Crustal Structure Beneath KLNI Station in Lombok Island Based on Teleseismic Receiver Function

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Abstract. Lombok Island is part of the Sunda-Banda arc system which is one of the most active tectonic regions in the world. In Lombok area there are two subduction zones namely Java trench in the south and Flores back arc thrust in the north. Information on crustal structure is needed to explain the tectonic development and geodynamic interaction of the area. The receiver function is one of the techniques used in the study to identify subsurface and wave velocity structures based on earthquake data regardless of the source mechanism. We analyzed receiver function of teleseismic events (epicenter distance 30-90°) and magnitude more than 6 (M>6) to estimate crustal thickness, Vp/Vs ratio and wave velocity structure beneath KLNI station using H-κ stacking and inversion method. We obtained that the crustal thickness and Vp/Vs ratio beneath KLNI station is about 21.38 km and 2.05. The high Vp/Vs ratio might be an indication of partial melting related to the upwelling of hot asthenosphere material through the subduction slab of Java Trench. The depth of the low velocity zone beneath KLNI station is at 10-18 km which is estimated due to the presence of geothermal

1. Introduction
Lombok Island is part of the Sunda-Banda arc system which stretches 6000 km north of Sumatra Island on the north side of the Banda Sea and is one of the most active tectonic areas [1]. In the Sunda-Banda Arc transition zone there are two arc systems namely the inner volcanic arc located in the north and the outer non-volcanic arc in the south [2]. Lombok island is included in the volcanic island arc system which is marked by the presence of an active volcano, Mt. Rinjani.

The tectonic area of Lombok marks the convergence zone of three main plates namely the Indo-Australian Plate, the Eurasian Plate and the Pacific Plate [3], that causes the subduction zone, Java Trench in the south and Flores back arc thrust in the north. The two tectonic structures can be seen in the Fig. 1. During July to August 2018, Lombok Island was rocked by 5 strong earthquakes with magnitude Mw = 6.4; Mw = 7.0; Mw = 5.8; Mw = 6.2; and Mw = 6.9 [4]. Therefore, research on the crustal structure in the Lombok region is needed. It’s crucial in order to understanding geodynamics interaction and tectonic development.

Receiver function is one of the techniques used in the study of identification of crustal structure and velocity structures based on earthquake data regardless of the source mechanism, because these factors have been eliminated in the deconvolution process. With the receiver function method, we can estimate
crustal thickness, $V_p/V_s$ ratio and the structure of the local wave velocity ($V_p$ and $V_s$). Studies with similar techniques have been carried out by previous researchers [5-10].

![Figure 1. Subduction zone in the Lombok region](image)

2. Data and Method
We utilized waveforms from teleseismic events recorded by KLNI broadband Geophone-BMKG station located in Lombok ($8.42^\circ$ S and $116.09^\circ$ E). The criteria for selected events are earthquakes with epicenter $30^\circ$-$90^\circ$ ($1^\circ = \approx 111$ km) and magnitude greater than 6 ($M>6$). Distribution of teleseismic events and station location used in this study are depicted in Fig. 2 and Fig. 3. Earthquakes catalogue obtained from ISC (International Seismological Centre).

![Figure 2. Distribution of teleseismic events used in this study. The blue solid box represents the study area.](image)

![Figure 3. Location of KLNI station (blue triangle) and Mt. Rinjani (red triangle)](image)

The seismograms were pre-processing before computing receiver function. We inspect manually to select the best quality of seismograms. The selected seismograms are baseline-corrected and removing
the instrument response. Furthermore, rotating the original component system on the seismogram (ZNE = vertical, north-south, and east west) to the ZRT component (vertical, radial, and tangential) following this equation:

\[
\begin{bmatrix}
Z \\
R \\
T \\
\end{bmatrix}
= \begin{bmatrix}
0 & 0 & 1 \\
-cos \gamma & -sin \gamma & 0 \\
sin \gamma & -cos \gamma & 0 \\
\end{bmatrix}
\begin{bmatrix}
N \\
E \\
Z \\
\end{bmatrix}
\] (1)

Where \( Z \) is the vertical component, \( R \) is the radial component, \( T \) is the tangential component, \( N \) is the north-south component, \( E \) is the east-west component, and \( \gamma \) is back azimuth. Finally, we selected the time windows started 10 s before and 40 s after the P-wave arrival.

We only calculate the receiver function of the radial component using time domain deconvolution developed by Ligorria and Ammon [11]. The basis of iterative time domain deconvolution approach is the least-square minimization of the difference between observational seismogram and synthetic seismogram. The signal on the radial component \( R(t) \) is obtained from the convolution result (*) iteratively between the wavelet model \( E(t) \) and the vertical component \( Z(t) \) seismogram according to the equation:

\[
R(t) = E_{R_{i}}(t) * Z(t)
\] (2)

\( E(t) \) will be equivalent with \( E_{R_{i}}(t) \) if the misfit between \( R(t) \) and convolution between \( E_{R_{i}}(t) \) with \( Z(t) \) is minimum (fit more than 90%). We applied Gaussian filter to control the frequency content of the receiver functions with bandwidth 1.5. This filter can control high frequency noise. Illustration of a simple receiver function depicted in Fig. 4.

\[\text{Figure 4. Receiver function diagram [12]}\]

We applied stacking H-\( \kappa \) method to estimate crustal thickness (H) and \( Vp/Vs \) ratio (\( \kappa \)) [13]. This technique calculates the difference in the propagation time of \( Ps, Pp Ps, \) and \( PpSs+PsPs \) waves against direct P waves, which can be formulated as:

\[
s (H, \kappa) = \sum_{j=1}^{N} W_{i} \eta_{i} (t_{1} [H, \kappa]) + w_{2} \eta_{2} (t_{2} [H, \kappa]) - w_{3} \eta_{3} (t_{3} [H, \kappa])
\] (3)

Where \( s (H, \kappa) \) is the stacked amplitude arrival, \( \eta_{j} \) is the receiver function, \( \sum W_{i} \) is weight value, with the provision of \( \sum W = 1 \), in this study we applied weight 0.7, 0.2 and 0.1, \( t_{j} \), \( t_{2} \), and \( t_{3} \) are the predicted time of the corresponding arrival (\( Ps \) phase, multiple phases \( PpSs \) and \( PsPs+PpSs \), respectively). The values \( s (H, \kappa) \) of will be high when all three phases of the wave have maximum coherence when stacked which means they reflect the actual H and \( \kappa \) values. We inverted the stacked receiver function using the Computer Programs in Seismology (CPS) package developed by Herrmann.
[14] to estimate the local wave velocity profiles ($V_p$ and $V_s$) beneath the KLNI station. The initial velocity model for the inversion was derived from the velocity model ak135 [15].

3. Results and Discussion

We get 42 receiver functions with fit $> 90\%$. The 42 receiver functions are plotted as the back azimuth is shown in the Fig. 5. The P-S converted waves which is associated with Moho are visible at $\sim$3.5s. In the middle of quadrant 1 and 2, P-S Moho conversion arrival is separated from the direct P arrival by large negative amplitude (depicted in the yellow oval). Negative amplitude indicates low velocity zone [9]

Zubaidah et al. [16] have conducted research on Lombok Island using magnetic data. The results of their study showed a similar pattern in the area identified as the low velocity zone to the Sembalun area which is identified geothermal presence. So, we suggest that the low velocity zone in the middle of quadrants 1 and 2 is due to presence of geothermal.

![Figure 5. Receiver functions are plotted based on back azimuth (left panel) and stacked receiver function (right panel)](image)

Fig. 6 shows the crustal thickness and $V_p/V_s$ ratio for station KLNI obtained using stacking H-$\kappa$ method. The estimated crustal thickness and $V_p/V_s$ ratio beneath the station based on this method are 21.38 km and 2.05. The $V_p/V_s$ ratio value is relatively high ($> 1.84$) [8]. We estimate due to presence of partial melting beneath Mt. Rinjani. The estimation of the partial melting beneath Lombok Island is supported by tomography studies conducted by Nugraha [17]. The results of tomography method show the existence of partial melting which rise from the subduction zone of Java Trench. The presence of partial melting will cause a significant decrease in the S wave compared to the P wave, thus causing a high $V_p/V_s$ ratio value. The geological feature of Lombok Island is characterized by a volcano island arc formed late Oligocene to Quaternary age [3].
Figure 6. H-κ grid search result for KLNI station

$P$ and $S$ wave velocity structure depicted in Fig. 7 and Fig 8. The crustal structure beneath this station is characterized by $P$ and $S$ wave velocities. At depth of 0-10 km the velocity range of $P$ wave is $\sim$ 3.5-7.7 km/s and the velocity range of $S$ wave is $\sim$1.95-4.2 km/s. The low velocity zones are identified at depths of 10-20 km, we estimate due to presence of geothermal. The Moho depth is reached around 19-22 km which is consistent with that obtained from stacking H-κ method.

Figure 7. $P$ wave velocity profile beneath KLNI station
4. Conclusion
We estimated the Moho depth, $Vp/Vs$ ratio, and $P$ and $S$ wave velocity structure beneath KLNI station (Lombok). We found the Moho depth beneath KLNI is 21.38 km. The high $Vp/Vs$ ratio (2.05) beneath that station could be due to the presence of partial melting which rise from the subduction zone of Java Trench. The low velocity zone was observed at a depth of 10-20 km which is probably due to geothermal presence.

5. References
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