Java (figure 1), in the boundary separating the Bandung zone and the southern mountains [3, 4]. This fault zone lies along the Cimandiri River, extending from Pelabuhan Ratu Bay to Padalarang. The tectonic history of Cimandiri fault zone is suggested to be related to the Meratus trends, connecting this fault zone to the Meratus mountains in south east of Kalimantan as result of northward subduction beneath Sundaland in the Cretaceous [5, 6]. Some geological investigations have been conducted to investigate the geometry of the fault with various interpretations. For instance, Dardji et al. in [4] suggests that the Cimandiri fault zone is a sinistral strike-slip fault; Martodjojo in [7] and Haryanto in [8] show that the Cimandiri fault is a normal fault. A recent geophysical study using audio-frequency magnetotelluric and gravity method suggests that the Cimandiri fault zone is thrust fault [9]. In this research, we follow initial receiver function work conducted in the southern part of west Java [10]. The previous study measured the crustal properties beneath this area. The study found complicated pattern on the receiver functions at station SKJI located near the Cimandiri fault zone, which suggest the presence of shallow complex structure. The new study will elaborate further about this shallow complex interface using receiver function analysis and forward modelling technique.

![Figure 1](image1.png)

**Figure 1.** Map showing the tectonic setting of the study area. The map on the right figure shows the distribution of teleseismic events used in this study (white circles). A blue star in the map denotes the study area enlarged on the left figure.

### 2. Data and Method

In this research, we use the same seismic data recorded at SKJI station as in the previous receiver function study [10, figure 1]. All events used for the study have magnitude greater than 6 and epicentre distance between 30° and 90°. The restriction using large event magnitude is applied because this large teleseismic events might provide good signal to noise ratio, whereas this distance range is used to avoid contamination from unexpected phase arrivals from other reflections (such as from core mantel boundary [11]). To compute receiver functions, we follow the procedure as described in the previous study [10]. First, we select 60 s time windows on each seismogram (beginning at 10 s before P arrival and ending 50 S after the P arrival). We then remove the mean, the trend and the effect of instrument response. We rotate the pair horizontal components into radial and transverse components.
The iterative deconvolution technique [12] is then applied to calculate receiver functions by deconvolving the vertical component seismogram from both radial and transverse components. The stable results of receiver functions are obtained by performing a Gaussian filter with a width of 1.5 filtering frequencies above approximately 0.75 Hz. We assess the quality of the computed receiver function using a least square misfit criterion. The misfit is calculated the difference between the observed radial component and the convolution of the observed vertical component with the predicted receiver function. In this analysis we only use receiver functions with a fit of 90% or above. Figure 2 shows the receiver functions computed on radial and transverse components for station SKJI and plotted as function of back azimuth.

![Figure 2](image-url)

**Figure 2.** Receiver functions computed for station SKJI plotted as a function of backazimuth. The black ellipse on the radial component represents the feature related to the presence of dipping interface beneath the station.

3. Result and discussion
As found by previous study [10], the pattern of receiver functions on radial component is very complex in the first 5 second implying that shallow complex structure might be presence beneath the station. In this research, we only focus the ensuing discussion on that shallow complicated structure. Therefore, we search unusual pattern of phase arrival for the first 5 s of receiver function in both component such as amplitude reversal or amplitude dependency as function of backazimuth [2] due to dipping or anisotropic shallow structure. The positive pulses on figure 2 denoted by red colour represent an increase in velocity with depth. The negative pulses marked by blue colour represent a velocity decrease. Receiver functions on radial component show a possible polarity flip at 2-3 s between backazimuth of 20° and 120° (a change from positive to negative with increasing backazimuth). We also observe non-zero energy on the transverse component at zero time, which may indicate the presence of dipping structure [1].
Table 1. Model parameters used to obtain the best model of receiver functions shown in figure 3.

| Depth (m) | P (g/cm$^3$) | Vp (m/s) | Vs (m/s) | % Anisotropy | Trend anisotropy (°) | Plunge anisotropy (°) | Strike (°) | Dip (°) |
|-----------|--------------|----------|----------|--------------|-----------------------|------------------------|------------|--------|
| 400       | 1730         | 1800     | 1000     | -            | -                     | -                      | -          | -      |
| 3000      | 1730         | 1800     | 1000     | 10           | 270                   | 0                      | 90         | 30     |
| 30000     | 3200         | 6300     | 3500     | -            | -                     | -                      | -          | -      |
| 10000     | 3200         | 6800     | 3800     | 3            | 0                     | 0                      | 0          | 0      |
| 3300      | 8200         | 4700     | -        | -            | -                     | 120                    | 30         |        |

Figure 3. Comparison between receiver functions computed using actual data and syntetic data generated by the RAYSUM code and the model parameter shown in table 1. Here, we search the similarity of the features at the first 5 s (unshaded area). The green ellipse on the radial component shows the feature that fits quite well for both models.
To obtain better constraint on this possible dipping structure beneath the station, we perform forward modelling of receiver functions using RAYSUM package [13]. This code generates theoretical receiver function in the presence of dipping or anisotropic interfaces. In this forward model, we first define parameter for the input model such as the number of layers, the layer thickness, density, Vp, Vs, percent anisotropy, trend and plunge anisotropic fast axis, interface strike and dip. We make a number of trials in this forward model involving a range of structure geometries and a range of model parameters to identify model that fit the observed data. As we only focus on the first 5 second of the receiver functions, we try to match the polarity flip on the radial component receiver functions at 2-3 s. We obtain satisfactory model by adding anisotropic dipping layers structure in the near surface (table 1 and figure 3).

The best fitting model related to the shallow structure beneath SKJI station is shown by a cartoon sketch in figure 4. The model shows the presence of dipping structure with low velocity at shallow depth around 2-3 km with strike and dip around 90° and 30°, respectively. We suggest that this dipping shallow structure might be associated with the Cimandiri fault zone as inferred by other geological and geophysical studies. Dardji et al. in [4] suggest that the Cimandiri fault zone has the geological strike around N70-80E interpreted as a sinistral strike-slip fault zone. A recent geoelectromagnetic study also found the evidence for a dipping structure related to the Cimandiri fault zone around the station [9]. The study observed that the shallow structure of the Cimandiri fault zone is characterized by shallow conductive and low density zone at depth of 1-3 km, which is consistent with shallow low velocity zone obtained by this receiver function study.

**Figure 4.** Illustration of the Earth structure beneath station SKJI used to generate the best model receiver functions.

### 4. Conclusions

We investigate the presence of dipping anisotropic structure related to the Cimandiri fault using teleseismic P wave receiver functions recorded at single permanent seismic station. We find significant backazimuthal variation in the amplitude converted waves at the first 2-3 second of receiver functions suggesting that the complicated shallow structure may be present beneath the station. We perform forward modelling of receiver functions to confirm the likely presence of this structure. The model suggests the presence of at least 2 km thick low velocity structure dipping N-E at 30° which may be related to the Cimandiri fault.
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