Relative present-day motion on Palu-Koro Fault

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Abstract. Palu-Koro Fault (PKF) is an active fault zone in Sulawesi, Indonesia. PKF cuts across Palu city and bisects the Sulawesi Island into Makassar and North Sula blocks. Based on geodynamics reconstruction, the PKF is a transform fault that formed when two tectonic plates slid past each other. In this study, we determined the relative present-day motion on PKF (Latitude 0 Longitude 119) using PB2002 Model rotation pole calculation. From the Model, we could find that Banda Sea plate and Moluccas Sea plate are the plates that influence PKF activities. We attempt to calculate the magnitude and azimuth of velocity from the motion of Banda Sea plate and Moluccas Sea plate. The result shows that the Banda Sea plate is moving related to the Moluccas Sea plate at PKF with velocity 66.56 mm/a and azimuth 101.820°. This method gives us a simple model from which provides a simple calculation for the development of geodynamics reference frame for present-day deformation studies in the Banda Sea – Moluccas Sea plate boundary and can give advice to the government for preparing hazard mitigation in the areas.

1. Introduction
Palu-Koro Fault (PKF) is an active fault zone in Sulawesi, Indonesia. PKF cuts across Palu city and bisects the Sulawesi Island into Makassar and North Sula blocks. It is a roughly 500 km long left-lateral fault but with only about 200 km onshore [1]. Based on geodynamics reconstruction, the PKF is a transform fault that formed when two tectonic plates slid past each other [2].

PB2002 Model [3] is currently the present version of plate boundaries. It is a major refinement from the previous Model, PB1999 Model [4]. In this study, we use the PB2002 Model [3] to calculate the present-day motion of plates that influence PKF, which are Banda Sea plate and Moluccas Sea plate (Figure 1).

PB2002 Model [3], in Figure 1, pointed out that the boundary types are: CCB continental convergent boundary, CTF continental transform fault, CRB continental rift boundary, OSR oceanic spreading ridge, OTF oceanic transform fault, OCB oceanic convergent boundary, SUB subduction zone. Cross-hatched regions are orogens. The color shows topography from ETOPO5. ISC epicenters are omitted for clarity; beach balls are lower-hemisphere projections of double-couple parts of moment tensors of shallow centroids. White triangles are sub-aerial recent volcanoes from [5]. Black vectors give model velocities (with numbers in mm/a) relative to the plate whose identifier is underlined. Geodetic velocities from [6] and [7] are plotted relative to Sunda Plate. Black circles are locations of Euler poles, about which the first-named plate rotates counter-clockwise relative to the second. Oblique Mercator projection with great circle passing E-W through (125E, 2.5S) [3].
2. Research Material and Method

The method that we used to determine the relative present-day motion on PKF is by calculating the magnitude and azimuth of the velocity of Banda Sea Plate related to Moluccas Sea Plate and vice versa. When the rotation pole and rotation rate from a pair of adjacent plates have been known, we can calculate the direction and magnitude of relative present-day motion from any point in the plate boundary. In this case, we used the rotation pole and rotation rate (Table 1) from PB2002 Model.

Table 1. Plate and Euler Poles based on PB2002 Model [3].

| Plate Name      | Latitude, deg. N. | Longitude, deg. E | Rotation Rate, deg./a |
|-----------------|-------------------|-------------------|-----------------------|
| Banda Sea       | 16.007            | 122.442           | 2.125 x 10^{-6}       |
| Moluccas Sea    | 11.103            | -56.746           | 4.070 x 10^{-6}       |

To calculate the magnitude and azimuth of velocity, we used equations that were taken from [8]. The symbols used in the following equations are given in Figure 2 and Table 2.
Figure 2. A diagram showing the relative positions of the positive rotation pole $P$ and point $X$ on the plate boundary. $N$ is the North Pole [8].

Table 2. Symbols used in calculations [8].

| Symbol | Meaning | Information |
|--------|---------|-------------|
| $\lambda_p$ | Latitude of rotation pole $P$ | $^\circ$N positive |
| $\lambda_x$ | Latitude of point $X$ on plate boundary | $^\circ$S negative |
| $\Phi_p$ | Longitude of rotation pole $P$ | $^\circ$W negative |
| $\Phi_x$ | Longitude of point $X$ on plate boundary | $^\circ$E positive |
| $v$ | Amplitude of velocity | |
| $\beta$ | Azimuth of the velocity with respect to north $N$ | Clockwise positive |
| $R$ | Radius of the Earth (assume 6371 km) | |
| $\omega$ | Angular velocity about rotation pole $P$ | |

Angular length $a$ (Figure 2) can be determined using equation [8],

$$a = \cos^{-1} \left[ \sin \lambda_x \sin \lambda_p + \cos \lambda_x \cos \lambda_p \cos (\Phi_p - \Phi_x) \right]$$  \hspace{1cm} (1)

To calculate the angle at the $X$, $C$ (Figure 2), we can use this equation [8],

$$C = \sin^{-1} \left[ \left( \cos \lambda_p \sin (\Phi_p - \Phi_x) / \sin a \right) \right]$$  \hspace{1cm} (2)

The magnitude of velocity, $v$ (Figure 2), can be calculated with this equation [8],

$$v = \omega R \sin a$$  \hspace{1cm} (3)

To calculate the azimuth of velocity, $\beta$ (Figure 2), we can used this equation [8],

$$\beta = 90 + C$$  \hspace{1cm} (4)
We chose $\lambda_x$ and $\Phi_x$ for PKF is Latitude $0^\circ$N Longitude $119^\circ$E. Parameters used in the calculation are given in Table 3.

**Table 3. Parameters used in calculations.**

| Symbol | Banda Sea | Moluccas Sea |
|--------|-----------|--------------|
| $\lambda_p$ | 16.007$^\circ$ | 11.103$^\circ$ |
| $\lambda_x$ | 0$^\circ$ | 0$^\circ$ |
| $\Phi_p$ | 122.442$^\circ$ | -56.746$^\circ$ |
| $\Phi_x$ | 119$^\circ$ | 119$^\circ$ |
| $R$ | 6371 km | 6371 km |
| $\omega$ | 2.125 x $10^{-6}$ deg./a | 4.070 x $10^{-6}$ deg./a |

3. Results and discussions

Based on Table 3, we evaluate the relative present-day motion on PKF. The result can be seen in Table 4.

**Table 4. Results.**

| Symbol | Banda Sea | Moluccas Sea |
|--------|-----------|--------------|
| $a$ | 16.363$^\circ$ | 168.119$^\circ$ |
| C | 11.820$^\circ$ | -2.705$^\circ$ |
| $v$ | 66.56 mm/a | 93.16 mm/a |
| $\beta$ | 101.820$^\circ$ | 69.294$^\circ$ |

We got that the Banda Sea plate is moving related to the Moluccas Sea plate at PKF with velocity 66.56 mm/a and azimuth 101.820$^\circ$. This azimuth looks like PKF direction. Moluccas Sea plate is moving related to the Banda Sea plate at PKF with velocity 93.16 mm/a and azimuth 69.294$^\circ$. This azimuth is perpendicular-relative with PKF direction. This may because the pole of the Moluccas Sea is far away from PKF. So, we took the first result as the main result of this study.

**Table 5. Comparison with other research.**

| Reference | Velocity (mm/a) |
|-----------|----------------|
| This study | 66.56 |
| [1] | 40 |
| [9] | 34 |
| [9] | 41 – 44 |
| [10] | 50 |
| [10] | 30 |
| [10] | $> 5.2 \pm 2$ |
| [11] | $35 \pm 18$ |
| [11] | $35 \pm 15$ |
| [11] | $29 \pm 5$ |
| [12] | $34 \pm 3$ |

We compared the result with other research (Table 5). Our result is faster than other results. Our result shows simple calculation to get relative velocity and its azimuth of PKF movement.

4. Conclusions

This study is aimed for the developing of geodynamics reference frame for present-day deformation studies in the PKF as Banda Sea – Moluccas Sea plate boundary activity. Based on the calculation, we
could see that Banda Sea plate is moving related to the Moluccas Sea plate at PKF with velocity 66.56 mm/ and azimuth 101.820°. This result provides simple calculation to get relative velocity and its azimuth of PKF movement as a good reference for current and future studies of geodynamics and geophysical processes along PKF in the Banda Sea – Moluccas Sea plate boundary. This study also provides information to the government to mitigate the earthquake and other hazards that always happened in the area because of the PKF activities.

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